PHYSICS
SYLLABUS
Pre-University
Higher 1
Syllabus 8867

Implementation starting with
2020 Pre-University One Cohort

Ministry of Education
SINGAPORE

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

Design of the A-Level science curriculum

As scientific and technological advances influence and impact how we live, communicate and interact with each other, it is important to offer a science education that develops in individuals knowledge of the core ideas in science and an understanding of the practices associated with scientific inquiry, which will enable them to make decisions on science-related issues and challenges brought about by these advances. To develop such individuals, research in science education has shown that there is a need to strike a balance between teaching the products of science (e.g. core ideas, theories, and models), the processes of science and the nature of science. These products, processes and nature of science have been articulated in the revised H2 science curriculum. The H1 science curriculum, which is designed as a subset of H2 science, will also incorporate these key features.

Purpose of H1 science curriculum

While H2 science develops in our students the disciplinary understanding, skills and attitudes necessary for further studies in the subject and related fields, H1 science is designed to broaden students' learning that will support the development of scientific literacy. This is especially important for future citizens in an increasingly technologically-driven world and for leaders of the country to be equipped to make informed decisions based on sound scientific knowledge and principles about current and emerging science-related issues which are important to self, society and the world at large (for example, in appreciating the energy constraints faced by Singapore, or in understanding the mechanisms involved in epidemics).

Key changes to H1 science curriculum

The key changes to the H1 science curriculum are in tandem with the changes in the H2 science curriculum. Namely, the use of Core Ideas to frame the teaching and learning of science, and the introduction of the Practices of Science to place emphasis on science as a way of knowing and doing, beyond viewing it as an acquisition of a body of knowledge. Like H2 science, H1 science also encourages the use of real-world contexts in teaching and learning, and in using a wider range of pedagogies through Learning Experiences.

Differences between H2 and H1 science curriculum

The *Learning Experiences* outlined in H2 science are largely relevant and applicable to H1 science. However, the actual choice of pedagogy and *Learning Experiences* would need to be carefully adapted and designed to suit the teaching for H1 science, especially in the area of science practical activities. There would be less emphasis on developing students' proficiency in handling equipment and in carrying out various laboratory tests and techniques. Instead, the focus of science practical experiences will be on developing students' scientific knowledge and providing opportunities for students to understand the evidence-based nature of scientific knowledge.

The Practices of Science is a key feature in H1 science where greater emphasis would be placed on the development of those components that will enable students to become scientifically literate consumers and citizens who can use scientific understanding to explain and make informed choices concerning science-related issues. In particular, opportunities should be given for students to be engaged in discussion of important socio-scientific issues, such as the impact of climate change, the safe and responsible use of materials and the potential benefits and risks associated with the use of nuclear energy.

1.2 PURPOSE AND VALUE OF PHYSICS

Physics is a fundamental science which is concerned with understanding the natural world. A small number of basic principles and laws can be applied to explain and predict a wide range of physical events and phenomena. The fundamental theories of physics form the bedrock of many modern technologies and are responsible for practical applications in and the advancement of several different fields of science and technology. H1 Physics exposes students to the science process skills of investigation, reasoning, analysis and evaluation, which are transferrable and useful to everyday life. It also develops attitudes and dispositions such as critical thinking and logical analysis, a curious and inquiring mind, and the ability to solve problems and grasp complex concepts.

A unique feature in the study and practice of physics is the extensive use of models, especially those expressed in mathematical language, to explain observations and make predictions. A model serves as a bridge between abstract scientific theories and the observations and experiences of the real world. Models should be tested through experiments and must be consistent with available evidence. Hence, they can change and evolve with new evidence. The learner should be cognisant of the assumptions and limitations that are inherent in the use of models as they simplify complex real world phenomena. Knowledge and understanding of the use of models in the learning of physics is highly transferable to other disciplines, such as modelling of biological processes, weather patterns, earthquakes, and even the movement of people or financial markets.

1.3 AIMS

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

1. provide students with an experience that develops their interest in physics and builds the knowledge, skills and attitudes necessary for them to become scientifically literate citizens who are well-prepared for the challenges of the 21st century
2. develop in students the understanding, skills, ethics and attitudes relevant to the Practices of Science, including the following:
    - understanding the nature of scientific knowledge
    - demonstrating science inquiry skills
    - relating science and society
3. develop in students an understanding that a small number of basic principles and core ideas can be applied to explain, analyse and solve problems in a variety of systems in the physical world.

1.4 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.

Teaching students the nature of science helps them develop an accurate understanding of what science is and how it is practised and applied in society. Students should be encouraged to consider relevant ethical issues, how scientific knowledge is developed, and the strengths and limitations of science. Teaching the nature of science also enhances the students' understanding of science content, increases their interest in science and helps show its human side. Science teaching should emphasise *how* we know as well as *what* we know.

Understanding the nature of scientific knowledge, demonstrating science inquiry skills and relating science and society are the three components that form our Practices of Science which are explicitly articulated in the syllabus to allow teachers to embed them as learning objectives in their lessons. The students' understanding of the nature and 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 curriculum provides opportunities for students to reflect how the Practices of Science contribute to the accumulation of scientific knowledge. Students are encouraged to think about the ‘whys’ when planning and conducting investigations, developing models or engaging in scientific arguments. Through such reflection, they can come to understand the importance of each practice and develop a nuanced appreciation of the nature of science.

The Practices of Science comprise three components:
A. Understanding the Nature of Scientific Knowledge
B. Demonstrating Science Inquiry Skills
C. Relating Science and Society

A. Understanding the Nature of Scientific Knowledge

A1. Understand that science is an evidence-based, model-building enterprise concerned with the natural world
A2. Understand that the use of both logic and creativity is required in the generation of scientific knowledge
A3. Recognise that scientific knowledge is generated from consensus within the community of scientists through a process of critical debate and peer review
A4. Understand that scientific knowledge is reliable and durable, yet subject to revision in the light of new evidence

B. Demonstrating Science Inquiry Skills

B1. Identify scientific problems, observe phenomena and pose scientific questions/hypotheses
B2. Plan and conduct investigations by selecting appropriate experimental procedures, apparatus and materials with due regard for accuracy, precision and safety
B3. Obtain, organise and represent data in an appropriate manner
B4. Analyse and interpret data
B5. Construct explanations based on evidence and justify these explanations through reasoning and logical argument
B6. Use appropriate models to explain concepts, solve problems and make predictions
B7. Make decisions based on evaluation of evidence, processes, claims and conclusions
B8. Communicate scientific findings and information using appropriate language and terminology

C. Relating Science and Society

C1. Recognise that the application of scientific knowledge to problem solving could be influenced by other considerations such as economic, social, environmental and ethical factors
C2. Demonstrate an understanding of the benefits and risks associated with the application of science to society
C3. Use scientific principles and reasoning to understand, analyse and evaluate real-world systems as well as to generate solutions for problem solving

Developing 21st Century Competencies through the learning of science

To prepare our students for the future, a Framework for 21st Century Competencies (21CC) and Student Outcomes was developed by MOE (see Figure 1.1). This 21CC framework is meant to equip students with the key competencies and mindsets to be successful in the 21st century.

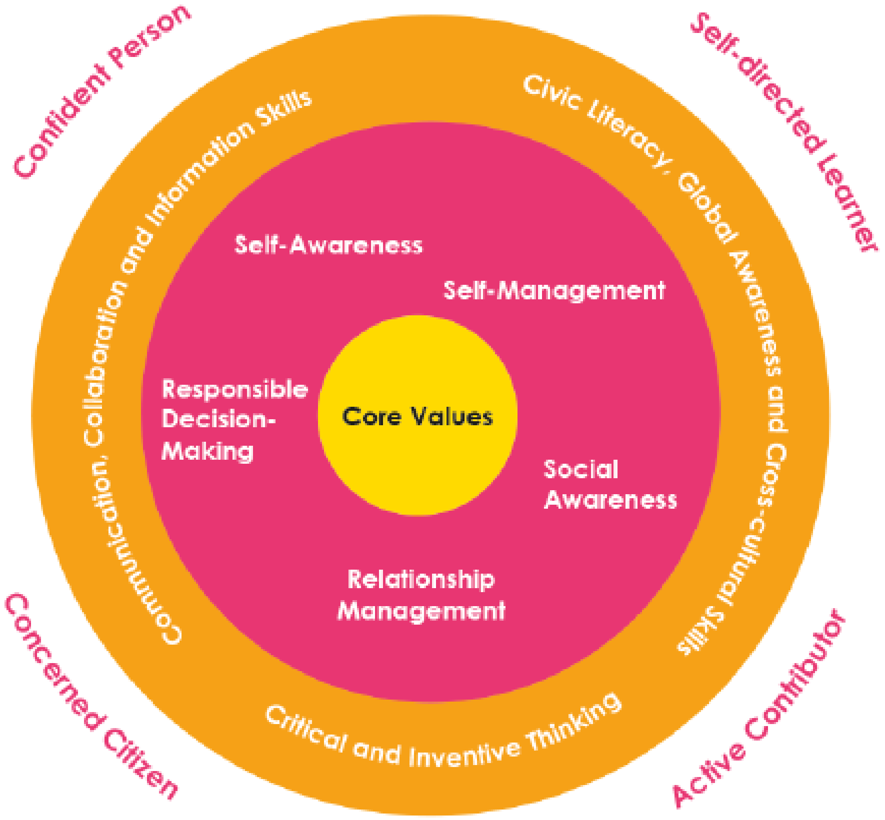

Figure 1.1: Framework for 21st Century Competencies and Student Outcomes

The features and intent of the Practices of Science are consistent with the emphasis on developing 21CC in our students.

The development of 21CC should not be seen as separate from the learning of science. The features of scientific inquiry, such as the processes of scientific investigation, reasoning, modelling and problem solving support a student's development of 21CC (see Table 1.1 for some examples). The students' understanding of the nature and limitations of science and scientific inquiry are developed effectively when scientific practices are taught in the context of relevant science content. Engaging our students in deep disciplinary learning in science will help to develop 21CC and promote the process of learning for transfer to other areas of life.

1.5 H1 Physics Curriculum Framework

The Practices of Science, Core Ideas and Learning Experiences are put together in a framework (see Figure 1.2) to guide the development of the H1 Physics curriculum.

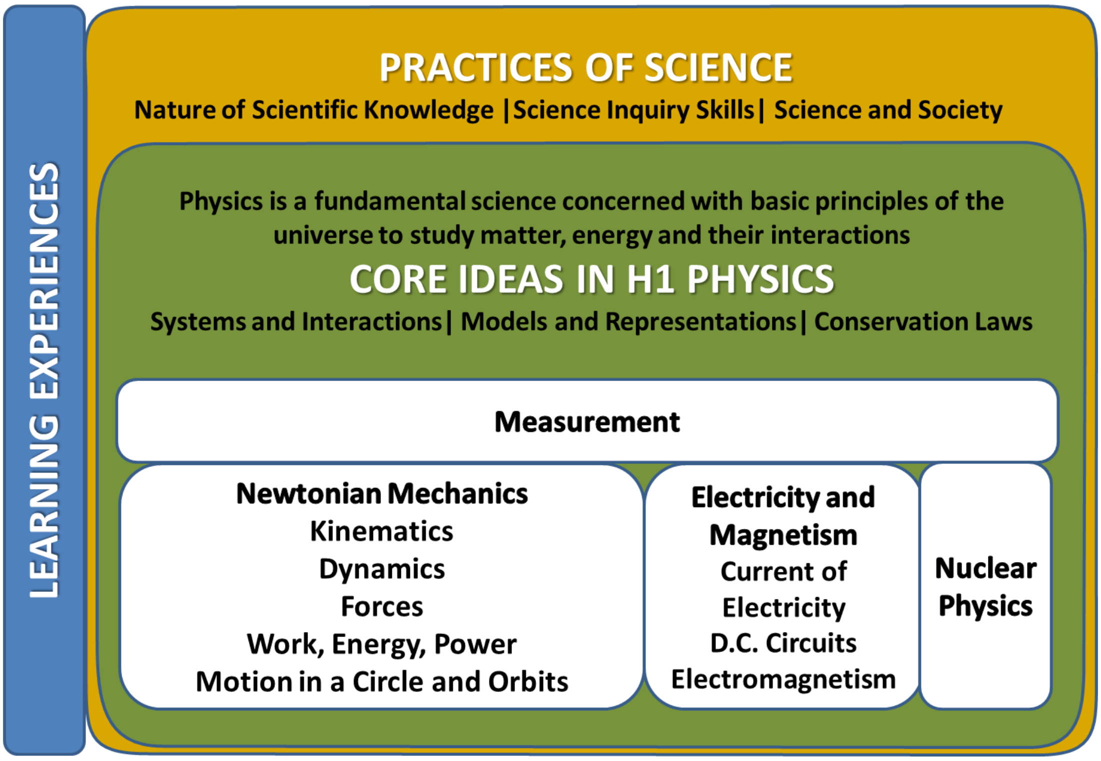

Figure 1.2: H1 Physics Curriculum Framework

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

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

The Learning Experiences refer to a range of learning opportunities that enhance students' learning by linking physics content with the Core Ideas and the Practices of Science. Real-world contexts can help illustrate the physics concepts and their applications. Experimental (practical work) activities and ICT tools can also be used to build students' understanding.

2. CONTENT

2.1 CORE IDEAS IN PHYSICS

Physics encompasses the study of systems spanning a wide range of distances and times: from 10^{-15} m (e.g. sub-atomic particles) to larger than 10^{30} m (e.g. galaxies), from near-instantaneous events, such as the current flow with a flick of a switch, to slow-evolving phenomena, 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 **systems** under study (by specifying their **boundaries** and making explicit **models** of the systems) provides tools for understanding and testing ideas that are applicable throughout physics.

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

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

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

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

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

1.7 **Equilibrium** is a unique state where the relevant physical properties of a system are balanced (e.g. equilibrium in a single particle arises if there is no resultant force acting on it, a rigid body is considered to be in static equilibrium if, in addition, there is no resultant moment about any point).

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

1.8.1 Microscopic models are applied in the study of electricity, thermodynamics Microscopic models are applied in the study of electricity. Macroscopic properties (e.g. current) 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 half-life of unstable nuclei decaying randomly.

1.8.3 Such complex systems may also be better characterised by **statistical averages** (e.g. half life) as these quantities may be more meaningful than the properties and behaviours of individual components (e.g. which unstable nuclei is decaying and when).

2 Models and Representations

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

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

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

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

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

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

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

3 Conservation Laws

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

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

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

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

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

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

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

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

3.7.2 Conservation of energy to calculate the change in total energy in systems that are open to energy transfer due to external forces (work is done).

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.

2.2 SECTIONS AND TOPICS IN H1 PHYSICS

The 10 topics in H1 Physics are organised into four main sections, as listed in Table 2.1. In this teaching and learning guide, a broad narrative is provided for each of the main sections, followed by a list of guiding questions, learning outcomes, and learning experiences for each of the topics.

Table 2.1: Main sections and topics for H1 Physics

Sections	Topics
I. Measurement	1. Measurement
II. Newtonian Mechanics	2. Kinematics 3. Dynamics 4. Forces 5. Work, Energy, Power 6. Motion in a Circle and Orbits
III. Electricity and Magnetism	7. Current of Electricity 8. D.C. Circuits 9. Electromagnetism
IV. Nuclear Physics	10. Nuclear Physics

2.3 SECTION I: MEASUREMENT

Links between sections and topics

Physics is an experimental science. Precise measurements enable the collection of useful experimental data that can be tested against theoretical predictions to refine the development of physical theories. Experimental evidence is the ultimate authority in discriminating between competing physical theories. Scientific knowledge continues to evolve as data from new or improved measurements helps us to understand and quantify the natural world.

Measurements are subject to uncertainty (also known as error), and it is important to estimate these to understand the reliability of the measurements. Error analysis involves estimating uncertainties and figuring out how to reduce them if necessary. In an experiment, the record of measurements made should include the estimated uncertainties, and document an analysis of the possible sources of errors with a discussion of steps taken to reduce the uncertainties. Doing this enables better conclusions to be drawn from the experimental data.

The act of measurement sometimes affects the system being measured due to the interaction between the measuring device and the measured system. Common examples of this include measurements made using a thermometer, voltmeter or ammeter. Thus, improving the accuracy of measurements often requires the invention of better instruments or processes. At the quantum scale, however, there is an inherent limit to the precision of observations because any measurement inevitably alters the quantum state of the system being measured.

Applications and relevance to daily life

Physicists are very serious about measurement, and the other sciences and society as a whole have benefited from the spill-over effects of the invention of many amazing measuring devices and techniques. Modern engineering also depends heavily on accurate measurements in areas like design, construction, optimisation and communication. Precise measurements have made many advanced technological applications possible; examples include the study and manipulation of materials, and breakthroughs in fields as diverse as geophysics and biology. Measurements using sophisticated devices like magnetic resonance imaging (MRI) scanners are also important for the medical industry, to provide a wealth of data that aids in clinical diagnosis and informs treatment decisions.

Topic 1: Measurement

GUIDING QUESTIONS

- How are the standards for measurements established?
- Why is uncertainty inherent in all measurements?
- How can uncertainties be estimated? How can they be reduced if necessary?
- Why does the uncertainty of a measurement matter?
- How is the skill of making estimates of physical quantities useful and how can this skill be developed?

Measurement	**Learning Outcomes** Students should be able to:
Physical quantities and SI units	(a) recall the following base quantities and their SI units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol). (b) state that one mole of any substance contains 6.02×10^{23} particles and use the Avogadro number $N_A = 6.02 \times 10^{23}$ mol^{-1}. (c) express derived units as products or quotients of the base units and use the named units listed in 'Summary of Key Quantities, Symbols and Units' as appropriate. (d) use SI base units to check the homogeneity of physical equations. (e) show an understanding of and use the conventions for labelling graph axes and table columns as set out in the ASE publication *Signs, Symbols and Systematics (The ASE Companion to 16–19 Science, 2000)*. (f) use the following prefixes and their symbols to indicate decimal sub-multiples or multiples of both base and derived units: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T). (g) make reasonable estimates of physical quantities included within the syllabus.
Scalars and vectors	(h) distinguish between scalar and vector quantities, and give examples of each. (i) add and subtract coplanar vectors. (j) represent a vector as two perpendicular components.
Errors and uncertainties	(k) show an understanding of the distinction between systematic errors (including zero error) and random errors. (l) show an understanding of the distinction between precision and accuracy. (m) assess the uncertainty in a derived quantity by addition of actual, fractional, percentage uncertainties or by numerical substitution (a rigorous statistical treatment is not required).

2.4 SECTION II: NEWTONIAN MECHANICS

Links between sections and topics

Newtonian mechanics is a successful physical theory that explains the relationship between force and motion. Conceptually, mechanics consists of the study of how objects move (kinematics) and of the reason why objects move in the way they do (dynamics). It is usually assumed that all students of physics have at least an understanding of Newtonian mechanics.

The study of kinematics begins with the introduction of precise terminology and language for describing motion, to reduce ambiguity in expression and confusion in thought. One-dimensional motion is introduced and discussed with the (verbal, mathematical, graphical) language of kinematics before more complex two-dimensional motions such as projectile motion and circular motion are studied. To scope the syllabus, we restrict ourselves to modelling the motion of bodies where effects such as the rotation or even the change in shape of the body are insignificant, and hence such bodies are assumed to be well-described as point objects.

The study of dynamics is grounded on Newton's three laws of motion, which accurately model systems as diverse as the planets of the solar system and helium atoms in a container. However, experiments and observations have proven that the validity of Newtonian mechanics breaks down for objects moving close to the speed of light, or objects at the subatomic scale. In these situations, special relativity and quantum mechanics respectively are the more appropriate physical theories that apply.

Forces play a central role in Newton's laws of motion, and forces common in everyday life such as tension, friction, air resistance, etc. are discussed. Many of these everyday forces are actually electromagnetic interactions, one of the four fundamental forces in nature (other than gravitation, the weak interaction, and the strong interaction). We pay particular attention also to situations in which various forces act on a rigid object yet the object is maintained in static equilibrium.

The concept of energy is one of the most fundamental concepts in science, and is discussed in the context of Newtonian mechanics. Energy is present in various forms, endlessly transformed from one form to another. The conservation of energy is an essential principle in physics. The concept of work links energy and force, as work is a means of transferring energy through the application of a force. In certain situations, the concepts of work and energy can be applied to solve the dynamics of a mechanical system without directly resorting to Newton's laws. Beyond mechanics, this problem-solving approach focusing on energy can be applied to a wide range of phenomena in electromagnetism, and thermal and nuclear physics. The work-energy approach often provides a much simpler analysis than that obtained from the direct application of Newton's laws, since the former deals with scalar rather than vector quantities.

Applications and relevance to daily life

Newtonian mechanics is the foundation of contemporary science and is also the basis for much engineering and applied science. It is of paramount importance to a civil engineer to know the effects of forces acting on a structure such as a bridge. Someone designing a vehicle to break the world speed record had better be conversant in the concepts of force and energy to stand a chance in the competition. While relativistic corrections are sometimes important for space science, the principles of Newtonian mechanics are largely sufficient for satellite technologies that give us global communication and navigation systems such as GPS.

Links to Core Ideas		
Systems and Interactions	**Models and Representations**	**Conservation Laws**
• The interactions of an object with other objects can be described by forces • A force acting on an object can cause a change in its momentum (or velocity) or its kinetic energy or produce a torque on it • Potential energy and kinetic energy are two basic types of energy • Work is the transfer of mechanical energy • F_G as interaction between a mass placed in an external g-field	• Newton's laws of motion • Newton's law of gravitation • Uniform circular motion • Common representations: e.g. motion diagrams, free-body diagrams, energy bar charts, field lines and equipotential lines, force-position graph of g-field (inverse square law), etc. • Simplifying assumptions: e.g. point masses, frictionless planes, massless strings, isolated systems, incompressible fluids, taking g on surface of Earth as approximately constant, etc.	• Conservation of mass • Conservation of energy (e.g. work-energy theorem) • Conservation of momentum

Topic 2: Kinematics

GUIDING QUESTIONS

- How can the motion of objects be described, represented, quantified and predicted?
- How would an object falling freely in a gravitational field move?

Kinematics	**Learning Outcomes** Students should be able to:
Rectilinear motion	(a) show an understanding of and use the terms distance, displacement, speed, velocity and acceleration. (b) use graphical methods to represent distance, displacement, speed, velocity and acceleration. (c) identify and use the physical quantities from the gradients of displacement-time graphs and areas under and gradients of velocity-time graphs, including cases of non-uniform acceleration. (d) derive, from the definitions of velocity and acceleration, equations which represent uniformly accelerated motion in a straight line. (e) solve problems using equations which represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance. (f) describe qualitatively the motion of bodies falling in a uniform gravitational field with air resistance.
Non-linear motion	(g) describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.

Topic 3: Dynamics

GUIDING QUESTIONS

- How do forces affect the motion of an object?
- When is momentum conserved during interactions between objects?
- How can we analyse interactions using the principle of momentum conservation?

Dynamics	**Learning Outcomes** Students should be able to:
Newton's laws of motion	(a) state and apply each of Newton's laws of motion. (b) show an understanding that mass is the property of a body which resists change in motion (inertia). (c) describe and use the concept of weight as the force experienced by a mass in a gravitational field.
Linear momentum	(d) define and use linear momentum as the product of mass and velocity. (e) define and use impulse as the product of force and time of impact.

Dynamics	**Learning Outcomes** Students should be able to:
and its conservation	(f) relate resultant force to the rate of change of momentum. (g) recall and solve problems using the relationship $F = ma$, appreciating that resultant force and acceleration are always in the same direction. (h) state the principle of conservation of momentum. (i) apply the principle of conservation of momentum to solve simple problems including inelastic and (perfectly) elastic interactions between two bodies in one dimension (knowledge of the concept of coefficient of restitution is not required). (j) show an understanding that, for a (perfectly) elastic collision between two bodies, the relative speed of approach is equal to the relative speed of separation. (k) show an understanding that, whilst the momentum of a closed system is always conserved in interactions between bodies, some change in kinetic energy usually takes place.

Topic 4: Forces

GUIDING QUESTIONS

- What are the different types of forces?
- How do we solve problems involving translational and rotational equilibrium?

Forces	**Learning Outcomes** Students should be able to:
Types of force	(a) recall and apply Hooke's law ($F = kx$, where k is the force constant) to new situations or to solve related problems. (b) describe the forces on a mass, charge and current-carrying conductor in gravitational, electric and magnetic fields, as appropriate. (c) show a qualitative understanding of normal contact forces, frictional forces and viscous forces including air resistance (no treatment of the coefficients of friction and viscosity is required).
Centre of gravity	(d) show an understanding that the weight of a body may be taken as acting at a single point known as its centre of gravity.
Turning effects of forces	(e) define and apply the moment of a force and the torque of a couple. (f) show an understanding that a couple is a pair of forces which tends to produce rotation only. (g) apply the principle of moments to new situations or to solve related problems.

Forces	**Learning Outcomes** Students should be able to:
Equilibrium of forces	(h) show an understanding that, when there is no resultant force and no resultant torque, a system is in equilibrium. (i) use a vector triangle to represent forces in equilibrium.

Topic 5: Work, Energy, Power

GUIDING QUESTIONS

- What is energy and how does it relate to work done?
- How does energy get transferred and transformed?

Work, Energy, Power	**Learning Outcomes** Students should be able to:
Work	(a) define and use work done by a force as the product of the force and displacement in the direction of the force. (b) calculate the work done in a number of situations.
Energy conversion and conservation	(c) give examples of energy in different forms, its conversion and conservation, and apply the principle of energy conservation.
Efficiency	(d) show an appreciation for the implications of energy losses in practical devices and use the concept of efficiency to solve problems.
Potential energy and kinetic energy	(e) derive, from the equations for uniformly accelerated motion in a straight line, the equation $E_k = \frac{1}{2}mv^2$. (f) recall and use the equation $E_k = \frac{1}{2}mv^2$. (g) distinguish between gravitational potential energy, electric potential energy and elastic potential energy. (h) deduce that the elastic potential energy in a deformed material is related to the area under the force-extension graph. (i) show an understanding of and use the relationship between force and potential energy in a uniform field to solve problems. (j) derive, from the definition of work done by a force, the equation $E_p = mgh$ for gravitational potential energy changes near the Earth's surface. (k) recall and use the equation $E_p = mgh$ for gravitational potential energy changes near the Earth's surface.
Power	(l) define power as work done per unit time and derive power as the product of a force and velocity in the direction of the force.

Topic 6: Motion in a Circle and Orbits

GUIDING QUESTIONS

- How do we describe the motion of an object moving in a circular path?
- What causes an object to move in a circular path?

Motion in a Circle	**Learning Outcomes** Students should be able to:
Kinematics of uniform circular motion	(a) express angular displacement in radians. (b) show an understanding of and use the concept of angular velocity to solve problems. (c) recall and use $v = r\omega$ to solve problems.
Centripetal acceleration	(d) describe qualitatively motion in a curved path due to a perpendicular force, and understand the centripetal acceleration in the case of uniform motion in a circle. (e) recall and use centripetal acceleration $a = r\omega^2$, and $a = \frac{v^2}{r}$ to solve problems.
Centripetal force	(f) recall and use centripetal force $F = mr\omega^2$, and $F = \frac{mv^2}{r}$ to solve problems.
Gravitational force between point masses	(g) recall and use Newton's law of gravitation in the form $F = \frac{Gm_1m_2}{r^2}$.
Circular orbits	(h) analyse circular orbits in inverse square law fields by relating the gravitational force to the centripetal acceleration it causes. (i) show an understanding of geostationary orbits and their application.

2.5 SECTION III: ELECTRICITY AND MAGNETISM

Links between sections and topics

There are four fundamental forces in physics: the gravitational, electromagnetic, strong and weak interactions. While the strong and weak interactions explain phenomena at the sub-atomic level, a large number of daily human experiences can be explained by gravitational and electromagnetic interactions.

Electromagnetic interactions involve particles that have a property called electric charge, an attribute that appears to be just as fundamental as mass, or even more so – charge seems to be precisely quantised, while it is not clear if mass is quantised. An object with mass experiences a force in a gravitational field, and electrically-charged objects experience forces in electric and magnetic fields. Like mass-energy, charge obeys a conservation law as well.

Practical use of electricity often occurs in circuits rather than in free space. Circuits provide a means of conveying energy and information from one place to another. Within a circuit, the complicated effects of forces and electric fields at the microscopic level result in a macroscopic description where consideration of energy and electric potentials mostly suffices. The collective movement of charges results in electrical current, driven by potential differences (also known as voltages). Both current and voltage can be experimentally measured. Applying the principles of charge and energy conservation provide powerful tools to analyse a variety of electrical circuits.

The mystery of magnetism was first discovered in magnetic stones by the ancients. Today, we understand magnetism as an effect inseparable from electricity, summarised by Maxwell's laws of electromagnetism. Unlike electric forces, which act on electric charges whether moving or stationary, magnetic forces act only on moving charges. Moving charges produce a magnetic field, and another moving charge or current placed in this magnetic field experiences a force. This apparent asymmetry in electromagnetic phenomena contributed to the development of the theory of relativity, and Einstein's 1905 paper on relativity begins with the following description:

> *It is known that Maxwell's electrodynamics – as usually understood at the present time – when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion. For if the magnet is in motion and the conductor at rest, there arises in the neighborhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is stationary and the conductor in motion, no electric field arises in the neighborhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise – assuming equality of relative motion in the two cases discussed – to electric currents of the same path and intensity as those produced by the electric forces in the former case.*
>
> *— A. Einstein, On the electrodynamics of moving bodies (1905)*

Applications and relevance to daily life

Technologies harnessing electrical and magnetic properties pervade modern society. Converting energy into electrical energy traditionally involves the induced electromotive force and current produced by a changing magnetic flux or a time-varying magnetic field. Transmitting electrical energy over long distances is made feasible by the use of alternating current and voltage transformers. Semiconductor devices in computers and smartphones are the product of our deep understanding of the physics of electricity and magnetism in solid state materials. Innovations are also pushing on the quantum frontier.

Even more fundamentally, elastic forces in springs and contact forces between surfaces arise from electrical forces at the atomic level. In biology, electricity is also important in signalling and control. The heart rhythms are maintained by waves of electrical excitation, from nerve impulses that spread through special tissue in the heart muscles.

Links to Core Ideas		
Systems and Interactions	**Models and Representations**	**Conservation Laws**
• F_E as the interaction between a charge and an external E-field • F_B as the interaction between a moving charge and an external B-field	• Ohm's law (for ohmic conductors) • Common representations: diagrams of electric circuits, field lines, magnetic flux density patterns, etc • Simplifying assumptions: e.g. point charges, negligible internal resistance, infinitely extended planes	• Conservation of charges in circuits • Conservation of energy in circuits

Topic 7: Current of Electricity

GUIDING QUESTIONS

- How does the macroscopic phenomenon of current flow relate to the movement of microscopic charges?
- How are current, voltage, and resistance related in an electrical circuit?
- What happens to energy in an electrical circuit?

Current of Electricity	**Learning Outcomes** Students should be able to:
Electric current	(a) show an understanding that electric current is the rate of flow of charge. (b) recall and solve problems using the equation $Q = It$.
Potential difference	(c) recall and solve problems using the equation $V = \frac{W}{Q}$. (d) recall and solve problems using the equations $P = VI$, $P = I^2R$ and $P = \frac{V^2}{R}$.
Resistance and resistivity	(e) define the resistance of a circuit component as the ratio of the potential difference across the component to the current passing through it, and solve problems using the equation $V = IR$. (f) sketch and explain the I-V characteristics of various electrical components such as an ohmic resistor, a semiconductor diode, a filament lamp and a negative temperature coefficient (NTC) thermistor. (g) sketch the resistance-temperature characteristic of an NTC thermistor. (h) recall and solve problems using the equation $R = \frac{\rho l}{A}$.
Electromotive force	(i) distinguish between electromotive force (e.m.f.) and potential difference (p.d.) using energy considerations. (j) show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

Topic 8: D.C. Circuits

GUIDING QUESTIONS

- How are symbols and diagrams used to represent real circuits?
- How are the principles of charge and energy conservation applied to analyse circuits?

D.C. Circuits	**Learning Outcomes** Students should be able to:
Circuit symbols and diagrams	(a) recall and use appropriate circuit symbols as set out in the ASE publication *Signs, Symbols and Systematics (The ASE Companion to 16–19 Science, 2000)*. (b) draw and interpret circuit diagrams containing sources, switches, resistors, ammeters, voltmeters, and/or any other type of component referred to in the syllabus.
Series and parallel arrangements	(c) solve problems using the formula for the combined resistance of two or more resistors in series. (d) solve problems using the formula for the combined resistance of two or more resistors in parallel. (e) solve problems involving series and parallel circuits for one source of e.m.f.
Potential divider	(f) show an understanding of the use of a potential divider circuit as a source of variable p.d. (g) explain the use of thermistors and light-dependent resistors in potential divider circuits to provide a potential difference which is dependent on temperature and illumination respectively.

Topic 9: Electromagnetism

GUIDING QUESTIONS

- What is a magnet? Are there “magnetic” charges?
- Do magnetic fields have effects on electric charges?
- What do field lines represent? Do field lines represent similar things for electric fields and magnetic fields?
- Why is the word “flux” used when talking about a magnetic field?

Electromagnetism	**Learning Outcomes** Students should be able to:
Concept of an electric field	(a) show an understanding of the concept of an electric field as an example of a field of force and define electric field strength at a point as the electric force exerted per unit positive charge placed at that point. (b) represent an electric field by means of field lines.

Electromagnetism	**Learning Outcomes** Students should be able to:
Concept of a magnetic field	(c) show an understanding that a magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets.
Magnetic fields due to currents	(d) sketch flux patterns due to currents in a long straight wire, a flat circular coil and a long solenoid. (e) show an understanding that the magnetic field due to a solenoid may be influenced by the presence of a ferrous core.
Force on a current-carrying conductor	(f) show an understanding that a current-carrying conductor placed in a magnetic field might experience a force. (g) recall and solve problems using the equation $F = BIl \sin\theta$, with directions as interpreted by Fleming's left-hand rule. (h) define magnetic flux density. (i) show an understanding of how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field using a current balance.
Force between current-carrying conductors	(j) explain the forces between current-carrying conductors and predict the direction of the forces.
Force on a moving charge	(k) predict the direction of the force on a charge moving in a magnetic field. (l) recall and solve problems using the equation $F = BQv \sin\theta$. (m) calculate the forces on charges in uniform electric fields using the equation $F = Eq$. (n) describe the effect of a uniform electric field on the motion of charged particles.

2.6 SECTION IV: NUCLEAR PHYSICS

Links between sections and topics

Nuclear physics and relativity were also developed during the early 1900s. Nuclear physics started with the observations of radioactivity in uranium. The study of radioactivity is an attempt to understand the nature of radiation emitted by radioactive nuclei. Radioactivity can be explained as the result of decay or disintegration of unstable nuclei. The stability or instability of a particular nucleus is affected by the competition between the attractive nuclear forces among the protons and neutrons and the repulsive electrical interactions among the protons. A nucleus might be induced to decay by colliding it with an energetic particle. Ultimately, these are all quantum processes.

Nuclear reactions can generally be classified as fusion or fission. While we have harnessed fission for the generation of nuclear energy, research laboratories around the world are still working on fusion reactors that promise to provide abundant clean energy and create an ‘artificial sun’. Conservation laws are a powerful way to analyse nuclear reactions, and the conservation of mass-energy is an especially important conservation law introduced in this topic. In 1905, the so-called ‘miracle year’ for Einstein, he also published a paper on mass-energy equivalence, which we now know as the famous equation $E = mc^2$.

Applications and relevance to daily life

The applications of nuclear physics have had enormous effects on humankind – some beneficial, some catastrophic. Radioactive dating using carbon-14 and nuclear energy produced through fission are some examples of beneficial applications, while the world now lives with global stockpiles of nuclear warheads that can destroy the Earth many times over. Accidents at nuclear energy reactors, such as those at Chernobyl and Fukushima, also show the dangers associated with nuclear energy.

Links to Core Ideas		
Systems and Interactions	**Models and Representations**	**Conservation Laws**
• Interaction of alpha particles with atoms of thin foil of metal in Rutherford scattering experiment.	• Models of the atom • Exponential form of radioactive decay as a random process with a fixed probability	• Conservation of nucleon number, proton number and mass-energy in nuclear processes • The use of conservations laws of energy in nuclear reactions

Topic 10: Nuclear Physics

GUIDING QUESTIONS

- Why are some nuclei radioactive? What happens during radioactive decay? Where does the energy come from?
- What is emitted during radioactive decay, and is it harmful? How do decay products interact with matter?
- What are the uses of radioactivity?
- How are nuclear reactions different from chemical reactions? How are they similar?
- What can conservation laws tell us about nuclear processes?

Nuclear Physics	**Learning Outcomes** Students should be able to:
The nucleus	(a) infer from the results of the Rutherford α -particle scattering experiment the existence and small size of the atomic nucleus. (b) distinguish between nucleon number (mass number) and proton number (atomic number).
Isotopes	(c) show an understanding that an element can exist in various isotopic forms each with a different number of neutrons in the nucleus.
Nuclear processes	(d) use the usual notation for the representation of nuclides and represent simple nuclear reactions by nuclear equations of the form $^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$. (e) state and apply to problem solving the concept that nucleon number, charge and mass-energy are all conserved in nuclear processes.
Mass defect and nuclear binding energy	(f) show an understanding of the concept of mass defect. (g) recall and apply the equivalence between energy and mass as represented by $E = mc^2$ to solve problems. (h) show an understanding of the concept of nuclear binding energy and its relation to mass defect. (i) sketch the variation of binding energy per nucleon with nucleon number. (j) explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission.
Radioactive decay	(k) show an understanding of the spontaneous and random nature of nuclear decay, and use term activity. (l) infer the random nature of radioactive decay from the fluctuations in count rate. (m) show an understanding of the origin and significance of background radiation.

Nuclear Physics	**Learning Outcomes** Students should be able to:
	(n) show an understanding of the nature of α, β and γ radiations. (o) define half-life as the time taken for a quantity x to reduce to half its initial value and use the term to solve problems which might involve information in tables or decay curves.
Biological effects of radiation	(p) discuss qualitatively the effects, both direct and indirect, of ionising radiation on living tissues and cells.

3. PEDAGOGY

The starting point for the science curriculum is that every child wants to and can learn. The science curriculum nurtures students as inquirers and taps on their innate curiosity and desire to seek answers to questions or solve problems relating to science. Besides developing a strong conceptual understanding of scientific models and theories, students' curiosity is stimulated and they are encouraged to see the value of science and its applications and connection to their everyday lives.

3.1 DEVELOPING CONCEPTUAL UNDERSTANDING

Conceptual understanding is more than factual knowledge which is commonly associated with the memorising of facts and definitions. Conceptual understanding is built by using facts as tools to discern patterns, connections, and deeper, transferable understanding. One approach to develop students' conceptual understanding is through conceptual change that occurs when they are dissatisfied with a prior conception and the available replacement conception is logical, reasonable and/or meaningful.

3.2 ENGAGING IN THE PRACTICES OF SCIENCE

Science is not just a body of knowledge, but also a way of knowing and doing. The 'ways of thinking and doing' refer to a discipline's distinctive mode of inquiry and approach to working with the observations and knowledge about the world. Through the Practices of Science, students should appreciate the following:

- **Nature of scientific knowledge:** Students understand the nature of scientific knowledge implicitly through the process of 'doing science'. To complement this, an explicit approach may be used. This approach utilises elements from the history of science or the processes in science to improve students' views of the nature of scientific knowledge.

- **Science as an inquiry:** Scientific inquiry refers to the different approaches by which scientists study and develop an understanding of the natural and physical world around us. Inquiry-based instruction could be used to develop the different aspects of the Practices of Science together with the understanding of science concepts as well as the dispositions and attitudes associated with science. Inquiry-based strategies could include questioning, demonstrations, use of technology, as well as models and modelling.

- **Relating science and society:** Students should appreciate how science and technology are used in daily life. They should apply and experience the potential of science to generate creative solutions to solve a wide range of real-world problems, ranging from those affecting everyday lives to complex problems affecting humanity, while appreciating the values and ethical implications of these applications. Science education needs to equip students with the ability to articulate their ethical stance as they participate in discussions about socio-scientific issues that involve ethical dilemmas, with no single right answers.

3.3 PRACTICAL WORK

Science practical work supports the teaching and learning of science through developing the Practices of Science, experimental techniques, practical manipulative skills and conceptual understanding. It also cultivates interest in science and in learning science. In addition, attitudes like objectivity and integrity, which are important in the learning of the discipline of science, are reinforced.

3.4 THE SINGAPORE STUDENT LEARNING SPACE (SLS)

The Singapore Student Learning Space (SLS) is an online platform that supports teaching and learning, it

- **enables our students to learn anytime, anywhere**
  As SLS is available to all students and teachers in every school it can be a key lever to bring about more pervasive and seamless integration of technology in teaching and learning at schools. Students can access SLS through different devices and learn at their own pace.

- **allows our students to take greater ownership of their learning and work collaboratively**
  Students can do self-directed learning by accessing the resources in SLS on their own or complete learning packages assigned by teachers. Quizzes are auto-graded to give immediate feedback to students. These resources complement other teaching and learning resources such as lecture notes, tutorials, physical manipulatives, etc. There are learning tools available on SLS that enable students to curate and organise information, connect with peers and to create works to demonstrate their learning.

- **complements classroom teaching**
  Teachers can use the MOE curriculum-aligned resources in the SLS, curate own resources from the world-wide-web or develop own resources to complement their teaching. In addition, teachers are supported by visualisation tools in SLS to easily monitor students' learning progress and check for understanding.

- **is collectively shaped by schools and owned by all**
  As SLS is accessible by teachers across all Singapore schools, it provides a unique opportunity for teachers to work collectively to co-develop, adapt and share lessons. Teachers can make use of the co-editing and sharing capabilities in SLS to curate and share lesson designs.

Students can access the SLS through *https://vle.learning.moe.edu.sg/login.*

4. ASSESSMENT

Assessment is the process of gathering and analysing evidence about student learning. This information is used to make decisions about students, curricula and programmes. Assessment for Learning (AfL) is assessment conducted constantly during classroom instruction to support teaching and learning. With the feedback about the state of students' learning, teachers then adapt their teaching strategies and pace based on the students' needs. Assessment of Learning (AoL) aims to summarize how much or how well students have achieved at the end of a course of study over an extended period of time. The A-level examination is an example of AoL.

4.1 A-LEVEL EXAMINATION

Candidates will be assumed to have knowledge and understanding of physics at O-Level, either as a single subject or as part of a balanced science course.

This syllabus is designed to place less emphasis on factual material and greater emphasis on the understanding and application of scientific concepts and principles. This approach has been adopted in recognition of the need for students to develop skills that will be of long-term value in an increasingly technological world rather than focusing on large quantities of factual material which may have only short-term relevance.

Experimental work is an important component and should underpin the teaching and learning of physics.

4.2 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; and
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, name, describe* or *explain* (see Section 4.6 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; and
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 candidates. 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 Section 4.6 Glossary of Terms).

4.3 SCHEME OF ASSESSMENT

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

Paper	Type of Paper	Duration	Weighting (%)	Marks
1	Multiple Choice	1 h	33	30
2	Structured Questions	2 h	67	80

Paper 1 (1 h, 30 marks)
This paper will consist of 30 multiple-choice questions. All questions will be of the direct-choice type with 4 options.

Paper 2 (2 h, 80 marks)
This paper will consist of 2 sections. All answers will be written in spaces provided on the Question Paper.

Section A (60 marks)
This section will consist of a variable number of structured questions including one or two data-based questions, all compulsory. The data-based question(s) will constitute 15-20 marks.

Section B (20 marks)
This section will consist of two 20-mark questions of which candidates will answer one. The questions will require candidates to integrate knowledge and understanding from different areas of the syllabus.

Weighting of Assessment Objectives
The assessment objectives are weighted as shown, for candidates taking H1 Physics (8867).

Assessment Objectives		Weighting (%)	Assessment Components
A	Knowledge with understanding	40	Papers 1, 2
B	Handling, applying and evaluating information	60	Papers 1, 2

4.4 ADDITIONAL INFORMATION

Disallowed Subject Combinations
Candidates may not simultaneously offer physics at H1 and H2 levels.

Mathematical Requirements
The mathematical requirements are given in Section 4.5.

Symbols, Signs and Abbreviations
Symbols, signs and abbreviations used in examination papers will follow the recommendations made in *Signs, Symbols and Systematics*. The units kWh, atmosphere, eV and unified atomic mass unit (u) may be used in examination papers without further explanation.

Data and Formulae
Data and Formulae, given in Section 4.8, will appear as pages 2 and 3 in Papers 1, 2 and 3.

4.5 MATHEMATICAL REQUIREMENTS

The following are the mathematical requirements for candidates taking H1 Physics (8867).

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 $<, >, \ll, \gg, \approx, /, \propto, \langle x \rangle (= \bar{x}), \Sigma, \Delta x, \delta x, \surd$.

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:

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

(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.

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 $\frac{1}{x}, x^2, \frac{1}{x^2}, \sin x, \cos x, e^{-x}$.

(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 $\frac{dy}{dx}$ for a rate of change.

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

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

4.6 GLOSSARY OF TERMS

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

1. **Calculate** is used when a numerical answer is required. In general, working should be shown.
2. **Compare** requires candidates to provide both similarities and differences between things or concepts.
3. **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 from an earlier part of the question.
4. **Define (the term(s) ...)** is intended literally. Only a formal statement or equivalent paraphrase, such as the defining equation with symbols identified, is required.

5. **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 needed should be interpreted in light of the indicated mark value.
6. **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.
7. **Discuss** requires candidates to give a critical account of the points involved in the topic.
8. **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.
9. **Explain** may imply reasoning or some reference to theory, depending on the context.
10. **List** requires a number of points with no elaboration. Where a given number of points is specified, this should not be exceeded.
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. **Predict**: (see **Deduce**).
13. **Show** is used when an algebraic deduction has to be made to prove a given equation. It is important that the terms used by candidates are stated explicitly.
14. **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.
15. **Sketch**, when applied to diagrams, implies that a simple freehand drawing is acceptable; nevertheless, care should be taken to ensure that proportions are correct and that important details are clearly shown.
16. **State** implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained ‘by inspection’.
17. **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 that may not be formally included in the syllabus.
18. **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.

4.7 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
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}
angle	θ	°, rad
angular displacement	θ	°, rad
angular speed	ω	rad s^{-1}
angular velocity	ω	rad s^{-1}
period	T	s
frequency	f	Hz
angular frequency	ω	rad s^{-1}
speed of electromagnetic waves	c	m s^{-1}
electric charge	Q	C
elementary charge	e	C
electric potential	V	V
electric potential difference	V	V

Quantity	**Usual symbols**	**Usual unit**
electromotive force	E	V
resistance	R	Ω
resistivity	ρ	Ω m
electric field strength	E	N C^{-1}, V m^{-1}
magnetic flux	Φ	Wb
magnetic flux density	B	T
force constant	k	N m^{-1}
Celsius temperature	θ	°C
Avogadro constant	N_A	mol^{-1}
number	N, n, m	
activity of radioactive source	A	Bq
half-life	$t_{1/2}$	s
relative atomic mass	A_r	
relative molecular mass	M_r	
atomic mass	m_a	kg, u
electron mass	m_e	kg, u
neutron mass	m_n	kg, u
proton mass	m_p	kg, u
molar mass	M	kg mol^{-1}
proton number	Z	
nucleon number	A	
neutron number	N	

4.8 DATA AND FORMULAE

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

Data

speed of light in free space	$c = 3.00 \times 10^{8}\ \text{m s}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19}\ \text{C}$
unified atomic mass constant	$u = 1.66 \times 10^{-27}\ \text{kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11}\ \text{N m}^{2}\ \text{kg}^{-2}$
acceleration of free fall	$g = 9.81\ \text{m s}^{-2}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
resistors in series	$R = R_1 + R_2 + \cdots$
resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

5. RESOURCES AND REFERENCES

Students may find the following references helpful.

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