# PHYSICS

## SYLLABUS

## Pre-University

### Higher 3

### Syllabus 9814

Implementation starting with
2021 Pre-University One Cohort

Ministry of Education
SINGAPORE

# CONTENTS

# 1.  INTRODUCTION

## 1.1  BACKGROUND

The MOE-H3 Physics (9814) syllabus has been designed to build on and extend the knowledge, understanding and skills acquired from the H2 Physics (9749) syllabus. It caters to students of strong ability and keen interest in physics, and is designed with a strong emphasis on independent and self-directed learning. Students should simultaneously offer H2 Physics. The MOE-H3 Physics syllabus is meant to provide greater depth and rigour in the subject for students pursuing further studies in physics-related fields, such as natural sciences and engineering.

## 1.2  AIMS

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

1. provide students an experience that deepens their knowledge and skills, and fosters 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; and

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

## 1.3    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. 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, precision, validity and reliability, objectivity, integrity and perseverance should be emphasised in the teaching of these practices where appropriate. As the progress of science and technology occur synergistically, students learning science should also be introduced to the use of relevant technology as an aid in practical work or more generically as tools for the interpretation of experimental and theoretical results.

To this end, time should be set aside to allow students to reflect on how the Practices of Science contribute to the accumulation of scientific knowledge. This means, for example, that when students pose questions, plan and conduct investigations, develop models[1] or engage in arguments, they should have opportunities to think about what they have done and why. They should be given opportunities to compare their own approaches to those of other students or professional scientists. Through this kind of reflection, they can come to understand the importance of each practice and develop a nuanced appreciation of the nature of science. The H3 syllabus allows for greater appreciation and deeper development of the Practices of Science.

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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 may or may not 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. Students should appreciate that model development requires making decisions about what aspects of a specific situation are important for the model being used, and understand that all models contain approximations and assumptions that allow them to be used and deployed while potentially limiting their validity and predictive power.

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

## 1.    UNDERSTANDING THE NATURE OF SCIENTIFIC KNOWLEDGE

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

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

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

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

## 2.    DEMONSTRATING SCIENCE INQUIRY SKILLS

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

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

2.3    Obtain, organise, and represent data in an appropriate manner

2.4    Analyse and interpret data

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

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

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

2.8    Communicate scientific findings and information using appropriate language and terminology

## 3.    RELATING SCIENCE AND SOCIETY

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

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

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

**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.
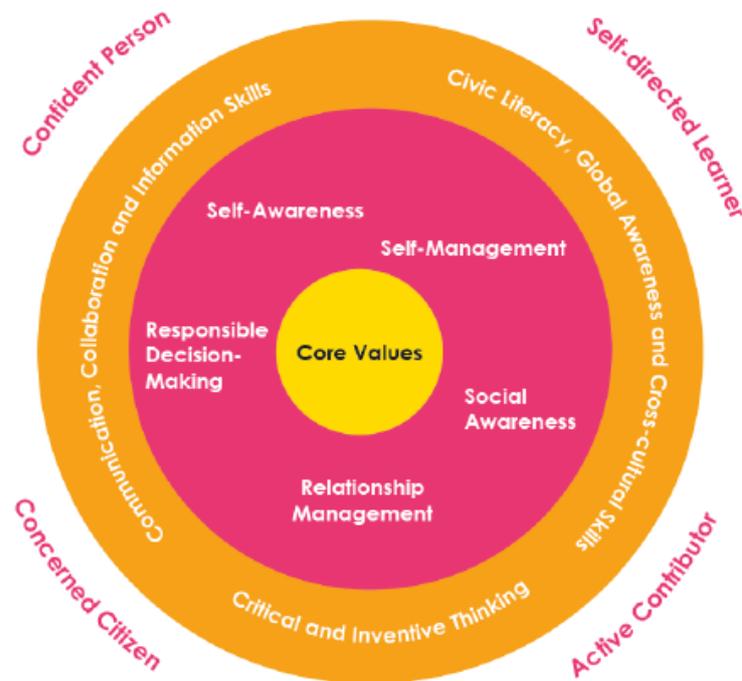


**Figure 1.1**: Framework for 21st Century Competencies and Student Outcomes

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

The development of 21CC is not 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. The nature and limitations of science and scientific inquiry are developed effectively when scientific practices are learnt in the context of relevant science content. Deep disciplinary learning in science develops 21CC and promotes the process of learning for transfer to other areas of life.

## 1.4 MOE-H3 PHYSICS CURRICULUM FRAMEWORK

The MOE-H3 Physics Curriculum Framework (see **Figure 1.2**) encapsulates the key features of the curriculum in broad strokes. This framework is aligned to that of H2 Physics, anchored by the same Core Ideas. Throughout the study of additional MOE-H3 content, explicit links will be made to the Core Ideas, deepening students' understanding of these and allowing a more sophisticated exploration of the Practices of Science (POS). Appropriate Learning Experiences will also feature prominently in MOE-H3 Physics to enhance students' learning.
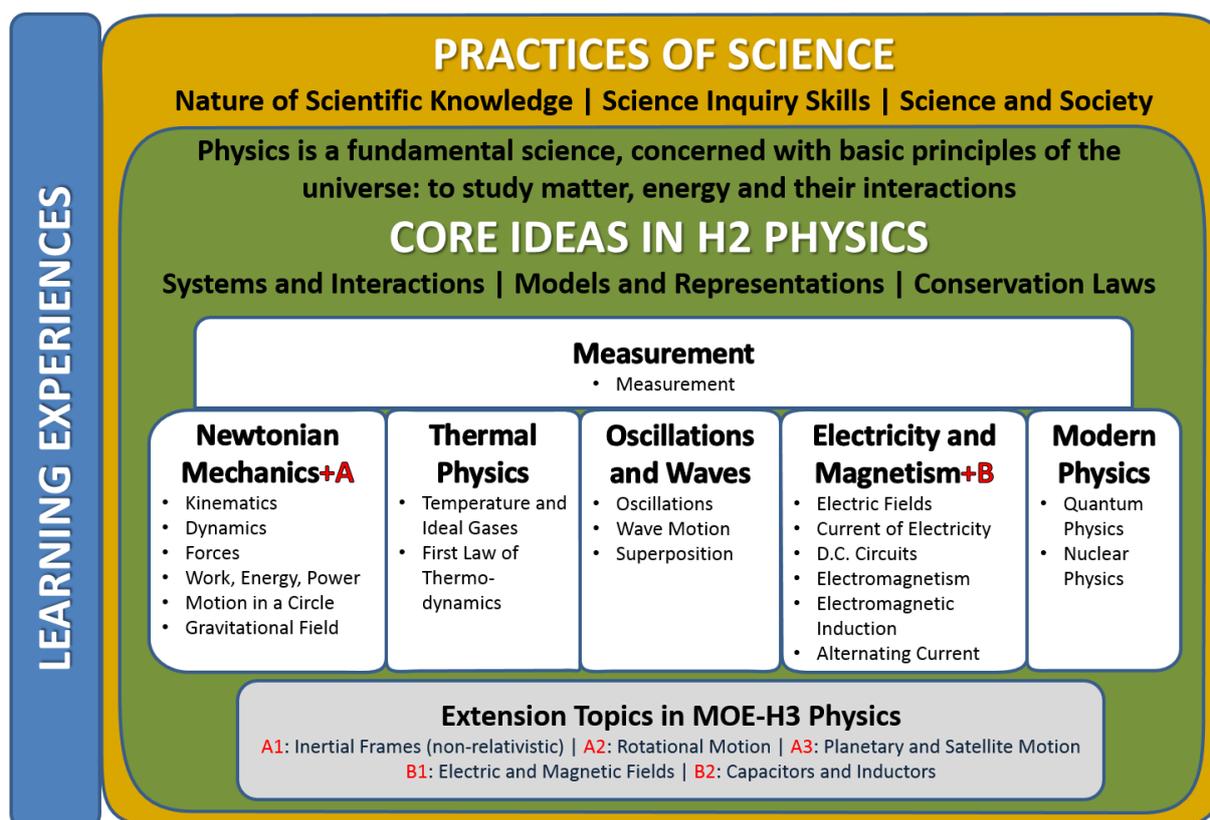


**Figure 1.2**: MOE-H3 Physics Curriculum Framework

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

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

# 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. the attainment of constant temperature at thermal equilibrium when objects of different temperatures interact, or an object returning to its equilibrium position after undergoing damped oscillatory motion).

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

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

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

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

## 2 MODELS AND REPRESENTATIONS

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

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

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

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

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

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

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

**3 CONSERVATION LAWS**

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

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

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

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

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

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

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

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

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

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

## 2.2 SECTIONS AND TOPICS IN MOE-H3 PHYSICS

The syllabus for MOE-H3 Physics (9814) builds on that for H2 Physics, and includes the whole of the H2 Physics (9749) syllabus. Only content that is not already part of the H2 Physics syllabus is specifically set out here. Students taking MOE-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 MOE-H3 Physics syllabus introduces additional content in two of these sections, namely "Newtonian Mechanics" and "Electricity and Magnetism". The additional content has been selected to highlight basic principles in physics and to strengthen the focus on applications. The topics chosen as extensions to the H2 syllabus expand the scope for students to engage in solving challenging problems, while allowing a deeper appreciation of the unity and beauty of the discipline of physics. The main sections and topics for H2 and MOE-H3 are listed in **Table 2.1**.

**Table 2.1**: Main sections and topics for H2 and MOE-H3 Physics

| Sections | Topics (from H2 Physics) | Topics (MOE-H3 Physics only) |
|---|---|---|
| **I.    Measurement** | 1.    Measurement | |
| **II.   Newtonian Mechanics** | 2.    Kinematics<br>3.    Dynamics<br>4.    Forces<br>5.    Work, Energy, Power<br>6.    Motion in a Circle<br>7.    Gravitational Field | **MOE-H3 Newtonian Mechanics**<br>A1. Inertial Frames (non-relativistic)<br>A2. Rotational Motion<br>A3. Planetary and Satellite Motion |
| **III.  Thermal Physics** | 8.    Temperature and Ideal Gases<br>9.    First Law of Thermodynamics | |
| **IV.  Oscillations and Waves** | 10. Oscillations<br>11. Wave Motion<br>12. Superposition | |
| **V.   Electricity and Magnetism** | 13. Electric Fields<br>14. Current of Electricity<br>15. D.C. Circuits<br>16. Electromagnetism<br>17. Electromagnetic Induction<br>18. Alternating Current | **MOE-H3 Electricity and Magnetism**<br>B1. Electric and Magnetic Fields<br>B2. Capacitors and Inductors |
| **VI.  Modern Physics** | 19. Quantum Physics<br>20. Nuclear Physics | |

Students taking MOE-H3 Physics are expected to tackle more sophisticated problems than other students who only take H2 Physics, partly because of the expanded scope. Furthermore, the mathematical requirements for MOE-H3 Physics are higher than for H2 Physics, from the introduction of calculus, etc.

## 2.3    MOE-H3 PHYSICS: NEWTONIAN MECHANICS

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

### TOPIC A1: INERTIAL FRAMES (NON-RELATIVISTIC)

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

| Inertial Frames (non-relativistic) | Learning Outcomes<br>Students should be able to: |
|---|---|
| Inertial frames of reference | (a) show an understanding of what is meant by a frame of reference.<br><br>(b) recall and apply the Galilean transformation equations to solve problems relating observations in different frames of reference.<br><br>(c) show an understanding of what is meant by an inertial frame of reference, in the context of Newton's laws of motion. |
| Centre of mass frame | (d) show an understanding that the centre of mass moves as though the total mass is concentrated at that point and is acted upon by the net external force on the system (candidates are not expected to determine the position of the centre of mass using integration).<br><br>(e) solve two-dimensional collision problems by considering velocities relative to the centre of mass of the system (i.e. in the zero momentum frame). |

### TOPIC A2: ROTATIONAL MOTION

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

| Rotational Motion | Learning Outcomes<br>Students should be able to: |
|---|---|
| Kinematics of angular motion | (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.<br><br>(b) solve problems using the equations of motion for uniform angular acceleration that are analogous to the equations of motion for uniform linear acceleration. |
| Dynamics of angular motion | (c) show an understanding of and use the terms angular momentum and moment of inertia of a rotating rigid body. |

| Rotational Motion | Learning Outcomes Students should be able to: |
|---|---|
| | (d) calculate the moment of inertia about an axis for simple objects by using calculus, the parallel-axis theorem or otherwise (knowledge of the perpendicular-axis theorem 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 variable moment of inertia e.g. an ice-skater. |
| | (f) derive, from the equations of motion, and apply the formula $E_{K,rot} = \frac{1}{2}I\omega^2$ for the rotational kinetic energy of a rigid body. |
| Rigid body rotation about an axis of fixed orientation | (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 $F \leq \mu N$ for solid surfaces in no-slip contact (no distinction is made between the coefficient of static and kinetic friction). |

TOPIC A3: PLANETARY AND SATELLITE MOTION

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

| Planetary and Satellite Motion | Learning Outcomes Students should be able to: |
|---|---|
| Kepler's laws of planetary motion | (a) show an understanding of Kepler's laws of planetary motion, and |
| |     *I.* recall and apply Kepler's first law that the planets move in elliptical orbits with the Sun at one focus of the ellipse (knowledge of the eccentricity parameter is not required). |
| |     *II.* show an understanding of how Kepler's second law (that an imaginary line from the Sun to a moving planet sweeps out equal areas in equal intervals of time) is related to the conservation of angular momentum and apply this law to solve related problems. |
| |     *III.* recall and apply Kepler's third law that the ratio of the square of a planet's period of revolution to the cube of the semi-major axis of its orbit around the Sun is a constant, and this constant is the same for all planets. |

| Planetary and Satellite Motion | Learning Outcomes |
|---|---|
| | Students should be able to: |
| Gravitational potential energy of a spherical shell | (b) derive expressions for the gravitational potential energy of a point mass inside and outside a uniform spherical shell of mass, and relate these expressions to the justification for treating large spherical objects as point masses. |
| Elliptical orbits and orbital transfers | (c) solve problems involving elliptical orbits and orbital transfers e.g. when a satellite fires its thrusters (knowledge of parabolic and hyperbolic trajectories is not required). |
| Concept of an effective radial potential | (d) derive the expression for the mechanical energy of a mass $m$ interacting gravitationally with a large mass $M$, $E = \frac{1}{2}mv^2 - \frac{GMm}{r}$ $= \frac{1}{2}m\dot{r}^2 + \frac{L^2}{2mr^2} - \frac{GMm}{r}$, where $\dot{r}$ is the component of the velocity of mass $m$ in the radial direction and $L$ is the angular momentum of mass $m$ relative to mass $M$ (where mass $M$ is assumed to be stationary and $M \gg m$).<br><br>(e) discuss how the effective radial potential, $U_{eff} = \frac{L^2}{2mr^2} - \frac{GMm}{r}$, allows the determination of bound and unbound states, as well as turning points in the motion, and apply this to solve related problems. |

## 2.4 MOE-H3 PHYSICS: ELECTRICITY AND MAGNETISM

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

### TOPIC B1: ELECTRIC AND MAGNETIC FIELDS

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

| Electric and Magnetic Fields | Learning Outcomes<br>Students should be able to: |
|---|---|
| Electric fields in a conductor | (a) show an understanding that ideal conductors form an equipotential volume, and that the electric field within an ideal conductor is zero.<br><br>(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. |
| Gauss's law for electric and magnetic fields | (c) recall and apply Gauss's law[2] for electric and magnetic fields (knowledge of the differential form of Gauss's law is not required) and<br><br>*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.<br><br>*II.* show an understanding of the non-existence of "magnetic charge" expressed by Gauss's law for magnetism. |
| Ampère's law for magnetic fields | (d) recall and apply Ampère's law[3] 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 students 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.]* |

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[2] 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.
[3] 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.

| Electric and Magnetic Fields | Learning Outcomes<br>Students should be able to: |
|---|---|
| Electric and magnetic dipoles | (e) define the magnitude of the electric dipole moment as the product of the charge and the separation.<br><br>(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.<br><br>(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.<br><br>(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.<br><br>(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. |

**TOPIC B2: CAPACITORS AND INDUCTORS**

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

| Capacitors and Inductors | Learning Outcomes<br>Students should be able to: |
|---|---|
| Capacitance and inductance | (a) define capacitance as the ratio of the change in electric charge to the change in potential difference and use $C = \frac{Q}{V}$ to solve problems.<br><br>(b) 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.<br><br>(c) 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. |
| Dielectrics and ferromagnetic materials | (d) show a qualitative understanding that dielectric materials enhance capacitance, and that dielectric breakdown can occur when the electric field is sufficiently strong (knowledge of the quantitative modification of electric fields in matter through the permittivity is not required). |

| Capacitors and Inductors | Learning Outcomes Students should be able to: |
|---|---|
| | (e) show a qualitative understanding that ferromagnetic materials enhance inductance and that this enhancement is non-linear especially near saturation (knowledge of the quantitative modification of magnetic fields in matter through the permeability is not required). |
| Energy in a capacitor and in an inductor | (f) derive, by considering work done on charges, the expression for potential energy stored in a capacitor, $U = \frac{1}{2}CV^2$, and apply this to solve related problems. |
| | (g) derive, by considering work done on charges, the expression for potential energy stored in an inductor, $U = \frac{1}{2}LI^2$, and apply this to solve related problems. |
| Circuits with capacitors and inductors | (h) solve problems using the formulae for the combined capacitance of two or more capacitors in series and/or parallel. |
| | (i) solve problems using the formulae for the combined inductance of two or more inductors in series and/or parallel. |
| | (j) solve problems involving circuits with resistors, capacitors, and sources of constant e.m.f. (includes solving first-order differential equations). *[RC series circuits with constant e.m.f. source]* |
| | (k) solve problems involving circuits with resistors, inductors, and sources of constant e.m.f. (includes solving first-order differential equations). *[RL series circuits with constant e.m.f. source]* |
| | (l) solve problems involving circuits with inductors and capacitors only (includes solving second-order differential equations). *[LC series circuits without e.m.f. source]* |
| | (m) solve problems involving circuits with resistors, inductors and capacitors only (students 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]* |

# 3.  PEDAGOGY

To achieve the aims of the MOE-H3 Physics syllabus, the learning experience of the students should be one where they are given opportunities:

- to work independently and discuss collaboratively in solving a range of non-routine problems that require them to apply the different concepts, techniques and skills;

- to explore concepts through hands-on practical work and investigations; and

- to participate and learn through a variety of channels such as face-to-face or online talks, seminars, discussion forums, symposia and learning journeys related to physics, but in which the content may not directly correspond to topics within the syllabus, to allow students to explore more contemporary topics such as cosmology and relativity, statistical physics, particle physics and quantum mechanics.

The pedagogy and assessment should support this approach to learning. Formative assessment, in particular, should focus on the process of problem solving and reasoning, with feedback on the strategies used and how the presentation of solutions can be improved, beyond just a focus on the correctness of the solutions.

Learning science is more than acquiring the facts and the outcomes of scientific investigations as a body of knowledge. Science is also a way of knowing and doing. Through the Practices of Science, students should acquire an appreciation of the nature of scientific knowledge and the scientific enterprise, as well as further develop the attitudes and skills of scientific inquiry:

- **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:** Broadly, 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. Strategies that could be used to support inquiry-based learning in science 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. Learning science in a real-life context accessible to students can increase their interest and enhance their awareness of the interconnections among science, technology, society and the environment.

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.

Through critical reading and scientific argumentation, scientific articles and journals could provide students with both up-to-date advances in science and authentic problems encountered by scientists. Peer discussion sessions could provide a platform for students to analyse the situation and share their thoughts. In particular, students are encouraged to read beyond the required learning outcomes, and be kept up-to-date through reading books and articles about cutting-edge science.

Through partnership with Institutes of Higher Learning (IHLs), research institutes and industries, students are encouraged to participate in science fairs, learning journeys, workshops, seminars and dialogues with scientists. These varied experiences aim to give students an authentic taste of how science features in society, and would greatly enrich students' learning and inspire them to take up science as a career.

# 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.

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.

## 4.1 ASSESSMENT OBJECTIVES

The assessment objectives listed below reflect those parts of the aims that will be assessed in the examination.

### A    Knowledge with understanding

Candidates should be able to demonstrate knowledge and understanding in relation to:
1. scientific phenomena, facts, laws, definitions, concepts, theories;
2. scientific vocabulary, terminology, conventions (including symbols, quantities and units);
3. scientific instruments and apparatus, including techniques of operation and aspects of safety;
4. scientific quantities and their determination;
5. scientific and technological applications with their social, economic and environmental implications.

The syllabus content defines the factual knowledge that candidates may be required to recall and explain.

### B    Handling, applying and evaluating information

Candidates should be able (in words or by using symbolic, graphical and numerical forms of presentation) to:
1. locate, select, organise and present information from a variety of sources;
2. handle information, distinguishing the relevant from the extraneous;

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

These assessment objectives cannot be precisely specified in the syllabus content because questions testing such skills may be based on information that is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a novel situation.

## 4.2 SCHEME OF ASSESSMENT

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

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

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

*Weighting of Assessment Objectives*

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

## 4.3 ADDITIONAL INFORMATION

**Required Subject Combinations**
Candidates should simultaneously offer H2 Physics.

*For more information on assessment, please refer to the Singapore Examinations and Assessment Board http://www.seab.gov.sg/.*

# 5. RESOURCES AND REFERENCES

**TEXTBOOKS AND REFERENCES**

- Adams, S. & Allday, J. (2000). *Advanced Physics*. Oxford: Oxford University Press.
- Boohan, R and Needham, R (2016) *The Language of Mathematics in Science: A Guide for Teachers of 11–16 Science.* Association for Science Education. Accessible at www.ase.org.uk/mathsinscience
- 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.
- Giancoli, D. (2014). *Physics: Principles with Applications*. Boston: Pearson.
- Hutchings, R. (2000). *Physics*. Cheltenham: Nelson Thornes.
- 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. (2014). *What If?: Serious Scientific Answers to Absurd Hypothetical Questions*. Houghton Mifflin Harcourt.
- Povey, T. (2015). *Professor Povey's Perplexing Problems: Pre-University Physics and Maths Puzzles with Solutions*. London: Oneworld Publications.
- Randall, L. (2015). *Dark Matter and the Dinosaurs: The Astounding Interconnectedness of the Universe*. New York, NY: Ecco, an imprint of HarperCollins Publishers.

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

A wide range of online resources are available to schools on the [Student Learning Space (SLS)](#) and [One Portal All Learners (OPAL) 2.0](#). Specific links and suggestions have been provided in the Teaching and Learning Guide.

Many publishers are also producing videos and software appropriate for A-Level physics students. In addition, students can be encouraged to engage with the research community and develop their scientific literacies at the forefront of scientific development by reading relevant journals articles in the field. These may also take the form of "open-access" publishing or pre-prints hosted on the arXiv server [[https://arxiv.org/](https://arxiv.org/)].