Singapore Examinations and Assessment Board

Cambridge Assessment International Education

Singapore–Cambridge General Certificate of Education Ordinary Level (2024)

Physics (Syllabus 6091)

CONTENTS

INTRODUCTION

The O-Level physics syllabus provides students with a coherent understanding of energy, matter, and their interrelationships. It focuses on investigating natural phenomena and then applying patterns, models (including mathematical ones), principles, theories and laws to explain the physical behaviour of the universe. The theories and concepts presented in this syllabus belong to a branch of physics commonly referred to as classical physics. Modern physics, developed to explain the quantum properties at the atomic and sub-atomic level, is built on knowledge of these classical theories and concepts.

Students should think of physics in terms of scales. Whereas the classical theories such as Newton's laws of motion apply to common physical systems that are larger than the size of atoms, a more comprehensive theory, quantum theory, is needed to describe systems at the atomic and sub-atomic scales. It is at these scales that physicists are currently making new discoveries and inventing new applications.

It is envisaged that teaching and learning programmes based on this syllabus would feature a wide variety of learning experiences designed to promote acquisition of scientific expertise and understanding, and to develop values and attitudes relevant to science. Teachers are encouraged to use a combination of appropriate strategies to effectively engage and challenge their students. It is expected that students will apply investigative and problem-solving skills, effectively communicate the theoretical concepts covered in this course and appreciate the contribution physics makes to our understanding of the physical world.

AIMS

The syllabus aims to:

1. provide a worthwhile educational experience for all students, whether or not they go on to study science beyond this level

2. develop in students the understanding, and skills relevant to the practices of science, and enable them to

    2.1 appreciate practical applications of Physics in the real world

    2.2 deepen their interest in Physics for future learning and work

    2.3 become scientifically literate citizens who can innovate and seize opportunities in the 21st century

    2.4 use the disciplinary ideas in Physics to approach, analyse and solve problems in the physical world

3. develop in students the values, ethics and attitudes relevant to science such as

    3.1 curiosity – desiring to explore the environment and question what is found

    3.2 creativity – seeking innovative and relevant ways to solve problems

    3.3 integrity – handling and communicating data and information with complete honesty

    3.4 objectivity – seeking data and information to validate observations and explanations without bias

    3.5 open-mindedness – accepting all knowledge as tentative and suspending judgement, tolerance for ambiguity, willingness to change views if the evidence is convincing

3.6 resilience – not giving up on the pursuit of answers/solutions, willingness to take risks and embrace failure as part of the learning process

3.7 responsibility – showing care and concern for living things and awareness of our responsibility for the quality of the environment

3.8 healthy scepticism – questioning the observations, methods, processes and data, as well as trying to review one's own ideas

PRACTICES OF SCIENCE

The *Practices of Science* represent the set of established procedures and practices associated with scientific inquiry, what scientific knowledge is and how it is generated and established, and how Science is applied in society respectively. It consists of three components:

1. Demonstrating Ways of Thinking and Doing in Science (WoTD)

1.1 Posing questions and defining problems

1.2 Designing investigations

1.3 Conducting experiments and testing solutions

1.4 Analysing and interpreting data

1.5 Communicating, evaluating and defending ideas with evidence

1.6 Making informed decisions and taking responsible actions

1.7 Using and developing models

1.8 Constructing explanations and designing solutions

2. Understanding the Nature of Scientific Knowledge (NOS)

2.1 Science is an evidence-based, model-building enterprise concerned with understanding the natural world

2.2 Science assumes there are natural causes for physical phenomena and an order and consistency in natural systems

2.3 Scientific knowledge is generated using a set of established procedures and practices, and through a process of critical debate within the scientific community

2.4 Scientific knowledge is reliable and durable, yet open to change in the light of new evidence

3. Relating Science, Technology, Society and Environment (STSE)

3.1 There are risks and benefits associated with the application of science in society. Science and its applications have the potential to bring about both benefits and harm to society

3.2 Applications of science often have ethical, social, economic and environmental implications

3.3 Applications of new scientific discoveries often inspire technological advancements while advances in technology motivate scientists to ask new questions and/or empower scientists in their inquiry (e.g. collecting more precise data or carrying out more complex data analysis)

The *Practices of Science* serve to highlight that the discipline of Science is more than the acquisition of a *body of knowledge* (e.g. scientific facts, concepts, laws, and theories); it is also a way of *thinking and doing*. In particular, it is important to appreciate that the cognitive, epistemic and social aspects of the *Practices of Science* are intricately related. For example, observation of events can lead to the generation of scientific knowledge which is, simultaneously, shaped by the beliefs of scientific knowledge. In addition, scientists develop models to construct theories, based on the assumption that there is order and consistency in natural systems. The practice of theory-making, in turn, reinforces the explanatory power of scientific knowledge. The scientific endeavour is embedded in the wider ethical, social, economic and environmental contexts.

DISCIPLINARY IDEAS OF PHYSICS

The disciplinary ideas of Physics represent the overarching ideas essential for the understanding of Physics. An understanding of these ideas helps students see the interconnectedness of ideas within and across the sub-disciplines of Physics. Equipping students with a coherent view and conceptual framework facilitates the application and transfer of learning. These disciplinary ideas can be revisited and deepened at higher levels of learning and beyond the schooling years.

Disciplinary ideas are introduced at the upper secondary levels when students begin to specialise in the sub-disciplines of science.

1. Matter and energy make up the Universe

2. Matter interacts through forces and fields

3. Forces help us understand motion

4. Waves can transfer energy without transferring matter

5. Conservation laws constrain the changes in systems

6. Microscopic models can explain macroscopic phenomena

ASSESSMENT OBJECTIVES

The *Assessment Objectives* listed below reflect those parts of the *Aims* and *Practices of Science* that will be assessed.

A Knowledge with understanding

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

1. scientific phenomena, facts, laws, definitions, concepts and theories

2. scientific vocabulary, terminology and conventions (including symbols, quantities and units contained in *Signs, Symbols and Systematics: The ASE Companion to 16-19 Science*, *(2000)*)

3. scientific instruments and apparatus, including techniques of operation and aspects of safety

4. scientific quantities and their determination

5. scientific and technological applications with their social, economic and environmental implications.

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

B Handling Information and Solving Problems

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. translate information from one form to another
3. manipulate numerical and other data
4. use information to identify patterns, report trends and draw inferences
5. present reasoned explanations for phenomena, patterns and relationships
6. make predictions and propose hypotheses
7. solve problems.

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

C Experimental Skills and Investigations

Candidates should be able to:

1. follow a sequence of instructions
2. use techniques, apparatus and materials
3. make and record observations, measurements and estimates
4. interpret and evaluate observations and experimental results
5. plan investigations, select techniques, apparatus and materials
6. evaluate methods and suggest possible improvements.

Weighting of Assessment Objectives

Theory Papers (Papers 1 and 2)

A Knowledge with Understanding, approximately 45% of the marks with approximately 15% allocated to recall.

B Handling Information and Solving Problems, approximately 55% of the marks.

Practical Assessment (Paper 3)

Paper 3 will assess appropriate aspects of assessment objectives C1 to C6 in the following skill areas:

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

The assessment of Planning (P) will have a weighting of 15%. The assessment of skill areas MMO, PDO and ACE will have a weighting of 85%.

SCHEME OF ASSESSMENT

Candidates are required to enter for Papers 1, 2 and 3.

Paper	Type of Paper	Duration	Marks	Weighting
1	Multiple Choice	1 h	40	30%
2	Structured and Free Response	1 h 45 min	80	50%
3	Practical	1 h 50 min	40	20%

Theory Papers

Paper 1 (1 h, 40 marks)

This paper consists of 40 compulsory multiple-choice items.

Paper 2 (1 h 45 min, 80 marks)

This paper consists of two sections.

Section A will carry 70 marks and will consist of a variable number of compulsory structured questions. The last two questions will carry 20 marks, one of which is a data-based question requiring candidates to interpret, evaluate or solve problems using a stem of information. The data-based question will carry 8–12 marks.

Section B will carry 10 marks and will consist of two questions. Candidates must answer only one out of these two questions.

Practical Assessment

Paper 3 (1 h 50 min, 40 marks)

This paper will consist of 2 sections.

Section A will carry 20 marks and will consist of 1–2 compulsory practical experiment questions with a total duration of 55 min.

Section B will carry 20 marks and will consist of one compulsory 55 min practical experiment question.

One, or more, of the questions may incorporate assessment of Planning (P) and require candidates to apply and integrate knowledge and understanding from different sections of the syllabus. The assessment of PDO and ACE may include questions on data-analysis which do not require practical equipment and apparatus.

Candidates would be allocated a specified time for access to apparatus and materials of specific questions (see page 30).

Candidates are not allowed to refer to notebooks, textbooks or any other information during the assessment.

CONTENT STRUCTURE

Section	Topics
I. Measurement	1. Physical Quantities, Units and Measurement
II. Newtonian Mechanics	2. Kinematics 3. Dynamics 4. Turning Effect of Forces 5. Pressure 6. Energy
III. Thermal Physics	7. Kinetic Particle Model of Matter 8. Thermal Processes 9. Thermal Properties of Matter
IV. Waves	10. General Properties of Waves 11. Electromagnetic Spectrum 12. Light
V. Electricity and Magnetism	13. Static Electricity 14. Current of Electricity 15. D.C. Circuits 16. Practical Electricity 17. Magnetism 18. Electromagnetism 19. Electromagnetic Induction
VI. Radioactivity	20. Radioactivity

SUBJECT CONTENT

SECTION I: MEASUREMENT

Overview
Physics is an experimental science and precise measurements enable the collection of useful experimental data which can be tested against hypothesis for the development of physical theories. With the development of better measurement tools and techniques, the data available is improved and scientific knowledge continue to evolve in light of new information.

There is a variety of instruments available and our choice of instrument should take into consideration the precision, and feasibility of the choice of instrument when making measurements. We need to be cognisant of the limitations associated with the measurement process which can arise from the precision of the instrument chosen, the mechanics of the measuring instrument and the design of the experiment.

Apart from the need of accurate measurements, interactions between objects in systems should also be described with precisely defined quantities and units and as these interactions could range from celestial objects to sub-atomic particles, prefixes in order-of-ten are necessary to depict such diversity in range of magnitude.

1. Physical Quantities, Units and Measurement

Content

- Physical quantities and SI units
- Measurement
- Scalars and vectors

Learning Outcomes

Candidates should be able to:

(a) show an understanding that physical quantities typically consist of a numerical magnitude and a unit

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

(c) use the following prefixes and their symbols to indicate decimal sub-multiples and multiples of the SI units: nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T)

(d) show an understanding of the orders of magnitude of the sizes of common objects ranging from a typical atom to the Earth

(e) select and explain the use of appropriate measuring instruments to measure or determine physical quantities listed in 'Summary of key quantities, symbols and units' taking into consideration the range and precision of the instrument

(f) state what is meant by *scalar* and *vector* quantities and give common examples of each

(g) add two vectors to determine a resultant by a graphical method.

SECTION II: NEWTONIAN MECHANICS

Overview
Mechanics is the branch of physics that deals with the study of motion and its causes. Through a careful process of observation and experimentation, Galileo Galilei used experiments to overturn Aristotle's ideas of the motion of objects, for example the flawed idea that heavy objects fall faster than lighter ones, which dominated physics for about 2000 years.

The greatest contribution to the development of mechanics is by one of the greatest physicists of all time, Isaac Newton. By extending Galileo's methods and understanding of motion and gravitation, Newton developed the three laws of motion and his law of universal gravitation, and successfully applied them to both terrestrial and celestial systems to predict and explain phenomena. He showed that nature is governed by a few special rules or laws that can be expressed in mathematical formulae. Newton's combination of logical experimentation and mathematical analysis shaped the way science has been done ever since.

2. Kinematics

Content

- Speed, velocity and acceleration
- Graphical analysis of motion
- Free-fall

Learning Outcomes

Candidates should be able to:

(a) state what is meant by speed and velocity

(b) calculate *average speed = distance travelled / time taken*

(c) state what is meant by *uniform acceleration* and calculate the value of acceleration using *change in velocity / time taken*

(d) interpret given examples of non-uniform acceleration

(e) plot and interpret a displacement-time graph and a velocity-time graph for motion in one dimension

(f) deduce from the shape of a displacement-time graph when a body is:
  (i) at rest
  (ii) moving with uniform velocity
  (iii) moving with non-uniform velocity

(g) deduce from the shape of a velocity-time graph when a body is:
  (i) at rest
  (ii) moving with uniform velocity
  (iii) moving with uniform acceleration
  (iv) moving with non-uniform acceleration

(h) calculate the area under a velocity-time graph to determine the displacement for motion with uniform velocity or uniform acceleration

(i) state that the acceleration of free fall for a body near to the Earth is constant and is approximately $10\ m/s^2$.

3. Dynamics

Content

- Types of forces
- Mass, weight and gravitational field
- Newton's laws of motion
- Effects of resistive forces on motion

Learning Outcomes

Candidates should be able to:

(a) identify and distinguish between contact forces (e.g. friction, air resistance, tension and normal force) and non-contact forces (e.g. gravitational, electrostatic and magnetic forces)

(b) state that mass is a measure of the amount of matter in a body

(c) state that a gravitational field is a region in which a mass experiences a force due to gravitational attraction

(d) define gravitational field strength, g, as *gravitational force per unit mass placed at that point*

(e) recall and apply the relationship *weight = mass* $\times$ *gravitational field strength* to new situations or to solve related problems

(f) distinguish between mass and weight

(g) apply Newton's Laws to:
  (i) describe the effect of balanced and unbalanced forces on a body
  (ii) describe the ways in which a force may change the motion of a body
  (iii) identify action-reaction pairs acting on two interacting bodies
  (stating of Newton's Laws is not required)

(h) identify forces acting on a body and draw free body diagram(s) representing the forces acting on the body (for cases involving forces acting in at most two dimensions)

(i) solve problems for a static point mass under the action of three forces for two-dimensional cases by a graphical method

(j) recall and apply the relationship *resultant force = mass* $\times$ *acceleration* to new situations or to solve related problems

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

(l) explain the effects of friction on the motion of a body

(m) describe the motion of bodies with constant mass falling in uniform gravitational field with or without air resistance, including reference to terminal velocity.

4. Turning Effects of Forces

Content

- Moments
- Equilibrium
- Centre of gravity and stability

Learning Outcomes

Candidates should be able to:

(a) describe the moment of a force about a pivot in terms of its turning effect and relate this to everyday examples

(b) recall and apply the relationship *moment of a force (or torque) = force* × *perpendicular distance from the pivot* to new situations or to solve related problems

(c) state the principle of moments for a body in equilibrium

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

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

(f) describe qualitatively the effect of the position of the centre of gravity on the stability of objects.

5. Pressure

Content

- Pressure
- Density and fluid pressure

Learning Outcomes

Candidates should be able to:

(a) define pressure in terms of force and area

(b) recall and apply the relationship *pressure = force / area* to new situations or to solve related problems

(c) describe and explain the transmission of pressure in hydraulic systems with particular reference to the hydraulic press

(d) recall and apply the relationship *density = mass / volume* to new situations or to solve related problems

(e) recall and apply the relationship *pressure due to a liquid column = height of column* × *density* of the *liquid* × *gravitational field strength* to new situations or to solve related problems

(f) describe how the height of a liquid column may be used to measure the atmospheric pressure

(g) describe the use of a manometer in the measurement of pressure difference.

6. Energy

Content

- Energy stores and transfers
- Work, power and efficiency
- Energy resources

Learning Outcomes

Candidates should be able to:

(a) show an understanding that there are energy stores, e.g. kinetic, potential (gravitational, chemical, elastic), nuclear and internal, and that energy can be transferred from one store to another:
  (i) Mechanically (by a force acting over a distance)
  (ii) Electrically (by an electric current)
  (iii) By heating (due to a temperature difference)
  (iv) By propagation of waves (both electromagnetic and mechanical)

(b) recall and apply the relationships for kinetic energy ($E_k = \frac{1}{2}mv^2$) and gravitational potential energy near the Earth's surface ($E_p = mgh$) to new situations or to solve related problems

(c) state the principle of the conservation of energy and apply the principle to new situations or to solve related problems

(d) recall and apply the relationship *work done = force* × *distance moved in the direction of the force* to new situations or to solve related problems

(e) recall and apply the relationship *power = energy transfer / time taken* to new situations or to solve related problems

(f) calculate the efficiency of an energy transfer using the formula *efficiency = useful energy output / total energy input*

(g) discuss the use of non-renewable energy resources such as fossil fuel and nuclear fuel, and renewable energy resources such as biofuel, wind, tides, hydropower, geothermal reservoirs and solar to generate electricity in terms of efficiency of energy transfer, cost, reliability and their environmental impact.

SECTION III: THERMAL PHYSICS

Overview

When asked what was the most valuable scientific information in a single sentence, Richard Feynman response was, ‘All things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence ... there is an enormous amount of information about the world.’ (Six Easy Pieces, p.4)

Understanding thermal physics requires us to approach the concepts from both the macroscopic and microscopic lenses. The *Kinetic Particle Model of Matter* is a cornerstone theory that is used extensively to explain how different types of matter exhibit certain physical properties by relating them to behaviour of atoms and molecules.

By nature, energy exchange takes place between bodies of different temperatures until thermal equilibrium is reached. Energy may be transferred between bodies by heating through processes like conduction, convection and radiation. These processes could cause changes in the molecular structure of matter and result in macroscopic observations, e.g. monsoon winds and ocean currents observed are convectional currents produced in the process of regulating differences in temperature.

7. Kinetic Particle Model of Matter

Content

- States of matter
- Kinetic Particle Model

Learning Outcomes

Candidates should be able to:

(a) compare the physical properties of solids, liquids and gases

(b) use the kinetic particle model to describe the different states of matter (solids, liquids and gases), relating their physical properties to the arrangement and motion of the particles (e.g. molecules, atoms) and the forces and distances between particles

(c) infer from a Brownian motion experiment the evidence for the random movement of molecules in a liquid or gas

(d) relate the rise in temperature of a body to the increase in average kinetic energy of all the particles in the body

(e) explain the pressure of a gas in terms of the motion of its particles.

8. Thermal Processes

Content

- Thermal equilibrium
- Conduction
- Convection
- Radiation

Learning Outcomes

Candidates should be able to:

(a) show an understanding that energy is transferred (by heating) from a region of higher temperature to a region of lower temperature until thermal equilibrium is achieved between the two regions

(b) describe, in microscopic terms, how conduction occurs in solids (via vibration of atoms/molecules and movement of electrons)

(c) describe, in terms of density changes, how convection occurs in fluids

(d) explain that energy transfer by electromagnetic radiation does not require a material medium and that this rate of energy transfer to/from a body is affected by its:
(i) surface colour and texture
(ii) surface temperature
(iii) surface area

(e) apply the concepts of conduction, convection and radiation in everyday examples.

9. Thermal Properties of Matter

Content

- Internal energy
- Specific heat capacity
- Melting, boiling and evaporation
- Specific latent heat

Learning Outcomes

Candidates should be able to:

(a) describe internal energy as an energy store that is made up of the total kinetic energy associated with the random motion of the particles and the total potential energy between the particles in the system

(b) define *heat capacity* and *specific heat capacity*

(c) recall and apply the relationship *energy transfer (by heating)* = *mass* $\times$ *specific heat capacity* x *change in temperature* to new situations or to solve related problems

(d) describe melting/solidification and boiling/condensation as processes of energy transfer without a change in temperature

(e) explain the difference between boiling and evaporation

(f) define *latent heat* and *specific latent heat*

(g) recall and apply the relationship *energy transfer* (by *heating* for a change of state) = *mass* $\times$ *specific latent heat* to new situations or to solve related problems

(h) explain latent heat in terms of behaviour of particles in a body

(i) sketch and interpret a cooling curve.

SECTION IV: WAVES

Overview

All waves have properties in common and a wave model can be used to explain many phenomena, both natural (like water waves and sound) and artificial (like many forms of electromagnetic waves). The ability of waves to transfer energy at great speed provides valuable propositions.

Much of our current understanding of wave motion has come from the study of acoustics, which is the science of sound. Many of the ancient Greek philosophers were interested in music. They had hypothesized that there was a connection between waves and sound, and that vibrations must be responsible for sounds. Pythagoras observed in 550 BC that vibrating strings produced sound and worked to determine the mathematical relationships between the lengths of strings that made harmonious tones.

Scientific theories of wave propagation became more prominent in the 17th Century, when Galileo Galilei published a clear statement that connected vibrating bodies to the sounds they produce. In 1640 Robert Boyle's classic experiment on the sound produced by a ticking watch in a partially evacuated glass vessel provided evidence that air is necessary, either for the production or transmission of sound.

The mathematical theory of sound propagation began with Isaac Newton, whose *Principia* (1686) included a mechanical interpretation of sound as being 'pressure' pulses transmitted through neighbouring fluid particles. In the 18th Century, French mathematician and scientist Jean Le Rond d'Alembert derived the wave equation, a thorough and general mathematical description of waves, which laid the foundation for generations of scientists to study and describe wave phenomena.

10. General Properties of Waves

Content

- Describing wave motion
- Wave properties
- Sound

Learning Outcomes

Candidates should be able to:

(a) describe what is meant by wave motion as illustrated by vibrations in ropes and springs and by waves in a ripple tank (including use of the term wavefront)

(b) show an understanding that waves transfer energy without transferring matter

(c) define and use the terms *speed*, *frequency, wavelength*, *period* and *amplitude*, including graphical representation

(d) recall and apply the relationship *speed of wave = frequency* × *wavelength* to new situations or to solve related problems

(e) compare transverse and longitudinal waves and give suitable examples of each

(f) show an understanding that sound can be produced by vibrating sources and a medium is required for the transmission of sound.

(g) describe the longitudinal nature of sound waves in terms of the processes of compression and rarefaction

(h) relate loudness of a sound wave to its amplitude and pitch to its frequency

(i) describe how the reflection of sound may produce an echo, and how this may be used for measuring distances

(j) describe and explain how ultrasound is used, e.g. including sonar and medical scanning of soft tissue.

11. Electromagnetic Spectrum

Content

- Properties of electromagnetic waves
- Applications of electromagnetic waves
- Effects of electromagnetic waves on cells and tissues

Learning Outcomes

Candidates should be able to:

(a) state that all electromagnetic waves are transverse waves that travel with the same speed in vacuum

(b) describe the main regions of the electromagnetic spectrum in order of wavelength and frequency

(c) state examples of typical uses of the following regions of the electromagnetic spectrum:
    (i) radio waves (e.g. radio and television communication, astronomy and RFID tags)
    (ii) microwaves (e.g. mobile (cell) phones, microwave oven and satellite television)
    (iii) infrared (e.g. infrared remote controllers, intruder alarms and thermal imaging)
    (iv) visible light (e.g. photography, optical fibres in medicine and telecommunications)
    (v) ultraviolet (e.g. sunbeds, bank note authentication and disinfecting water)
    (vi) X-rays (e.g. medical radiology, security screening and industrial defect detection)
    (vii) gamma (γ) rays (e.g. sterilising food, detection of cancer and its treatment)

(d) describe how over-exposure to electromagnetic waves can have hazardous effects (e.g. heating and ionising effects of radiation) on living cells and tissue.

12. Light

Content

- Reflection of light
- Refraction of light
- Thin converging lenses

Learning Outcomes

Candidates should be able to:

(a) recall and use the terms *normal, angle of incidence* and *angle of reflection* to describe the reflection of light

(b) state that, for reflection, the angle of incidence is equal to the angle of reflection and use this principle in constructions, measurements and calculations

(c) recall and use the terms *normal, angle of incidence* and *angle of refraction* to describe the refraction of light

(d) recall and apply the relationship *sin i* / *sin r = constant* to new situations or to solve related problems

(e) define *refractive index* of a medium in terms of the ratio of speed of light in vacuum and in the medium

(f) explain the terms *critical angle* and *total internal reflection*

(g) apply total internal reflection to the use of optical fibres in telecommunication and medicine, stating the advantages of such use

(h) describe the action of a thin converging lens on a beam of light

(i) define the *focal length* for a converging lens

(j) draw ray diagrams to illustrate the formation of real and virtual images of an object by a thin converging lens

(k) describe the characteristics of images (e.g. real/virtual, magnified/diminished, and upright/inverted) formed by a thin converging lens.

SECTION V: ELECTRICITY AND MAGNETISM

Overview

Electricity and magnetism were seen as separate and independent phenomena in the past. It only was when Danish physicist Hans Christian Ørsted discovered, accidentally, in 1820 that a magnetic needle is deflected when the current in a nearby wire varies - a phenomenon establishing a relationship between electricity and magnetism.

Inspired by Ørsted's discovery, André-Marie Ampère conducted a series of experiments in the same year to designed to elucidate the exact nature of the relationship between electric current-flow and magnetism. Further works by Michael Faraday reinforced the magnetic effect of a current and introduced the idea of a ‘field’ of action to explain why electricity and magnetism had and ‘area of activity’.

However, it was the work of James Clerk Maxwell, a mathematical physicist, who provided mathematical tools and equations to describe Faraday’s ideas of the field. His works went on to prove that electromagnetic fields have wave-like properties which was a very important discovery in physics.

13. Static Electricity

Content

- Electric charge
- Electric field
- Dangers and applications of electrostatic charging

Learning Outcomes

Candidates should be able to:

(a) state that there are positive and negative charges and that charge is measured in coulombs

(b) state that unlike charges attract and like charges repel

(c) describe an electric field as a region in which an electric charge experiences a force

(d) draw the electric field of an isolated point charge and recall that the direction of the field lines gives the direction of the force acting on a positive test charge

(e) draw the electric field pattern between two isolated point charges

(f) show an understanding that electrostatic charging by rubbing involves a transfer of electrons

(g) describe experiments to show electrostatic charging by induction

(h) describe examples where electrostatic charging may be a potential hazard

(i) describe the use of electrostatic charging in an electrostatic precipitator and apply the use of electrostatic charging to new situations.

14. Current of Electricity

Content

- Conventional current and electron flow
- Electromotive force and potential difference
- Resistance

Learning Outcomes

Candidates should be able to:

(a) state that current is the rate of flow of charge and that it is measured in amperes

(b) distinguish between conventional current and electron flow

(c) recall and apply the relationship *charge = current* × *time* to new situations or to solve related problems

(d) state that the electromotive force (e.m.f.) of a source is the work done per unit charge by the source in driving charges around a complete circuit and that it is measured in volts

(e) calculate the total e.m.f. where several sources are arranged in series

(f) state that the potential difference (p.d.) across a component in a circuit is the work done per unit charge in driving charges through the component and that it is measured in volts

(g) state that *resistance = p.d. / current*

(h) apply the relationship $R = V / I$ to new situations or to solve related problems

(i) recall and apply the relationship of the proportionality between resistance and the length and cross-sectional area of a wire to new situations or to solve related problems

(j) describe the effect of temperature increase on the resistance of a metallic conductor

(k) sketch and interpret the I-V characteristic graphs for a metallic conductor at constant temperature (ohmic conductor), for a filament lamp and for a semiconductor diode.

15. D.C. Circuits

Content

- Circuit diagrams
- Series and parallel circuits
- Action and use of circuit components

Learning Outcomes

Candidates should be able to:

(a) draw circuit diagrams with power sources (cell, battery, d.c. supply or a.c. supply), switches, lamps, resistors (fixed and variable), variable potential divider (potentiometer), fuses, ammeters and voltmeters, bells, light-dependent resistors, thermistors and light-emitting diodes

(b) state that the current at every point in a series circuit is the same and apply the principle to new situations or to solve related problems

(c) state that the sum of the potential differences in a series circuit is equal to the potential difference across the whole circuit and apply the principle to new situations or to solve related problems

(d) state that the sum of the currents in the separate branches of a parallel circuit is equal to the current from the source and apply the principle to new situations or to solve related problems

(e) state that the potential difference across the separate branches of a parallel circuit is the same and apply the principle to new situations or to solve related problems

(f) recall and apply the formulae for the effective resistance of a number of resistors in series and in parallel to new situations or to solve related problems

(g) recall and apply the relevant relationships, including $R = V / I$ and those for current, potential differences and resistors in series and in parallel circuits, in calculations involving a whole circuit

(h) describe the action of a variable potential divider (potentiometer)

(i) describe the action of negative temperature coefficient (NTC) thermistors and light-dependent resistors and explain their use as input transducers in potential dividers

(j) solve simple circuit problems involving NTC thermistors and light-dependent resistors.

16. Practical Electricity

Content

- Electrical working, power and energy
- Dangers of electricity
- Safe use of electricity in the home

Learning Outcomes

Candidates should be able to:

(a) describe the use of the heating effect of electricity in appliances such as electric kettles, ovens and heaters

(b) recall and apply the relationships $P = VI$ and $E = VIt$ to new situations or to solve related problems

(c) calculate the cost of using electrical appliances where the energy unit is the kW h

(d) state the hazards of using electricity in the following situations:
(i) damaged insulation
(ii) overheating of cables
(iii) damp conditions

(e) explain the use of fuses and circuit breakers in electrical circuits and of fuse ratings

(f) explain the need for earthing metal casings and for double insulation

(g) state the meaning of the terms *live, neutral and earth*

(h) describe the wiring in a mains plug

(i) explain why switches, fuses, and circuit breakers are fitted to the live wire.

17. Magnetism

Content

- Laws of magnetism
- Magnetic properties of matter
- Magnetic field

Learning Outcomes

Candidates should be able to:

(a) state the properties of magnets

(b) describe induced magnetism caused by placing magnetic material close to a strong magnet or within a current-carrying solenoid

(c) distinguish between temporary magnets (e.g. iron) and permanent magnets (e.g. steel) in terms of their properties and uses

(d) describe how a bar magnet (e.g. a compass) can be used to determine the direction of a magnetic field

(e) draw the magnetic field pattern around a bar magnet and between the poles of two bar magnets.

18. Electromagnetism

Content

- Magnetic effect of a current
- Force on a current-carrying conductor
- The d.c. motor

Learning Outcomes

Candidates should be able to:

(a) draw the pattern of the magnetic field due to currents in straight wires and in solenoids and state the effect on the magnetic field of changing the magnitude and/or direction of the current

(b) describe the application of the magnetic effect of a current in electromagnets (e.g. circuit breakers)

(c) describe experiments to show the force on a current-carrying conductor, and on a beam of charged particles, in a magnetic field, including the effect of reversing
(i) the current
(ii) the direction of the field

(d) deduce the relative directions of force, field and current when any two of these quantities are at right angles to each other using Fleming's left-hand rule

(e) explain how a current-carrying coil in a magnetic field (e.g. in a motor) experiences a turning effect and that the effect is increased by increasing
(i) the number of turns on the coil
(ii) the current

(f) describe the action of a split-ring commutator in a two-pole, single-coil motor and the effect of winding the coil on to a soft-iron cylinder.

19. Electromagnetic Induction

Content

- Principles of electromagnetic induction
- The a.c. generator
- The transformer

Learning Outcomes

Candidates should be able to:

(a) deduce from Faraday's experiments on electromagnetic induction or other appropriate experiments:
  (i) that a changing magnetic field can induce an e.m.f. in a circuit
  (ii) that the direction of the induced e.m.f. opposes the change producing it
  (iii) the factors affecting the magnitude of the induced e.m.f.

(b) describe a simple a.c. generator (rotating coil or rotating magnet) and the use of slip rings (where needed)

(c) sketch a graph of voltage output against time for a simple a.c. generator

(d) describe the structure and principle of operation of a simple iron-cored transformer as used for voltage transformations

(e) recall and apply the equations $V_P / V_S = N_P / N_S$ and $V_P I_P = V_S I_S$ to new situations or to solve related problems (for an ideal transformer)

(f) describe the energy loss in cables and deduce the advantages of high voltage transmission.

SECTION VI: RADIOACTIVITY

Overview

Radioactivity was first discovered through the handling of radioactive uranium by physicists Pierre and Marie Curie during which they suffered radioactive burns due to inadequate handling of the substance. *Radioactivity* is the study of the nature of the radiation emitted by radioactive materials. It was later understood that there are three types of emissions: the alpha particles (helium atoms with no electrons), beta particles (fast moving electrons) and the gamma rays (electromagnetic radiation similar to X-rays). These emissions are the result of the decay or disintegration of an unstable atomic nucleus.

Radioactivity have important medical uses, which include the killing of cancer cells. However excessive exposure to radioactivity can cause cancer if the dose is too high. Many early scientists working with radioactive materials died early from the harmful effects of high radiation before proper safety guidelines were drawn. 'Radiometric dating' makes use of a radioactive element's half-life to help determine the age of rocks or carbon.

Large amounts of energy are also involved in radioactive emissions and physicists quickly recognized the power of this. Many scientists working on this from 1930 to 1940 in Europe were forced to leave their home countries, fleeing to the United States due to the development of the war. This led to a 'brain drain' which benefited the United States and allowed them to develop the two atomic bombs which ended the war. This highlights the impact on science on society and human interactions. Since the development of the atomic bomb, much has been learnt about how to control the release of energy and nuclear power can generate electricity with only a fraction of the greenhouse gases released by burning coal and other fossil fuels.

Because radiation cannot be easily seen, it is commonly feared and shunned. Coupled with news about the dangers of nuclear radiation and the potential detriments to health, the general public is apprehensive about the use and application of any form of radiation. This topic aims to provide an objective evaluation of the risks and benefits of the use of radiation through the development of a good understanding of the many practical uses of radioactive materials.

20. Radioactivity

Content

- The composition of the atom
- Radioactive decay
- Dangers and uses of radioactivity

Learning Outcomes

Candidates should be able to:

(a) describe the composition of an atom in terms of a positive nucleus (with protons and neutrons) and negatively charged electrons

(b) use the terms proton (atomic) number Z, nucleon (mass) number A and isotope

(c) use and interpret the term nuclide and use the nuclide notation ${}^{A}_{Z}X$

(d) show an understanding that nuclear decay is a random and spontaneous process whereby an unstable nucleus loses energy by emitting radiation

(e) show an understanding of the nature of alpha (α), beta (β), and gamma (γ) radiation (including ionising effect and penetrating power) [β-particles are assumed to be β^- particles only]

(f) use equations involving nuclide notation to represent changes in the composition of the nucleus when radioactive emissions occur

(g) show an understanding of background radiation

(h) use the term half-life in simple calculations, which might involve information in tables or decay curves

(i) discuss the applications (e.g. medical and industrial uses) and hazards of radioactivity based on:
(i) half-life of radioactive materials,
(ii) penetrating abilities and ionising effects of radioactive emissions

(j) state the meaning of nuclear fusion and nuclear fission and relate these nuclear processes with the release of energy from nuclear fuels (recall of the energy-mass equivalence and details of technologies in nuclear power plants are not required).

SUMMARY OF KEY QUANTITIES, SYMBOLS AND UNITS

Candidates should be able to state the symbols for the following physical quantities and, where indicated, state the units in which they are measured. Candidates should be able to define those items indicated by an asterisk (*).

Quantity	***Symbol***	***Unit***
length	*l, h* …	km, m, cm, mm
area	*A*	m^2, cm^2
volume	*V*	m^3, cm^3
weight*	*W*	N
mass	*m, M*	kg, g, mg
time	*t*	h, min, s, ms
period*	*T*	s
density*	ρ	g / cm^3, kg / m^3
speed*	*u, v*	km / h, m / s, cm / s
acceleration*	*a*	m / s^2
acceleration of free fall	*g*	m / s^2, N / kg
force*	*F, f*	N
moment of force*		N m
work done*	*W, E*	J
energy	*E*	J, kW h
power*	*P*	W
pressure*	*p, P*	Pa, N / m^2, mm Hg
temperature	θ, *T*	°C, K
heat capacity	*C*	J / °C, J / K
specific heat capacity*	*c*	J / (g °C), J / (g K)
latent heat	*L*	J
specific latent heat*	*l*	J / kg, J / g
frequency*	*f*	Hz
wavelength*	λ	m, cm
focal length	*f*	m, cm
angle of incidence	*i*	degree (°)
angles of reflection, refraction	*r*	degree (°)
critical angle	*c*	degree (°)
potential difference* / voltage	*V*	V, mV
current*	*I*	A, mA
charge	*q, Q*	C, A s

e.m.f.*	E	V
resistance	R	Ω
proton number	Z	
nucleon number	A	
half-life	$t_{1/2}$	s
activity of a radioactive source	A	Bq

PRACTICAL ASSESSMENT

Scientific subjects are, by their nature, experimental. It is therefore important that an assessment of a candidate’s knowledge and understanding of science should include a component relating to practical work and experimental skills.

This assessment is provided in Paper 3 as a formal practical test and is outlined in the *Scheme of Assessment*.

Paper 3 Practical

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

Candidates should be able to:
- identify key variables for a given question/problem
- outline an experimental procedure to investigate the question/problem
- describe how the data should be used in order to reach a conclusion
- identify the risks of the experiment and state precautions that should be taken to keep risks to a minimum

(b) Manipulation, measurement and observation (MMO)

Candidates should be able to:
- set up apparatus correctly by following written instructions or diagrams
- use common laboratory apparatus and techniques to collect data and make observations
- describe and explain how apparatus and techniques are used correctly
- make and record accurate observations with good details and measurements to an appropriate degree of precision
- make appropriate decisions about measurements or observations

(c) Presentation of data and observations (PDO)

Candidates should be able to:
- present all information in an appropriate form
- manipulate measurements effectively for analysis
- present all quantitative data to an appropriate number of decimal places / significant figures

(d) Analysis, conclusions and evaluation (ACE)

Candidates should be able to:
- analyse and interpret data or observations appropriately in relation to the task
- draw conclusion(s) from the interpretation of experimental data or observations and underlying principles
- make predictions based on their data and conclusions
- identify significant sources of errors and explain how they affect the results
- state and explain how significant errors may be overcome or reduced, as appropriate, including how experimental procedures may be improved

One, or more, of the questions may incorporate some assessment of skill area P, set in the context of the syllabus content, requiring candidates to apply and integrate knowledge and understanding from different sections of the syllabus. It may also require the treatment of given experimental data in drawing relevant conclusion and analysis of proposed plan.

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

Candidates are not allowed to refer to notebooks, textbooks or any other information during the assessment.

Candidates should be able to make measurements or determinations of physical quantities such as mass, length, area, volume, time, current and potential difference. Candidates should be aware of the need to take simple precautions for safety and/or accuracy. Candidates will be required to follow the instructions given in the question paper and answer on the question paper itself.

Candidates may be asked to carry out exercises based on:

1. measurements of
   (i) length by using tapes, rules, digital calipers and digital micrometers
   (ii) time interval (including period of a simple pendulum) by using digital stopwatches
   (iii) volume of solids/liquids by using measuring cylinders
   (iv) mass and weight by using electronic balances and spring balances
   (v) temperature by using laboratory thermometers
   (vi) current and voltage by using ammeters and voltmeters

2. determination of the density of a liquid, or of a regularly or irregularly shaped solid that sinks in water

3. determination of the value of the acceleration of free fall

4. investigation of the effects of balanced and unbalanced forces

5. the principle of moments

6. determination of the position of the centre of gravity of a plane lamina

7. investigation of the factors affecting transfer of energy by thermal processes

8. determination of heat capacities of materials

9. latent heat of substances

10. the law of reflection

11. determination of the position and characteristics of an optical image formed by a plane mirror or a thin converging lens

12. the refraction of light through glass blocks

13. the principle of total internal reflection

14. the focal length of lenses

15. determination of the speed, wavelength and frequency of waves

16. determination of the resistance of a circuit

17. investigation of the magnetic effect of current in a conductor

18. investigation of the effects of electromagnetic induction

This is not intended to be an exhaustive list. Candidates are expected to be familiar with the use of data-loggers. Assessment of skill area P may include the appropriate use of data-loggers.

Responsibility for safety matters rests with Centres.

Reference may be made to the techniques used in these experiments in the theory papers but no detailed description of the experimental procedures will be required.

Within the Scheme of Assessment, the practical paper constitutes 20% of the O-Level Physics examination. It is therefore recommended that the schemes of work include learning opportunities that apportion a commensurate amount of time for the development and acquisition of practical skills.

Apparatus List

This list below gives guidance to Centres concerning the apparatus and items that are expected to be generally available for examination purposes. The list is not intended to be exhaustive.

The apparatus and materials requirement for Paper 3 will vary from year to year. Centres will be notified in advance of the details of the apparatus and materials required for each practical examination.

It is intended that candidates should have 55 minutes with the apparatus for each section of the paper. Please note the requirement to provide a seating plan of the examination, as indicated on the instructions. It is essential that candidates are warned of these arrangements in advance. Spare sets of apparatus must be available to allow for breakages and malfunctions.

Unless otherwise stated, the rate of allocation is 'per candidate'.

Electrical	**Mechanics and General Items**
Ammeter (analogue): f.s.d. 1 A	Pendulum bob
Voltmeter (analogue): f.s.d. 3 V, f.s.d. 5 V	Stand, boss and clamp: $\times$ 2 (Rod length: 60 cm)
Cells: 2 $\times$ 1.5 V with holder	
Lamp and holder: 2.5 V, 0.3 A	Pivot
Rheostat: Max resistance: 22 Ω, Rating: at least 3.3 A	Pulley
Resistors, various	Newton-meter: 1 N, 2.5 N
Switch	Rule with millimetre scale (1 $\times$ 1 m, 1 $\times$ 0.5 m, 1 $\times$ 300 mm)
Jockey	
Leads and crocodile clips	Digital calipers to 0.01 mm (1 per 4–6 candidates)
Wire: constantan 28 s.w.g. or metric equivalents	Digital micrometer screw gauge to 0.001 mm (1 per 4–6 candidates)
Wire: nichrome 28, 32 s.w.g. or metric equivalents	
Magnets: 2 $\times$ bar magnets	Stopwatch (reading to 0.1 s or better)
Compass: 1 $\times$ small	Balance to 0.01 g (1 per 8–12 candidates)
	Plasticine
	Blu-Tack
Heat	Springs
Long stem thermometer: –10 °C to 110 °C at 1 °C	Optical pin
Beaker: 500 cm^3, 2 $\times$ 250 cm^3	Slotted masses: 1 $\times$ 5 g; 1 $\times$ 10 g; 2 $\times$ 20 g; 4 $\times$ 50 g; 1 $\times$ 50 g hanger
Boiling tube, 150 mm $\times$ 25 mm	
Measuring cylinder: 50 cm^3, 100 cm^3	Slotted masses: 4 $\times$ 100 g; 1 $\times$ 100 g hanger
Plastic or polystyrene cup 200 cm^3	Burette
Means to heat water safely to boiling	Rubber tubing
Heating mat	Cork
Stirrer	Dropper
	String / thread / twine
Light	Scissors
Glass block (120 mm $\times$ 60 mm $\times$ 20 mm)	Adhesive tape
Microscope slides	Card (assorted sizes)
Mirror, plane (100 mm $\times$ 50 mm)	Wood (assorted sizes, for various uses, e.g. support)
Lens, converging f = 15 cm	
Lens holder	Wooden board
Screen (10 cm wide, 15 cm high)	Sand and tray
Torchlight	Bricks: 2 $\times$ (approx. 22 cm $\times$ 10 cm $\times$ 7 cm)
Protractor	
Pin board (23 cm $\times$ 30 cm)	
Pins	
Tracing paper	

General marking points

Taking readings

During the course of their preparation for this paper, candidates should be taught to observe the following points of good practice, which are often featured in the mark scheme. A measuring instrument should be used to its full precision. Thermometers are often marked with intervals of 1° C. It is appropriate to record a reading which coincides exactly with a mark as, for example, 22.0° C, rather than as a bald 22° C. Interpolation between scale divisions should be to better than one half of a division. For example, consider a thermometer with scale divisions of 1° C. A reading of 22.3° C might best be recorded as 22.5° C, since '0.3' is nearer '0.5' than '0'. That is, where a reading lies between two scale marks, an attempt should be made to interpolate between those two marks, rather than simply rounding to the nearest mark. The length of an object measured on a rule with a centimetre and millimetre scale should be recorded as 12.0 cm rather than a bald 12 cm, if the ends of the object coincide exactly with the 0 and 12 cm marks.

A measurement or calculated quantity must be accompanied by a correct unit, where appropriate.

Recording readings

A table of results should include, in the heading of each column, the name or symbol of the measured or calculated quantity, together with the appropriate unit. Solidus notation is expected. Each reading should be repeated, if possible, and recorded. The number of significant figures given for calculated quantities should be the same as the least number of significant figures in the raw data used. A ratio should be calculated as a decimal number, to two or three significant figures.

Drawing graphs

A graph should be drawn with a sharp pencil. The axes should be labelled with quantity and unit. The scales for the axes should allow the majority of the graph paper to be used in both directions and be based on sensible ratios, e.g. 2 cm on the graph paper representing 1 or 2 or 5 units of the variable (or 10, 20 or 50, etc.). Each data point should be plotted to an accuracy better than one half of one of the smallest squares on the grid. Points should be indicated by a small cross or a fine dot with a circle drawn around it. Large 'dots' are penalised. Where a straight line is required to be drawn through the data points, Examiners expect to see an equal number of points either side of the line over its entire length. That is, points should not be seen to lie all above the line at one end, and all below the line at the other end. The gradient of a straight line should be taken by using a triangle with a hypotenuse that extends over at least half the length of the candidate's line. Data values should be read from the line to an accuracy better than one half of one of the smallest squares on the grid. The same accuracy should be used in reading off an intercept. Calculation of the gradient should be to two or three significant figures.

MATHEMATICAL REQUIREMENTS

Arithmetic

Candidates should be able to:

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

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

(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, rounding answers correctly when necessary

(d) make approximations and estimates to obtain reasonable answers

Algebra

Candidates should be able to:

(a) change the subject of an equation

(b) solve simple algebraic equations, including linear simultaneous equations

(c) use direct and inverse proportion

(d) substitute physical quantities into physical equations using consistent units

(e) formulate simple algebraic equations as mathematical models of physical situations and to represent information given in words

Geometry and trigonometry

Candidates should be able to:

(a) understand the meaning of angle, curve, circle, radius, diameter, square, parallelogram, rectangle and diagonal

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

(c) use Pythagoras' theorem, the angle sum of a right angle and adjacent angles on a straight line

(d) use sines, cosines and tangents

(e) use usual mathematical instruments (rules, compasses, protractor, set square)

(f) recognise and use points of the compass (N, S, E, W)

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 and state the 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) understand, draw and use the slope of a tangent to a curve as a means to obtain the gradient

GLOSSARY OF TERMS

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

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

2. *Explain*/*What is meant by* ... normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in the light of the indicated mark value.

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

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

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 intended should be interpreted in the light of the indicated mark value.

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

7. *Predict* or *deduce* implies that candidates are not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an earlier part of the question.

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

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

10. *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.

11. *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.

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

13. *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.

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.

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

SPECIAL NOTE

Nomenclature

The proposals in 'Signs, Symbols and Systematics (*The Association for Science Education Companion to 16–19 Science, 2000*)' will generally be adopted.

Units, significant figures

Candidates should be aware that misuse of units and/or significant figures, i.e. failure to quote units where necessary, the inclusion of units in quantities defined as ratios or quoting answers to an inappropriate number of significant figures, is liable to be penalised.

Calculators

An approved calculator may be used in all papers.

Geometrical Instruments

Candidates should have geometrical instruments with them for Paper 1 and Paper 2.