Physics

Singapore-Cambridge General Certificate of Education Ordinary Level (2020)

(Syllabus 6091)

CONTENTS

The Common Last Topics highlighted in yellow will not be examined in 2020 O-Level national examination.

Singapore Examinations and Assessment Board

CAMBRIDGE International Examinations

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

These are not listed in order of priority.

The aims are to:

1. provide, through well-designed studies of experimental and practical physics, a worthwhile educational experience for all students, whether or not they go on to study science beyond this level and, in particular, to enable them to acquire sufficient understanding and knowledge to

   1.1 become confident citizens in a technological world, able to take or develop an informed interest in matters of scientific importance

   1.2 recognise the usefulness, and limitations, of scientific method and to appreciate its applicability in other disciplines and in everyday life

   1.3 be suitably prepared for studies beyond Ordinary Level in physics, in applied sciences or in science-related courses.

2. develop abilities and skills that

   2.1 are relevant to the study and practice of science

   2.2 are useful in everyday life

   2.3 encourage efficient and safe practice

   2.4 encourage effective communication.

3. develop attitudes relevant to science such as

   3.1 concern for accuracy and precision

   3.2 objectivity

   3.3 integrity

   3.4 inquiry

   3.5 initiative

   3.6 inventiveness.

4. stimulate interest in and care for the local and global environment.

5. promote an awareness that

   5.1 the study and practice of science are co-operative and cumulative activities, and are subject to social, economic, technological, ethical and cultural influences and limitations

   5.2 the applications of science may be both beneficial and detrimental to the individual, the community and the environment

   5.3 science transcends national boundaries and that the language of science, correctly and rigorously applied, is universal

   5.4 the use of information technology is important for communications, as an aid to experiments and as a tool for the interpretation of experimental and theoretical results.

ASSESSMENT OBJECTIVES

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 contained in 'Signs, Symbols and Systematics 16–19', Association for Science Education, 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 subject content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these objectives will often begin with one of the following words: *define, state, describe, 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 subject 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, 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 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 will consist of 40 compulsory multiple choice items of the direct choice type.

Paper 2 (1 h 45 min, 80 marks)
This paper will consist of 2 sections.

Section A will carry 50 marks and will consist of a variable number of compulsory structured questions.

Section B will carry 30 marks and will consist of three questions. The first two questions are compulsory questions, one of which will be a data-based question requiring candidates to interpret, evaluate or solve problems using a stem of information. This question will carry 8–12 marks. The last question will be presented in an either/or form and will carry 10 marks.

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 25).

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. Mass, Weight and Density 5. Turning Effect of Forces 6. Pressure 7. Energy, Work and Power
III. Thermal Physics	8. Kinetic Model of Matter 9. Transfer of Thermal Energy 10. Temperature 11. Thermal Properties of Matter
IV. Waves	12. General Wave Properties 13. Light 14. Electromagnetic Spectrum 15. Sound
V. Electricity and Magnetism	16. Static Electricity 17. Current of Electricity 18. D.C. Circuits 19. Practical Electricity 20. Magnetism 21. Electromagnetism 22. Electromagnetic Induction

SUBJECT CONTENT

SECTION I: MEASUREMENT

Overview
In order to gain a better understanding of the physical world, scientists use a process of investigation that follows a general cycle of observation, hypothesis, deduction, test and revision, sometimes referred to as the scientific method. Galileo Galilei, one of the earliest architects of this method, believed that the study of science had a strong logical basis that involved precise definitions of terms and physical quantities, and a mathematical structure to express relationships between these physical quantities.

In this section, we study a set of base physical quantities and units that can be used to derive all other physical quantities. These precisely defined quantities and units, with accompanying order-of-ten prefixes (e.g. milli, centi and kilo), can then be used to describe the interactions between objects in systems that range from celestial objects in space to sub-atomic particles.

1. Physical Quantities, Units and Measurement

Content
- Physical quantities
- SI units
- Prefixes
- Scalars and vectors
- Measurement of length and time

Learning Outcomes

Candidates should be able to:

(a) show understanding that all physical quantities 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)

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

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

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

(g) describe how to measure a variety of lengths with appropriate accuracy by means of tapes, rules, micrometers and calipers, using a vernier scale as necessary

(h) describe how to measure a short interval of time including the period of a simple pendulum with appropriate accuracy using stopwatches or appropriate instruments

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.

In this section, we begin by examining kinematics, which is a study of motion without regard for the cause. After which, we study the conditions required for an object to be accelerated and introduce the concept of forces through Newton's Laws. Subsequently, concepts of moments and pressure are introduced as consequences of a force. Finally, this section rounds up by leading the discussion from force to work and energy, and the use of the principle of conservation of energy to explain interactions between bodies.

2. Kinematics

Content

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

Learning Outcomes

Candidates should be able to:

(a) state what is meant by speed and velocity

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

(c) state what is meant by uniform acceleration and calculate the value of an 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

(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 travelled 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

(j) describe the motion of bodies with constant weight falling with or without air resistance, including reference to terminal velocity

3. Dynamics

Content

- Balanced and unbalanced forces
- Free-body diagram
- Friction

Learning Outcomes

Candidates should be able to:

(a) 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)

(b) identify forces acting on an object and draw free-body diagram(s) representing the forces acting on the object (for cases involving forces acting in at most 2 dimensions)

(c) solve problems for a static point mass under the action of 3 forces for 2-dimensional cases (a graphical method would suffice)

(d) recall and apply the relationship *resultant force = mass* × *acceleration* to new situations or to solve related problems

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

4. Mass, Weight and Density

Content

- Mass and weight
- Gravitational field and field strength
- Density

Learning Outcomes

Candidates should be able to:

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

(b) state that mass of a body resists a change in the state of rest or motion of the body (inertia)

(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*

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

(f) distinguish between mass and weight

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

5. Turning Effect of Forces

Content

- Moments
- Centre of gravity
- Stability

Learning Outcomes

Candidates should be able to:

(a) describe the moment of a force 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 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

6. Pressure

Content

- Pressure
- Pressure differences
- Pressure measurement

Learning Outcomes

Candidates should be able to:

(a) define the term 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 *pressure due to a liquid column* = *height of column* × *density of the liquid* × *gravitational field strength* to new situations or to solve related problems

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

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

7. Energy, Work and Power

Content

- Energy conversion and conservation
- Work
- Power

Learning Outcomes

Candidates should be able to:

(a) show understanding that kinetic energy, potential energy (chemical, gravitational, elastic), light energy, thermal energy, electrical energy and nuclear energy are examples of different forms of energy

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

(c) calculate the efficiency of an energy conversion using the formula *efficiency = energy converted to useful output / total energy input*

(d) state that kinetic energy $E_k = ½\,mv^2$ and gravitational potential energy $E_p = mgh$ (for potential energy changes near the Earth's surface)

(e) apply the relationships for kinetic energy and potential energy to new situations or to solve related problems

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

(g) recall and apply the relationship *power = work done / time taken* to new situations or to solve related problems

SECTION III: THERMAL PHYSICS

Overview
Amongst the early scientists, heat was thought of as some kind of invisible, massless fluid called ‘caloric’. Certain objects that released heat upon combustion were thought to be able to ‘store’ the fluid. However, this explanation failed to explain why friction was able to produce heat. In the 1840s, James Prescott Joule used a falling weight to drive an electrical generator that heated a wire immersed in water. This experiment demonstrated that work done by a falling object could be converted to heat.

In the previous section, we studied energy and its conversion. Many energy conversion processes which involve friction will have heat as a product. This section begins with the introduction of the kinetic model of matter. This model is then used to explain and predict the physical properties and changes of matter at the molecular level in relation to heat or thermal energy transfer.

8. Kinetic Model of Matter

Content
- States of matter
- Brownian motion
- Kinetic model

Learning Outcomes

Candidates should be able to:

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

(b) describe qualitatively the molecular structure of solids, liquids and gases, relating their properties to the forces and distances between molecules and to the motion of the molecules

(c) infer from a Brownian motion experiment the evidence for the movement of molecules

(d) describe the relationship between the motion of molecules and temperature

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

(f) recall and explain the following relationships using the kinetic model (stating of the corresponding gas laws is not required):
  (i) a change in pressure of a fixed mass of gas at constant volume is caused by a change in temperature of the gas
  (ii) a change in volume occupied by a fixed mass of gas at constant pressure is caused by a change in temperature of the gas
  (iii) a change in pressure of a fixed mass of gas at constant temperature is caused by a change in volume of the gas

(g) use the relationships in (f) in related situations and to solve problems (a qualitative treatment would suffice)

9. Transfer of Thermal Energy

Content
- Conduction
- Convection
- Radiation

Learning Outcomes

Candidates should be able to:

(a) show understanding that thermal energy is transferred from a region of higher temperature to a region of lower temperature

(b) describe, in molecular terms, how energy transfer occurs in solids

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

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

(e) apply the concept of thermal energy transfer to everyday applications

10. Temperature

Content
- Principles of thermometry

Learning Outcomes

Candidates should be able to:

(a) explain how a physical property which varies with temperature, such as volume of liquid column, resistance of metal wire and electromotive force (e.m.f.) produced by junctions formed with wires of two different metals, may be used to define temperature scales

(b) describe the process of calibration of a liquid-in-glass thermometer, including the need for fixed points such as the *ice point* and *steam point*

11. 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 a rise in temperature of a body in terms of an increase in its internal energy (random thermal energy)

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

(c) recall and apply the relationship *thermal energy = mass* × *specific heat capacity* × *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 the terms *latent heat* and *specific latent heat*

(g) recall and apply the relationship *thermal energy = mass* × *specific latent heat* to new situations or to solve related problems

(h) explain latent heat in terms of molecular behaviour

(i) sketch and interpret a cooling curve

SECTION IV: WAVES

Overview

Waves are inherent in our everyday lives. Much of our understanding of wave phenomena has been accumulated over the centuries through the study of light (optics) and sound (acoustics). The nature of oscillations in light was only understood when James Clerk Maxwell, in his unification of electricity, magnetism and electromagnetic waves, stated that all electromagnetic fields spread in the form of waves. Using a mathematical model (Maxwell's equations), he calculated the speed of electromagnetic waves and found it to be close to the speed of light, leading him to make a bold but correct inference that light consists of propagating electromagnetic disturbances. This gave the very nature of electromagnetic waves, and hence its name.

In this section, we examine the nature of waves in terms of the coordinated movement of particles. The discussion moves on to wave propagation and its uses by studying the properties of light, electromagnetic waves and sound, as well as their applications in wireless communication, home appliances, medicine and industry.

12. General Wave Properties

Content

- Describing wave motion
- Wave terms
- Longitudinal and transverse waves

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

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

(c) define *speed, frequency, wavelength*, *period* and *amplitude*

(d) state what is meant by the term *wavefront*

(e) recall and apply the relationship *velocity = frequency* × *wavelength* to new situations or to solve related problems

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

13. Light

Content

- Reflection of light
- Refraction of light
- Thin lenses

Learning Outcomes

Candidates should be able to:

(a) recall and use the terms for reflection, including *normal*, *angle of incidence* and *angle of reflection*

(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 for refraction, including *normal, angle of incidence* and *angle of refraction*

(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) identify the main ideas in total internal reflection and apply them to the use of optical fibres in telecommunication and state the advantages of their use

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

(i) define the term *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

14. Electromagnetic Spectrum

Content
- Properties of electromagnetic waves
- Applications of electromagnetic waves
- Effects of electromagnetic waves on cells and tissue

Learning Outcomes

Candidates should be able to:

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

(b) describe the main components of the electromagnetic spectrum

(c) state examples of the use of the following components:
  (i) radio waves (e.g. radio and television communication)
  (ii) microwaves (e.g. microwave oven and satellite television)
  (iii) infra-red (e.g. infra-red remote controllers and intruder alarms)
  (iv) light (e.g. optical fibres for medical uses and telecommunications)
  (v) ultra-violet (e.g. sunbeds and sterilisation)
  (vi) X-rays (e.g. radiological and engineering applications)
  (vii) gamma rays (e.g. medical treatment)

(d) describe the effects of absorbing electromagnetic waves, e.g. heating, ionisation and damage to living cells and tissue

15. Sound

Content
- Sound waves
- Speed of sound
- Echo
- Ultrasound

Learning Outcomes

Candidates should be able to:

(a) describe the production of sound by vibrating sources

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

(c) explain that a medium is required in order to transmit sound waves and that the speed of sound differs in air, liquids and solids

(d) describe a direct method for the determination of the speed of sound in air and make the necessary calculation

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

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

(g) define *ultrasound* and describe one use of ultrasound, e.g. quality control and pre-natal scanning

SECTION V: ELECTRICITY AND MAGNETISM

Overview
For a long time, electricity and magnetism were seen as independent phenomena. Hans Christian Oersted, in 1802, discovered that a current carrying conductor deflected a compass needle. This discovery was overlooked by the scientific community until 18 years later. It may be a chance discovery, but it takes an observant scientist to notice. The exact relationship between an electric current and the magnetic field it produced was deduced mainly through the work of Andre Marie Ampere. However, the major discoveries in electromagnetism were made by two of the greatest names in physics, Michael Faraday and James Clerk Maxwell.

The section begins with a discussion of electric charges that are static, i.e. not moving. Next, we study the phenomena associated with moving charges and the concepts of current, voltage and resistance. We also study how these concepts are applied to simple circuits and household electricity. Thereafter, we study the interaction of magnetic fields to pave the way for the study of the interrelationship between electricity and magnetism. The phenomenon in which a current interacts with a magnetic field is studied in electromagnetism, while the phenomenon in which a current or electromotive force is induced in a moving conductor within a magnetic field is studied in electromagnetic induction.

16. Static Electricity

Content
- Laws of electrostatics
- Principles of electrostatics
- Electric field
- Applications of electrostatics

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 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 a photocopier, and apply the use of electrostatic charging to new situations

17. Current of Electricity

Content

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

Learning Outcomes

Candidates should be able to:

(a) state that current is a 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) define electromotive force (e.m.f.) as the work done by a source in driving unit charge around a complete circuit

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

(f) state that the e.m.f. of a source and the potential difference (p.d.) across a circuit component are measured in volts

(g) define the p.d. across a component in a circuit as the work done to drive unit charge through the component

(h) state the definition that *resistance* = *p.d.* / *current*

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

(j) describe an experiment to determine the resistance of a metallic conductor using a voltmeter and an ammeter, and make the necessary calculations

(k) 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

(l) 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

(m) state Ohm's Law

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

(o) sketch and interpret the I / V characteristic graphs for a metallic conductor at constant temperature, for a filament lamp and for a semiconductor diode

18. D.C. Circuits

Content
- Current and potential difference in circuits
- Series and parallel circuits
- Potential divider circuit
- Thermistor and light-dependent resistor

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 current from the source is the sum of the currents in the separate branches of a parallel circuit 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 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

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

(h) describe the action of thermistors and light-dependent resistors and explain their use as input transducers in potential dividers

(i) solve simple circuit problems involving thermistors and light-dependent resistors

19. Practical Electricity

Content
- Electric 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) compare the use of non-renewable and renewable energy sources such as fossil fuels, nuclear energy, solar energy, wind energy and hydroelectric generation to generate electricity in terms of energy conversion efficiency, cost per kW h produced and environmental impact

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

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

(g) explain the need for earthing metal cases and for double insulation

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

(i) describe the wiring in a mains plug

(j) explain why switches, fuses, and circuit breakers are wired into the live conductor

20. 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

(c) describe electrical methods of magnetisation and demagnetisation

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

(e) describe the plotting of magnetic field lines with a compass

(f) distinguish between the properties and uses of temporary magnets (e.g. iron) and permanent magnets (e.g. steel)

21. Electromagnetism

Content

- Magnetic effect of a current
- Applications of the 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 a circuit breaker

(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) describe the field patterns between currents in parallel conductors and relate these to the forces which exist between the conductors (excluding the Earth's field)

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

(g) discuss how this turning effect is used in the action of an electric motor

(h) 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

22. Electromagnetic Induction

Content

- Principles of electromagnetic induction
- The a.c. generator
- Use of cathode-ray oscilloscope
- 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 form of 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 use of a cathode-ray oscilloscope (c.r.o.) to display waveforms and to measure potential differences and short intervals of time (detailed circuits, structure and operation of the c.r.o. are not required)

(e) interpret c.r.o. displays of waveforms, potential differences and time intervals to solve related problems

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

(g) 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)

(h) describe the energy loss in cables and deduce the advantages of high-voltage transmission

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

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
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 test of limited duration.
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 skill areas MMO, PDO and ACE will be set mainly in the context of the syllabus content. The assessment of PDO and ACE may 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 length, time interval, temperature, volume, mass and weight using appropriate instruments
2. determination of the density of a liquid, or of a regularly or irregularly shaped solid which 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 thermal energy transfer
8. determination of heat capacities of materials and latent heat of substances
9. the law of reflection
10. determination of the position and characteristics of an optical image formed by a plane mirror or a thin converging lens
11. the refraction of light through glass blocks
12. the principle of total internal reflection
13. the focal length of lenses
14. determination of the speed, wavelength and frequency of waves
15. measurements of current and voltage by using appropriate ammeters and voltmeters
16. determination of the resistance of a circuit element using appropriate instruments
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	Stand, boss and clamp: × 2 (Rod length: 60 cm)
Cells: 2 x 1.5 V with holder, 2 V	
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 × 1 m, 1 × 0.5 m, 1 × 300 mm)
Jockey	
Leads and crocodile clips	Vernier calipers (1 per 4–6 candidates)
Wire: constantan 28 s.w.g. or metric equivalents	Micrometer screw gauge (1 per 4–6 candidates)
Wire: nichrome 28, 32 s.w.g. or metric equivalents	
Magnets: 2 × bar magnets	Stopwatch (reading to 0.1 s or better)
Compass: 1 × 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 × 250 cm^3	Slotted masses: 1 × 5 g; 1 × 10 g; 2 × 20 g; 4 × 50 g; 1 × 50 g hanger
Boiling tube, 150 mm × 25 mm	
Measuring cylinder: 50 cm^3, 100 cm^3	Slotted masses: 4 × 100 g; 1 × 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 × 60 mm × 20 mm)	Adhesive tape
Microscope slides	Card (assorted sizes)
Mirror, plane (100 mm × 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
Torch	Bricks: 2 × (approx. 22 cm × 10 cm × 7 cm)
Protractor	
Pin board (23 cm × 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 and circles, areas and volumes of rectangular blocks, volumes of cylinders

(c) use 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.