CAMBRIDGE
INTERNATIONAL EXAMINATIONS

Physics

GCE Advanced Subsidiary and GCE Advanced Level, for Examination in 2003

These syllabuses may be used to contribute to the AICE Group Award

UNIVERSITY of CAMBRIDGE
Local Examinations Syndicate

PHYSICS

GCE Advanced Subsidiary Level and

GCE Advanced Level 9702

CONTENTS

NOTE

Additional copies of this syllabus and/or the accompanying specimen paper booklet can be ordered from CIE Publications. When ordering please quote the reference number to be found on the back cover of each of these documents.

INTRODUCTION

This syllabus is designed to give greater flexibility both to teachers and to candidates and to place greater emphasis on the understanding and application of scientific concepts and principles, and less emphasis on factual material whilst still giving a thorough introduction to the study of Physics. Centres and candidates may choose:

- to take all Advanced Level components in the same examination session leading to the full A Level.
- to follow a **staged** assessment route to the Advanced Level by taking the Advanced Subsidiary (AS) qualification in an earlier examination session. Subject to satisfactory performance such candidates are then only required to take the final part of the assessment (referred to in this syllabus as A2) leading to the full A Level.
- to take the Advanced Subsidiary (AS) qualification only.

AIMS

These are not listed in order of priority.

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

1. provide, through well-designed studies of experimental and practical science, 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 and able to take or develop an informed interest in matters of scientific import;
    - 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 A Level in Physics, in Engineering or in Physics-dependent vocational 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 the skills of enquiry;
    - 3.5 initiative;
    - 3.6 inventiveness.

4. stimulate interest in, and care for, the environment in relation to the environmental impact of Physics and its applications.

5. promote an awareness
    - 5.1 that the study and practice of Physics are co-operative and cumulative activities, and are subject to social, economic, technological, ethical and cultural influences and limitations;
    - 5.2 that the implications of Physics may be both beneficial and detrimental to the individual, the community and the environment;
    - 5.3 of the importance of the use of IT for communication, as an aid to experiments and as a tool for the interpretation of experimental and theoretical results.

6. stimulate students and create a sustained interest in Physics so that the study of the subject is enjoyable and satisfying.

ASSESSMENT OBJECTIVES

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

A Knowledge with understanding

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

1. scientific phenomena, facts, laws, definitions, concepts, theories;
2. scientific vocabulary, terminology, conventions (including symbols, quantities and units);
3. scientific instruments and apparatus, including techniques of operation and aspects of safety;
4. scientific quantities and their determination;
5. scientific and technological applications with their social, economic and environmental implications.

The syllabus content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these objectives will often begin with one of the following words: *define*, *state*, *describe*, or *explain*. (See the glossary of terms on pages 48 and 49.)

B Handling, applying and evaluating information

Candidates should be able — in words or by using written, 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, draw inferences and report conclusions;
5. present reasoned explanations for phenomena, patterns and relationships;
6. make predictions and put forward hypotheses;
7. apply knowledge, including principles, to novel situations;
8. evaluate information and hypotheses;
9 demonstrate an awareness of the limitations of physical theories and models.

These assessment objectives cannot be precisely specified in the syllabus content because questions testing such skills may be based on information which is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts which are within the syllabus and apply them in a logical, reasoned or deductive manner to a novel situation. Questions testing these objectives will often begin with one of the following words: *predict*, *suggest*, *deduce*, *calculate* or *determine*. (See the glossary of terms on pages 48 and 49.)

C Experimental skills and investigations

Candidates should be able to:

1. follow a detailed set or sequence of instructions and use techniques, apparatus and materials safely and effectively;
2. make observations and measurements with due regard for precision and accuracy;
3. interpret and evaluate observations and experimental data;
4. identify a problem, design and plan investigations, evaluate methods and techniques, and suggest possible improvement;
5. record observations, measurements, methods and techniques with due regard for precision, accuracy and units.

SCHEME OF ASSESSMENT

Paper	Type of Paper	Duration	Marks	Marks		
				AS	A2	A
1	Multiple-choice	1 h	40	32		16
2	Structured questions	1 h	60	48		24
3	Practical Test	1 h 15 min	25	20		10
4	Structured questions (Core)	1 h	60		46	23
5	Practical Test	1 h 30 min	30		22	11
6	Options	45 min	40		32	16

Paper 1
The paper will consist of 40 questions, all of the direct choice type.

Paper 2
This paper will consist of a variable number of structured questions of variable mark value. Candidates will answer all questions. Candidates will answer on the question paper.

Paper 3
This will consist of a single experiment. The Examiners will not be restricted by the subject content. The techniques required will be less demanding than those required for Paper 5: for instance, the use of logarithms will not be required.

Paper 4
This will consist of a variable number of structured questions of variable mark value. All questions will assess the A2 core. Candidates will answer all questions. Candidates will answer on the question paper.

Paper 5
This paper will consist of one experiment (20 marks) and one design question (10 marks). The examiners will not be restricted by the subject content.

Paper 6
Candidates will answer all the questions on two options (20 marks each). There will be no choice within each option. The questions will be structured and candidates will answer on the question paper.

Candidates for Advanced Subsidiary (AS) certification will take Papers 1, 2 and 3 at a single examination session.

Candidates who, having received AS certification, wish to continue their studies to the full Advanced Level qualification may carry their AS marks forward and take just Papers 4, 5 and 6 in the examination session in which they require certification.

Candidates taking the complete Advanced Level qualification at the end of the course take all the papers in a single examination session.

Candidates may not enter for single papers either on the first occasion or for re-sit purposes. Candidates may only enter for the papers in the combinations indicated above.

MARKS ALLOCATED TO ASSESSMENT OBJECTIVES

Objective	AS	A
A (Papers 1, 2, 4 and 6)	40	37
B (Papers 1, 2 ,4 and 6)	40	42
C (Paper 3 and 5)	20	21

Mathematical Requirements

The mathematical requirements are given on pages 46 to 47. Those in **bold** type are not required for the AS qualification.

Data and Formulae

Data and Formulae, as printed on pages 52 and 53 will appear as pages 2 and 3 in Papers 1, 2, 4 and 6. Those in **bold** type are not required for the AS qualification.

Symbols, Signs and Abbreviations

Wherever symbols, signs and abbreviations are used in examination papers, the recommendation made in the ASE publication *SI Units*, *Signs*, *Symbols* and *Abbreviations* (1981) will be followed, except where these have been superseded by *Signs*, *Symbols* and *Systematics* (*The ASE Companion to 5-16 Science*, 1995). The units kW h, atmosphere, eV and unified atomic mass unit (*u*) may be used in examination papers without further explanation. Symbols for logic gates will conform to the American Standard ANSI Y 32.14 (1973) as shown in the 1995 ASE publication.

STRUCTURE OF THE SYLLABUS

The Syllabus has been constructed with a compulsory Advanced Subsidiary core. A full Advanced Level qualification requires the study of further core material together with a choice of **two** out of five options. That part of the core syllabus, which will be examined only in the full Advanced Level qualification, is indicated in **bold** type. The options occupy about 16% of the full Advanced Level course.

Five options are available:

(a)	Option A	Astrophysics and Cosmology
(b)	Option F	The Physics of Fluids
(c)	Option M	Medical Physics
(d)	Option P	Environmental Physics
(e)	Option T	Telecommunications

Option booklets covering these topics can be purchased from CIE.

In order to specify the syllabus as precisely as possible and also to emphasise the importance of skills other than recall, Learning Outcomes have been used throughout. Each part of the syllabus is specified by a brief **Contents** section followed by detailed **Learning Outcomes.** Although this format, of necessity, makes the syllabus a much lengthier document, it is hoped that the format will be helpful to teachers and students. It must be emphasised that the syllabus is not intended to be used as a teaching syllabus, nor is it intended to represent a teaching order.

It is hoped that teachers will incorporate the social, environmental, economic and technological aspects of physics wherever possible throughout the syllabus (see **Aims** 4 and 5). Some examples are included in the syllabus and students should be encouraged to apply the principles of these examples to other situations introduced in the course. Inclusion of further examples in the syllabus has been resisted as this would merely increase the amount of factual recall required of students.

Aim 5.3 emphasises the importance of Information Technology in this Physics course. It is hoped that students will make full use of IT techniques in their practical work. Teachers may also use IT in demonstrations and simulations. Asterisks (*) placed alongside Learning Outcomes indicate areas of the syllabus where it is anticipated that teachers might use applications of IT, as appropriate. It should be appreciated that the list is not exhaustive.

Advice on the use of IT in A Level Physics is printed on pages 54 to 57.

SUBJECT CONTENT

(CORE: Sections I-VI inclusive)

SECTION I : GENERAL PHYSICS

Recommended Prior Knowledge

Candidates should be aware of the nature of a physical measurement, in terms of a magnitude and a unit. They should have experience of making and recording such measurements in the laboratory.

1. Physical Quantities and Units

Content

1.1 Physical quantities
1.2 SI Units
1.3 The Avogadro constant
1.4 Scalars and vectors

Learning Outcomes

Candidates should be able to:

(a) show an 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) express derived units as products or quotients of the base units and use the named units listed on pages 50 and 51 as appropriate.

(d) use base units to check the homogeneity of physical equations.

(e) show an understanding and use the conventions for labelling graph axes and table columns as set out in the ASE publication *SI Units, Signs, Symbols and Abbreviations*, except where these have been superseded by *Signs, Symbols and Systematics (The ASE Companion to 5-16 Science, 1995)*.

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

(g) make reasonable estimates of physical quantities included within the syllabus.

(h) **show an understanding of the significance of the Avogadro constant as the number of atoms in 0.012 kg of Carbon-12.**

(i) **use molar quantities where one mole of any substance is the amount containing a number of particles equal to the Avogadro constant.**

(j) distinguish scalar and vector quantities and give examples of each.

(k) add and subtract coplanar vectors.

(l) represent a vector as two perpendicular components.

2. Measurement Techniques

Content

2.1 Measurements
2.2 Errors and uncertainties

Learning Outcomes

Candidates should be able to:

(a) use techniques for the measurement of length, volume, angle, mass, time, temperature and electrical quantities appropriate to the ranges of magnitude implied by the relevant parts of the syllabus.

In particular, candidates should be able to:

(1) measure lengths using a ruler, vernier scale and micrometer;

(2) measure weight and hence mass using spring and lever balances;

(3) measure an angle using a protractor;

(4) measure time intervals using clocks, stopwatches and the calibrated time-base of a cathode-ray oscilloscope (c.r.o);

(5) measure temperature using a thermometer as a sensor;

(6) use ammeters and voltmeters with appropriate scales;

(7) use a galvanometer in null methods;

(8) use a cathode-ray oscilloscope (c.r.o);

(9) **use a calibrated Hall probe**.

* *(b)* use both analogue scales and digital displays.

* *(c)* use calibration curves.

(d) show an understanding of the distinction between systematic errors (including zero errors) and random errors.

(e) show an understanding of the distinction between precision and accuracy.

* *(f)* assess the uncertainty in a derived quantity by simple addition of actual, fractional or percentage uncertainties (a rigorous statistical treatment is not required).

SECTION II : NEWTONIAN MECHANICS

Recommended Prior Knowledge

Candidates should be able to describe the action of a force on a body. They should be able to describe the motion of a body and recognise acceleration and constant speed. They should be able to use the relationship *average speed* = *distance* / *time*.

3. Kinematics

Content

3.1 Linear motion
3.2 Non-linear motion

Learning Outcomes

Candidates should be able to:

(a) define displacement, speed, velocity and acceleration.

* (b) use graphical methods to represent displacement, speed, velocity and acceleration.

* (c) find displacement from the area under a velocity-time graph.

* (d) use the slope of a displacement-time graph to find the velocity.

* (e) use the slope of a velocity-time graph to find the acceleration.

(f) derive, from the definitions of velocity and acceleration, equations which represent uniformly accelerated motion in a straight line.

* (g) solve problems using equations which represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance.

(h) recall that the weight of a body is equal to the product of its weight and the acceleration of free fall.

* (i) describe an experiment to determine the acceleration of free fall using a falling body.

(j) describe qualitatively the motion of bodies falling in a uniform gravitational field with air resistance.

(k) describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.

4. Dynamics

Content

4.1 Newton's laws of motion
4.2 Linear momentum and its conservation

Learning Outcomes

Candidates should be able to:

(a) state each of Newton's laws of motion.

(b) show an understanding that mass is the property of a body which resists change in motion.

(c) describe and use the concept of weight as the effect of a gravitational field on a mass.

(d) define linear momentum as the product of mass and velocity.

(e) define force as rate of change of momentum.

* *(f)* recall and solve problems using the relationship $F = ma$, appreciating that acceleration and force are always in the same direction.

(g) state the principle of conservation of momentum.

* *(h)* apply the principle of conservation of momentum to solve simple problems including elastic and inelastic interactions between two bodies in one dimension. (Knowledge of the concept of coefficient of restitution is not required.)

* *(i)* recognise that, for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation.

* *(j)* show an understanding that, whilst momentum of a system is always conserved in interactions between bodies, some change in kinetic energy usually takes place.

5. Forces

Content

5.1 Types of force
5.2 Equilibrium of forces
5.3 Centre of gravity
5.4 Turning effects of forces

Learning Outcomes

Candidates should be able to:

(a) describe the forces on mass and charge in uniform gravitational and electric fields, as appropriate.

(b) show an understanding of the origin of the upthrust acting on a body in a fluid.

(c) show a qualitative understanding of frictional forces and viscous forces including air resistance. (No treatment of the coefficients of friction and viscosity is required.)

(d) use a vector triangle to represent forces in equilibrium.

(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) show an understanding that a couple is a pair of forces which tends to produce rotation only.

(g) define and apply the moment of a force and the torque of a couple.

(h) show an understanding that, when there is no resultant force and no resultant torque, a system is in equilibrium.

(i) apply the principle of moments.

6. Work, Energy, Power

Content

6.1 Energy conversion and conservation
6.2 Work
6.3 Potential energy, kinetic energy and internal energy
6.4 Power

Learning Outcomes

Candidates should be able to:

(a) give examples of energy in different forms, its conversion and conservation, and apply the principle of energy conservation to simple examples.

(b) show an understanding of the concept of work in terms of the product of a force and displacement in the direction of the force.

* *(c)* calculate the work done in a number of situations including the work done by a gas which is expanding against a constant external pressure: $W = p\Delta V$.

(d) derive, from the equations of motion, the formula $E_k = ½mv^2$.

(e) recall and apply the formula $E_k = ½mv^2$.

(f) distinguish between gravitational potential energy, electric potential energy and elastic potential energy.

* *(g)* show an understanding and use the relationship between force and potential energy in a uniform field to solve problems.

(h) derive, from the defining equation $W = Fs$, the formula $E_p = mgh$ for potential energy changes near the Earth's surface.

(i) recall and use the formula $E_p = mgh$ for potential energy changes near the Earth's surface.

(j) show an understanding of the concept of internal energy.

(k) show an appreciation for the implications of energy losses in practical devices and use the concept of efficiency to solve problems.

* *(l)* define power as work done per unit time and derive power as the product of force and velocity.

7. Motion in a Circle

Content

7.1 Kinematics of uniform circular motion
7.2 Centripetal acceleration
7.3 Centripetal force

Learning Outcomes

Candidates should be able to:

***(a)* express angular displacement in radians.**

***(b)* understand and use the concept of angular velocity to solve problems.**

***(c)* recall and use $v = r\omega$ to solve problems.**

* ***(d)* describe qualitatively motion in a curved path due to a perpendicular force, and understand the centripetal acceleration in the case of uniform motion in a circle.**

***(e)* recall and use centripetal acceleration $a = r\omega^2$, $a = v^2/r$.**

***(f)* recall and use centripetal force $F = m r\omega^2$, $F = mv^2/r$.**

8. Gravitational Field

Content

8.1 Gravitational field
8.2 Force between point masses
8.3 Field of a point mass
8.4 Field near to the surface of the Earth
8.5 Gravitational potential

Learning Outcomes

Candidates should be able to:

(a) **show an understanding of the concept of a gravitational field as an example of field of force and define gravitational field strength as force per unit mass.**

* *(b)* **recall and use Newton's law of gravitation in the form $F = G(m_1m_2)/r^2$.**

(c) **derive, from Newton's law of gravitation and the definition of gravitational field strength, the equation $g = \frac{GM}{r^2}$ for the gravitational field strength of a point mass.**

* *(d)* **recall and solve problems using the equation $g = \frac{GM}{r^2}$ for the gravitational field strength of a point mass.**

(e) **show an appreciation that on the surface of the Earth *g* is approximately constant and is called the acceleration of free fall.**

(f) **define potential at a point as the work done in bringing unit mass from infinity to the point.**

* *(g)* **solve problems using the equation $\phi = -\frac{GM}{r}$ for the potential in the field of a point mass.**

(h) **recognise the analogy between certain qualitative and quantitative aspects of gravitational field and electric field.**

* *(i)* **analyse circular orbits in inverse square law fields by relating the gravitational force to the centripetal acceleration it causes.**

(j) **show an understanding of geostationary orbits and their application.**

SECTION III : MATTER

Recommended Prior Knowledge

Candidates should be able to describe matter in terms of particles, with a qualitative understanding of their behaviour.

9. Phases of Matter

Content

9.1 Density
9.2 Solids, liquids, gases
9.3 Pressure in fluids
9.4 Change of phase

Learning Outcomes

Candidates should be able to:

(a) define the term density.

(b) relate the difference in the structures and densities of solids, liquids and gases to simple ideas of the spacing, ordering and motion of molecules.

(c) describe a simple kinetic model for solids, liquids and gases.

(d) describe an experiment which demonstrates Brownian motion and appreciate the evidence for the movement of molecules provided by such an experiment.

(e) distinguish between the structure of crystalline and non-crystalline solids with particular reference to metals, polymers and amorphous materials.

(f) define the term pressure and use the kinetic model to explain the pressure exerted by gases.

(g) derive, from the definitions of pressure and density, the equation $p = \rho g h$.

(h) use the equation $p = \rho g h$.

(i) distinguish between the processes of melting, boiling and evaporation.

10. Deformation of Solids

Content

10.1 Stress, strain
10.2 Elastic and plastic behaviour

Learning Outcomes

Candidates should be able to:

(a) appreciate that deformation is caused by a force and that, in one dimension, the deformation can be tensile or compressive.

(b) describe the behaviour of springs in terms of load, extension, elastic limit, Hooke's law and the spring constant (i.e. force per unit extension).

(c) define and use the terms stress, strain and the Young modulus.

(d) describe an experiment to determine the Young modulus of a metal in the form of a wire.

(e) distinguish between elastic and plastic deformation of a material.

(f) deduce the strain energy in a deformed material from the area under the force-extension graph.

(g) demonstrate knowledge of the force-extension graphs for typical ductile, brittle and polymeric materials, including an understanding of ultimate tensile stress.

11. Ideal Gases

Content

11.1 Equation of state
11.2 Kinetic theory of gases
11.3 Pressure of a gas
11.4 Kinetic energy of a molecule

Learning Outcomes

Candidates should be able to:

(a) **recall and solve problems using the equation of state for an ideal gas expressed as $pV = nRT$. (n = number of moles)**

(b) **infer from a Brownian motion experiment the evidence for the movement of molecules.**

(c) **state the basic assumptions of the kinetic theory of gases.**

(d) **explain how molecular movement causes the pressure exerted by a gas and hence deduce the relationship, $p = \frac{1}{3}\frac{Nm}{V} < c^2 >$. ($N$ = number of molecules)**
[A rigorous derivation is not required.]

(e) **compare $pV = \frac{1}{3} Nm < c^2 >$ with $pV = NkT$ and hence deduce that the average translational kinetic energy of a molecule is proportional to T.**

12. Temperature

Content

12.1 Thermal equilibrium
12.2 Temperature scales
12.3 Practical thermometers

Learning Outcomes

Candidates should be able to:

(a) **show an appreciation that thermal energy is transferred from a region of higher temperature to a region of lower temperature.**

(b) **show an understanding that regions of equal temperature are in thermal equilibrium.**

(c) **show an understanding that a physical property which varies with temperature may be used for the measurement of temperature and state examples of such properties.**

* *(d)* **compare the relative advantages and disadvantages of resistance and thermocouple thermometers as previously calibrated instruments.**

(e) **show an understanding that there is an absolute scale of temperature which does not depend on the property of any particular substance (i.e. the thermodynamic scale and the concept of absolute zero).**

(f) **convert temperatures measured in kelvin to degrees Celsius: T / K = T / °C + 273.15.**

13. Thermal Properties of Materials

Content

13.1 Specific heat capacity
13.2 Specific latent heat
13.3 Internal energy
13.4 First law of thermodynamics

Learning Outcomes

Candidates should be able to:

(*a*) explain using a simple kinetic model for matter why
- **(i) melting and boiling take place without a change in temperature,**
- **(ii) the specific latent heat of vaporisation is higher than specific latent heat of fusion for the same substance,**
- **(iii) a cooling effect accompanies evaporation.**

(b) **define and use the concept of specific heat capacity, and identify the main principles of its determination by electrical methods.**

(c) **define and use the concept of specific latent heat, and identify the main principles of its determination by electrical methods.**

(d) **relate a rise in temperature of a body to an increase in its internal energy.**

(e) **show an understanding that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system.**

(f) **recall and use the first law of thermodynamics expressed in terms of the change in internal energy, the heating of the system and the work done on the system.**

SECTION IV : OSCILLATIONS AND WAVES

Recommended Prior Knowledge

Candidates should be able to describe basic wave behaviour, gained through a study of optics. They should be aware of the basic ideas of reflection and refraction in light.

14. Oscillations

Content

14.1 Simple harmonic motion
14.2 Energy in simple harmonic motion
14.3 Damped and forced oscillations: resonance

Learning Outcomes

Candidates should be able to:

(a) **describe simple examples of free oscillations.**

* ***(b)*** **investigate the motion of an oscillator using experimental and graphical methods.**

(c) **understand and use the terms amplitude, period, frequency, angular frequency and phase difference and express the period in terms of both frequency and angular frequency.**

(d) **recognise and use the equation $a = -\omega^2 x$ as the defining equation of simple harmonic motion.**

(e) **recall and use $x = x_o \sin \omega t$ as a solution to the equation $a = -\omega^2 x$.**

(f) **recognise and use**
$v = v_o \cos \omega t$
$v = \pm\omega\sqrt{(x_o^2 - x^2)}$.

* **(g)** **describe with graphical illustrations, the changes in displacement, velocity and acceleration during simple harmonic motion.**

(h) **describe the interchange between kinetic and potential energy during simple harmonic motion.**

* **(i)** **describe practical examples of damped oscillations with particular reference to the effects of the degree of damping and the importance of critical damping in cases such as a car suspension system.**

(j) **describe practical examples of forced oscillations and resonance.**

* **(k)** **describe graphically how the amplitude of a forced oscillation changes with frequency near to the natural frequency of the system, and understand qualitatively the factors which determine the frequency response and sharpness of the resonance.**

(l) **show an appreciation that there are some circumstances in which resonance is useful and other circumstances in which resonance should be avoided.**

15. Waves

Content

15.1 Progressive waves
15.2 Transverse and longitudinal waves
15.3 Polarisation
15.4 Determination of speed, frequency and wavelength
15.5 Electromagnetic spectrum

Learning Outcomes

Candidates should be able to:

(a) describe what is meant by wave motion as illustrated by vibration in ropes, springs and ripple tanks.

(b) show an understanding and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed.

(c) deduce, from the definitions of speed, frequency and wavelength, the equation $v = f\lambda$.

(d) recall and use the equation $v = f\lambda$.

(e) show an understanding that energy is transferred due to a progressive wave.

(f) recall and use the relationship, *intensity* $\propto$ *(amplitude)*^{2}.

(g) compare transverse and longitudinal waves.

* (h) analyse and interpret graphical representations of transverse and longitudinal waves.

(i) show an understanding that polarisation is a phenomenon associated with transverse waves.

* (j) determine the frequency of sound using a calibrated c.r.o.

* (k) determine the wavelength of sound using stationary waves.

* (l) state that all electromagnetic waves travel with the same speed in free space and recall the orders of magnitude of the wavelengths of the principal radiations from radio waves to γ-rays.

16. Superposition

Content

16.1 Stationary waves
16.2 Diffraction
16.3 Interference
16.4 Two-source interference patterns
16.5 Diffraction grating

Learning Outcomes

Candidates should be able to:

* (a) explain and use the principle of superposition in simple applications.

* (b) show an understanding of experiments which demonstrate stationary waves using microwaves, stretched strings and air columns.

* (c) explain the formation of a stationary wave using a graphical method, and identify nodes and antinodes.

(d) explain the meaning of the term diffraction.

(e) show an understanding of experiments which demonstrate diffraction including the diffraction of water waves in a ripple tank with both a wide gap and a narrow gap.

(f) show an understanding of the terms interference and coherence.

(g) show an understanding of experiments which demonstrate two-source interference using water, light and microwaves.

(h) show an understanding of the conditions required if two-source interference fringes are to be observed.

(i) recall and solve problems using the equation $\lambda = ax / D$ for double-slit interference using light.

(j) recall and solve problems using the formula $d \sin\theta = n\lambda$ and describe the use of a diffraction grating to determine the wavelength of light. (The structure and use of the spectrometer is not included.)

SECTION V : ELECTRICITY AND MAGNETISM

Recommended Prior Knowledge

Candidates should be aware of the two types of charge, charging by friction and by induction. They should be able to distinguish between conductors and insulators using a simple electron model.

17. Electric Fields

Content

17.1 Concept of an electric field
17.2 Uniform electric fields
17.3 Force between point charges
17.4 Electric field of a point charge
17.5 Electric potential

Learning Outcomes

Candidates should be able to:

(a) show an understanding of the concept of an electric field as an example of a field of force and define electric field strength as force per unit positive charge.

(b) represent an electric field by means of field lines.

(c) recall and use $E = V/d$ to calculate the field strength of the uniform field between charged parallel plates in terms of potential difference and separation.

(d) calculate the forces on charges in uniform electric fields.

(e) describe the effect of a uniform electric field on the motion of charged particles.

* ***(f)*** **recall and use Coulomb's law in the form $F = Q_1Q_2/4\pi\varepsilon_o r^2$ for the force between two point charges in free space or air.**

* ***(g)*** **recall and use $E = Q/4\pi\varepsilon_o r^2$ for the field strength of a point charge in free space or air.**

(h) **define potential at a point in terms of the work done in bringing unit positive charge from infinity to the point.**

(i) **state that the field strength of the field at a point is numerically equal to the potential gradient at that point.**

* ***(j)*** **use the equation $V = Q/4\pi\varepsilon_o r$ for the potential in the field of a point charge.**

(k) **recognise the analogy between certain qualitative and quantitative aspects of electric field and gravitational fields.**

18. Capacitance

Content

18.1 Capacitors and capacitance
18.2 Energy stored in a capacitor

Learning Outcomes

Candidates should be able to:

(a) **show an understanding of the function of capacitors in simple circuits.**

(b) **define capacitance and the farad.**

(c) **recall and solve problems using $C = Q/V$.**

(d) **derive, using the formula $C = Q/V$, conservation of charge and the addition of p.ds, formulae for capacitors in series and in parallel.**

(e) **solve problems using formulae for capacitors in series and in parallel.**

* **(f)** **deduce from the area under a potential-charge graph, the equation $W = ½QV$ and hence $W = ½CV^2$.**

19. Current of Electricity

Content

19.1 Electric current
19.2 Potential difference
19.3 Resistance and resistivity
19.4 Sources of electromotive force

Learning Outcomes

Candidates should be able to:

(a) show an understanding that electric current is the rate of flow of charged particles.

(b) define charge and the coulomb.

(c) recall and solve problems using the equation $Q = It$.

(d) define potential difference and the volt.

(e) recall and solve problems using $V = W/Q$.

(f) recall and solve problems using $P = VI$, $P = I^2R$.

(g) define resistance and the ohm.

(h) recall and solve problems using $V = IR$.

* *(i)* sketch and explain the I-V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp.

(j) sketch the temperature characteristic of a thermistor.

(k) state Ohm's law.

(l) recall and solve problems using $R = \rho l/A$.

(m) define e.m.f. in terms of the energy transferred by a source in driving unit charge round a complete circuit.

(n) distinguish between e.m.f. and p.d in terms of energy considerations.

(o) show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

20. D.C. Circuits

Content

20.1 Practical circuits
20.2 Conservation of charge and energy
20.3 Balanced potentials

Learning Outcomes

Candidates should be able to:

(a) recall and use appropriate circuit symbols as set out in *SI Units, Signs, Symbols and Abbreviations* (ASE, 1981) and *Signs, Symbols and Systematics* (ASE, 1995).

(b) draw and interpret circuit diagrams containing sources, switches, resistors, ammeters, voltmeters, and/or any other type of component referred to in the syllabus.

(c) recall Kirchhoff's first law and appreciate the link to conservation of charge.

(d) recall Kirchhoff's second law and appreciate the link to conservation of energy.

(e) derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in series.

(f) solve problems using the formula for the combined resistance of two or more resistors in series.

(g) derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in parallel.

(h) solve problems using the formula for the combined resistance of two or more resistors in parallel.

(i) apply Kirchhoff's laws to solve simple circuit problems.

(j) show an understanding of the use of a potential divider circuit as a source of variable p.d.

* *(k)* explain the use of thermistors and light-dependent resistors in potential dividers to provide a potential difference which is dependent on temperature and illumination respectively.

(l) recall and solve problems using the principle of the potentiometer as a means of comparing potential differences.

21. Magnetic Fields

Content

21.1 Concept of magnetic field

Learning Outcomes

Candidates should be able to:

(a) **show an understanding that a magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets.**

(b) **represent a magnetic field by field lines.**

22. Electromagnetism

Content

22.1 Force on a current-carrying conductor
22.2 Force on a moving charge
22.3 Magnetic fields due to currents
22.4 Force between current-carrying conductors

Learning Outcomes

Candidates should be able to:

(a) **show an appreciation that a force might act on a current-carrying conductor placed in a magnetic field.**

(b) **recall and solve problems using the equation $F = BIl \sin\theta$, with directions as interpreted by Fleming's left-hand rule.**

(c) **define magnetic flux density and the tesla.**

(d) **show an understanding of how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field using a current balance.**

(e) **predict the direction of the force on a charge moving in a magnetic field.**

(f) **recall and solve problems using $F = BQv \sin\theta$.**

(g) **sketch flux patterns due to a long straight wire, a flat circular coil and a long solenoid.**

(h) **show an understanding that the field due to a solenoid may be influenced by the presence of a ferrous core.**

(i) **explain the forces between current-carrying conductors and predict the direction of the forces.**

(j) **describe and compare the forces on mass, charge and current in gravitational, electric and magnetic fields, as appropriate.**

23. Electromagnetic Induction

Content

23.1 Laws of electromagnetic induction

Learning Outcomes

Candidates should be able to:

(a) **define magnetic flux and the weber.**

(b) **recall and solve problems using $\Phi = BA$.**

(c) **define magnetic flux linkage.**

* *(d)* **infer from appropriate experiments on electromagnetic induction:**
  (i) that a changing magnetic flux 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.

(e) **recall and solve problems using Faraday's law of electromagnetic induction and Lenz's law.**

(f) **explain simple applications of electromagnetic induction.**

24. Alternating Currents

Content

24.1 Characteristics of alternating currents
24.2 The transformer
24.3 Transmission of electrical energy
24.4 Rectification

Learning Outcomes

Candidates should be able to:

(a) **show an understanding and use the terms period, frequency, peak value and root-mean-square value as applied to an alternating current or voltage.**

* *(b)* **deduce that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current.**

* *(c)* **represent an alternating current or an alternating voltage by an equation of the form $x = x_0 \sin \omega t$.**

(d) **distinguish between r.m.s. and peak values and recall and solve problems using the relationship $I_{rms} = I_0 / \sqrt{2}$ for the sinusoidal case.**

(e) **show an understanding of the principle of operation of a simple iron-cored transformer and solve problems using $N_s/N_p = V_s/V_p = I_p/I_s$ for an ideal transformer.**

(f) **show an appreciation of the scientific and economic advantages of alternating current and of high voltages for the transmission of electrical energy.**

* *(g)* **distinguish graphically between half-wave and full-wave rectification.**

(h) **explain the use of a single diode for the half-wave rectification of an alternating current.**

(i) **explain the use of four diodes (bridge rectifier) for the full-wave rectification of an alternating current.**

* *(j)* **analyse the effect of a single capacitor in smoothing, including the effect of the value of capacitance in relation to the load resistance.**

SECTION VI : MODERN PHYSICS

Recommended Prior Knowledge

Candidates should be able to describe matter in terms of atoms, with electrons orbiting a positively charged nucleus. Candidates should have studied some of the material in Section IV.

25. Charged Particles

Content

25.1 Electrons
25.2 Beams of charged particles

Learning Outcomes

Candidates should be able to:

* *(a)* **show an understanding of the main principles of determination of *e* by Millikan's experiment.**

(b) **summarise and interpret the experimental evidence for quantisation of charge.**

* *(c)* **describe and analyse qualitatively the deflection of beams of charged particles by uniform electric and uniform magnetic fields.**

(d) **explain how electric and magnetic fields can be used in velocity selection.**

* *(e)* **explain the main principles of one method for the determination of v and e/m_e for electrons.**

26. Quantum Physics

Content

26.1 Energy of a photon
26.2 Photoelectric emission of electrons
26.3 Wave-particle duality
26.4 Energy levels in atoms
26.5 Line spectra

Learning Outcomes

Candidates should be able to:

(a) **show an appreciation of the particulate nature of electromagnetic radiation.**

(b) **recall and use $E = hf$.**

* *(c)* **show an understanding that the photoelectric effect provides evidence for a particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for a wave nature.**

(d) **recall the significance of threshold frequency.**

(e) **explain photoelectric phenomena in terms of photon energy and work function energy.**

(f) **explain why the maximum photoelectric energy is independent of intensity whereas the photoelectric current is proportional to intensity.**

(g) **recall, use and explain the significance of $hf = \Phi + \frac{1}{2}mv_{max}^2$.**

* *(h)* **describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles.**

(i) **recall and use the relation for the de Broglie wavelength $\lambda = h/p$.**

* ***(j)*** **show an understanding of the existence of discrete electron energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to spectral lines.**

(k) **distinguish between emission and absorption line spectra.**

(l) **recall and solve problems using the relation $hf = E_1 - E_2$.**

27. Nuclear Physics

Content

27.1 The nucleus
27.2 Isotopes
27.3 Nuclear processes
27.4 Mass excess and nuclear binding energy
27.5 Radioactive decay

Learning Outcomes

Candidates should be able to:

* *(a)* infer from the results of the α-particle scattering experiment the existence and small size of the nucleus.

* *(b)* describe a simple model for the nuclear atom to include protons, neutrons and orbital electrons.

(c) distinguish between nucleon number (mass number) and proton number (atomic number).

(d) show an understanding that an element can exist in various isotopic forms each with a different number of neutrons.

(e) use the usual notation for the representation of nuclides.

(f) appreciate that nucleon number, proton number, and energy and mass are all conserved in nuclear processes.

(g) represent simple nuclear reactions by nuclear equations of the form
$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$.

(h) show an appreciation of the spontaneous and random nature of nuclear decay.

(i) show an understanding of the nature of α-, β- and γ- radiations.

* *(j)* infer the random nature of radioactive decay from the fluctuations in count rate.

(k) **show an appreciation of the association between energy and mass as represented by $E = mc^2$ and by recalling this relationship.**

(l) **sketch the variation of binding energy per nucleon with nucleon number.**

(m) **explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission.**

(n) **define the terms activity and decay constant and recall and solve problems using $A = \lambda N$.**

* *(o)* **infer and sketch the exponential nature of radioactive decay and solve problems using the relationship $x = x_o \exp(-\lambda t)$ where x could represent activity, number of undecayed particles or received count rate.**

(p) **define half-life.**

(q) **solve problems using the relation $\lambda = \frac{0.693}{t_{\frac{1}{2}}}$.**

The Options are studied only by those taking the complete Advanced Level qualification.

OPTION A

Astrophysics and Cosmology

[A detailed treatment of this topic is given in the Option Booklet *Astrophysics* and *Cosmology*.]

A1. Contents and Scale of the Universe

Content

1.1 Contents of the Universe
1.2 Scale of the Universe

Learning Outcomes

Candidates should be able to:

(a) describe the principal contents of the Universe, including stars, galaxies and radiation.

(b) describe the Solar system in terms of the Sun, planets, planetary satellites and comets. Details of individual planets are not required.

(c) define distances measured in astronomical units (AU), parsecs (pc) and light-years.

(d) recall the approximate magnitudes, in metres, of the AU, pc and light-year.

(e) appreciate the sizes and masses of objects in the Universe.

(f) appreciate the distances involved between objects in the Universe.

A2. The Standard Model of the Universe

Content

2.1 Hubble's law
2.2 Olbers' paradox
2.3 The Cosmological Principle
2.4 Age of the Universe
2.5 Evolution of the Universe

Learning Outcomes

Candidates should be able to:

**(a)* describe and interpret Hubble's redshift observations.

(b) recall and interpret Hubble's law

(c) convert the Hubble 'constant' (H_0) from its conventional units (km s^{-1} Mpc^{-1}) to SI (s^{-1}).

(d) recall Olbers' paradox.

(e) interpret Olbers' paradox to explain why it suggests that the model of an infinite, static Universe is incorrect.

(f) understand what is meant by the Cosmological Principle.

(g) describe, and interpret the significance of, the 3 K microwave background radiation.

(h) understand that the standard (hot big bang) model of the Universe implies a finite age for the Universe.

(i) recall and use the expression $t \approx 1/H_0$ to estimate the order of magnitude of the age of the Universe.

(j) describe qualitatively the evolution of the Universe from 0.01 s after the big bang to the present, including the production of an excess of matter over antimatter, the formation of light nuclei, the recombination of electrons and nuclei and the formation of stars, galaxies and galactic clusters.

(k) understand that the Universe may be 'open', 'flat' or 'closed', depending on its density.

(l) appreciate that the age of the Universe cannot be determined from the Hubble constant until its density is known accurately.

(m) understand that the ultimate fate of the Universe depends on its density.

(n) recall that it is currently believed that the density of the Universe is close to, and possibly exactly equal to, the critical density needed for a 'flat' cosmology.

(o) derive, from Newton's law of gravitation, the expression $\rho_0 = \frac{3H_o^2}{8\pi G}$ and recognise that General Relativity is needed for a strict derivation.

(p) use the expression $\rho_0 = \frac{3H_o^2}{8\pi G}$.

(q) appreciate that there is no experimental evidence for the physics involved at the energies prevailing during the evolution of the Universe before about 1 ms.

(r) outline the difficulties involved in projecting the evolution of the Universe back before 0.01 s.

A3. Techniques of Observation

Content

3.1 Electromagnetic radiation and the Earth's atmosphere
3.2 Observation platforms

Learning Outcomes

Candidates should be able to:

(a) appreciate that stars and galaxies are detected by the electromagnetic radiation which they emit.

**(b)* appreciate that planets are detected by reflected sunlight.

(c) describe the transparency of the Earth's atmosphere to different regions of the electromagnetic spectrum from radio waves to X-rays.

(d) explain why the transparency of the Earth's atmosphere has led to observations which are terrestrial, high-altitude, from satellites or from space probes.

(e) show awareness of the conflict between the value of astronomical research and economic consideration.

OPTION F

The Physics of Fluids

[A detailed treatment of this topic is given in the Option Booklet *The Physics of Fluids*.]

F1. Buoyant Forces

Content

1.1 Pressure in a liquid
1.2 Archimedes' principle
1.3 Equilibrium of floating objects

Learning Outcomes

Candidates should be able to:

(a) derive and use the equation $p = \rho gh$.

(b) state that an upthrust is provided by the fluid displaced by a submerged or floating object.

(c) calculate the upthrust in terms of the weight of the displaced fluid.

(d) show an understanding that, for an object floating in equilibrium, the upthrust is equal to the weight of the object.

(e) show an appreciation that the upthrust on a floating object acts at the centre of mass of the displaced fluid (the centre of buoyancy).

(f) show an appreciation of what is meant by the metacentre of a floating object, and deduce the stability of an object from the relative positions of the metacentre and the centre of mass of the object.

(g) apply Archimedes' principle to marine craft and submarines.

F2. Non-Viscous Fluid Flow

Content

2.1 Ideal fluids in motion
2.2 Streamlines and the equation of continuity
2.3 The Bernoulli effect

Learning Outcomes

Candidates should be able to:

(a) show an understanding of the terms steady (laminar, streamline) flow, incompressible flow and non-viscous flow, as applied to the motion of an ideal fluid.

(b) show an understanding of how the velocity vector of a particle in an ideal fluid in motion is related to the streamline associated with that particle.

(c) show an understanding of how streamlines can be used to define a tube of flow.

(d) derive and solve problems using the equation Av = constant (the equation of continuity) for the flow of an ideal, incompressible fluid.

(e) show an appreciation that the equation of continuity is a form of the principle of conservation of mass.

(f) show an appreciation that pressure differences can arise from different rates of flow of a fluid (the Bernoulli effect).

(g) derive the Bernoulli equation in form $p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2$ for the case of a horizontal tube of flow.

(h) show an appreciation that the Bernoulli equation is a form of the principle of conservation of energy.

* (i) explain how the Bernoulli effect is applied in the filter pump, in the Venturi meter, in atomisers and in the flow of air over an aerofoil.

F3. Viscous Fluids

Content

3.1 Viscosity
3.2 Terminal velocity
3.3 Turbulence

Learning Outcomes

Candidates should be able to:

(a) state that viscous forces in a fluid cause a retarding force to be exerted on an object moving through a fluid.

(b) show an understanding that, in viscous flow, different layers of the liquid move with different velocities.

(c) show an appreciation of what is meant by the velocity gradient in viscous flow.

(d) show an understanding of how the magnitude of the viscous force in fluid flow depends on the velocity gradient and on the viscosity of the fluid.

(e) apply base units to confirm the form of the equation $F = Ar\eta v$, where A is a dimensionless constant (Stokes' law), for the drag force under laminar conditions in a viscous fluid.

* (f) apply Stokes' law to explain quantitatively how a body falling through a viscous fluid under laminar conditions attains a terminal velocity.

(g) describe an experiment, based on the measurement of terminal velocity, to determine the viscosity of a liquid.

(h) show an appreciation that, at a sufficiently high velocity, the flow of viscous fluid undergoes a transition from laminar to turbulent conditions.

(i) apply base units to confirm the form of the equation $F = Br^2\rho v^2$, where B is a dimensionless constant, for the drag force under turbulent conditions in a viscous fluid.

(j) show an appreciation that the majority of practical examples of fluid flow and resistance to motion in fluids involve turbulent, rather than laminar, conditions.

(k) explain qualitatively, in terms of turbulence and the Bernoulli effect, for the swing of a spinning cricket ball and the lift of a spinning golf ball.

* (l) show an understanding of what is meant by the drag coefficient of a moving vehicle, and carry out simple calculations involving the coefficient.

OPTION M

Medical Physics

[A detailed treatment of this topic is given in the Option Booklet *Medical Physics*.]

M1. Medical Imaging

Content

1.1 Diagnostic techniques used in medicine
1.2 Production and use of X-rays
1.3 Production and use of ultrasound
1.4 Use of magnetic resonance, radioactive tracers and lasers

Learning Outcomes

Candidates should be able to:

(a) describe in simple terms the need for non-invasive techniques of diagnosis.

(b) show a qualitative understanding of the importance of limiting exposure to radiation with particular reference to the type of radiation.

(c) explain the principles of production of X-rays by electron bombardment of a metal target.

(d) show an understanding of the use of X-rays in imaging internal body structures, including a simple analysis of the causes of the sharpness and contrast in X-ray imaging.

* *(e)* recall and solve problems using the equation $I = I_0 e^{-\mu x}$ for the attenuation of X-rays in matter.

(f) explain the principles of generation of ultrasonic waves using piezo-electric transducers.

(g) identify and explain the main ideas behind the use of ultrasound to obtain diagnostic information about internal structures.

* *(h)* identify and explain the main ideas behind the use of magnetic resonance to obtain diagnostic information about internal structures.

(i) identify and explain the main ideas behind the use of lasers in diagnosis, e.g. in pulse oximetry and in endoscopes.

(j) describe examples of the use of radioactive tracers in diagnosis.

M2. Medical Treatment

Content

2.1 Biological effects
2.2 Radiotherapy
2.3 Laser treatment

Learning Outcomes

Candidates should be able to:

(a) explain in simple terms the effects of ionising radiation on living matter.

(b) show a qualitative understanding of the importance of limiting exposure to ionising radiation.

(c) distinguish between dose rate and dose, paying particular attention to the type of incident radiation.

(d) explain the use of X-rays and of implanted sources in the treatment of malignancy.

(e) describe examples of the use of lasers in clinical therapy, e.g. as a scalpel or as a coagulator.

M3. The Physics of Sight

Content

3.1 The eye
3.2 Defects of the eye

Learning Outcomes

Candidates should be able to:

(a) explain how the eye forms focused images of objects at different distances.

(b) show an understanding of the terms depth of focus and accommodation.

(c) distinguish between short sight, long sight and astigmatism.

(d) distinguish between converging and diverging lenses and show an understanding of the significance of focal length.

(e) explain how short sight, long sight and astigmatism can be corrected by using spectacle lenses or contact lenses.

(f) recall and apply the lens formula to calculate the focal length of the auxiliary lenses required to correct short sight and to correct long sight.

(g) relate the focal length of a lens to its power in dioptres.

M4. The Physics of Hearing

Content

4.1 The ear
4.2 Sensitivity and frequency response of the ear

Learning Outcomes

Candidates should be able to:

(a) explain how the ear responds to an incoming sound wave.

(b) show an understanding of the significance of the terms sensitivity and frequency response.

(c) show an appreciation of the very wide range of intensities which can be detected by the ear and recall the orders of magnitude of the threshold of hearing and the intensity at which discomfort is experienced.

(d) show an understanding of the significance of the logarithmic response of the ear to intensity.

* *(e)* recall and solve problems using the equation *intensity level* = 10 lg(I/I_0), giving intensity level in dB in terms of the intensity I and the threshold intensity I_0.

(f) show an understanding that loudness is the subjective response of an individual to an intensity level.

OPTION P

Environmental Physics

[A detailed treatment of this topic is given in the Option Booklet *Environmental Physics*.]

P1. Power Sources

Content

1.1 The solar constant
1.2 Fossil fuels
1.3 Nuclear power
1.4 Water power
1.5 Wind power
1.6 Geothermal and other feasible power sources

Learning Outcomes

Candidates should be able to:

(a) show an understanding of the term solar constant and use it to solve problems.

(b) show an understanding of the geographical variation of solar intensity at the Earth's surface.

(c) identify and explain the main component of the structure of solar cells and solar panels.

(d) show an appreciation that solar cells produce electrical energy whereas solar panels produce thermal energy.

* *(e)* distinguish between the terms resources and reserves.

(f) state the different types of fossil fuel and show an understanding that these fuels are abundant yet finite.

(g) state the principles of the fission process.

* *(h)* explain the role of fuel rods, moderator, coolant, control rods and the reactor vessel in a nuclear reactor.

(i) calculate the potential energy stored in a lake, given its average depth, area and altitude.

(j) show an understanding of the main principles of a pumped water storage scheme.

(k) estimate the power available from a water wave of given dimensions.

(l) show an understanding of how the potential energy of stored water is used to estimate the mean power output of a tidal barrage.

(m) estimate the maximum power available from a wind generator.

(n) comment on the difficulties and limitations associated with the following 'free' systems for producing power: geothermal including hot aquifers and geysers, biomass, methane generators from waste products.

P2. Power Consumption

Content

2.1 Variation in demand
2.2 Efficiency of different systems
2.3 Sankey diagrams
2.4 Long-term trends

Learning Outcomes

Candidates should be able to:

(a) explain the daily and seasonal variations in the demand for electrical power.

(b) describe the complications which arise due to predictable and unpredictable variations in demand for electrical power.

(c) explain the benefits of a pumped water storage scheme.

(d) show an understanding that, although the efficiency for conversion of electrical energy to internal energy for the consumer is 100%, the production of electrical energy is far less efficient.

(e) evaluate the overall efficiency, from production to consumer, of various domestic systems, e.g. cooking by gas or electricity.

(f) apply Sankey diagrams.

(g) predict the possible long-term effects on resources and on the environment of social changes such as increasing demand for housing, increasing affluence of third world countries and increasing use of air conditioning.

P3. Heat Engines

Content

3.1 Indicator diagrams
3.2 The petrol engine
3.3 The second law of thermodynamics

Learning Outcomes

Candidates should be able to:

(a) distinguish between an isothermal change and an adiabatic change.

(*b*) illustrate isothermal and adiabatic changes on indicator diagrams.

(c) use the indicator diagram to determine the work done on or by a gas.

(d) recall the cycle of a four-stroke petrol engine.

* *(e)* illustrate and explain the cycle of a four-stroke petrol engine with the aid of an indicator diagram.

(f) show an appreciation that the second law of thermodynamics places an overall limit on the efficiency of a heat engine, and that this limit depends on the temperatures between which the engine is operating.

(g) recall and solve problems using the equation $E_{MAX} = (1 - T_L / T_H)$ where E_{MAX} is the maximum efficiency.

(h) deduce from the second law the conclusion that CHP (combined heat and power) schemes should be economical propositions.

P4. Pollution

Content

4.1 Carbon dioxide emissions
4.2 Other forms of pollution

Learning Outcomes

Candidates should be able to:

(a) show an appreciation that zero pollution is not possible.

(b) distinguish the burning of fossil fuels from nuclear and hydroelectric power schemes in terms of the release of carbon dioxide into the atmosphere.

(c) show an understanding why carbon dioxide levels in the atmosphere are not rising rapidly.

(d) show an understanding of other forms of pollution such as thermal pollution of the atmosphere, noise pollution, pollution of rivers.

OPTION T

Telecommunications

[A detailed treatment of this topic is given in the Option Booklet *Telecommunications.*]

T1. Communication Principles

Content

1.1 Waveforms
1.2 Principles of modulation
1.3 Sidebands and bandwidth
1.4 Transmission of information by digital means
1.5 Transmission media
1.6 Communication and society

Learning Outcomes

Candidates should be able to:

* *(a)* recall that any waveform can be resolved into or synthesised from sinusoidal components.

* *(b)* understand the term modulation and distinguish between amplitude modulation (AM) and frequency modulation (FM).

* *(c)* recall that a carrier wave, amplitude modulated by a single audio frequency, is equivalent to the carrier wave frequency together with two sideband frequencies, leading to an understanding of the term bandwidth.

(d) demonstrate awareness of the relative advantages of FM and AM transmissions.

(e) recall the advantages of transmission of data in digital form.

(f) understand that the digital transmission of speech or music involves analogue-to-digital conversion on transmission and digital-to-analogue conversion on reception.

* *(g)* demonstrate an awareness of how waveforms are encoded by digital sampling.

(h) appreciate the scientific and economic advantages of fibre optic transmission, compared with metal cable and radio transmission.

(i) demonstrate an awareness of social, economic and technological changes arising from modern communication methods.

T2. Communication Channels

Contents

2.1 Channels of communication
2.2 Power levels

Learning Outcomes

Candidates should be able to:

(a) appreciate that information may be carried by a number of different channels, including wire-pairs, coaxial cables, radio and microwave links, and optic fibres.

(b) discuss the relative advantages and disadvantages of channels of communication in terms of available bandwidth, noise, cross-linking, security, signal attenuation, repeaters and regeneration, cost and convenience.

(c) understand and use signal attenuation expressed in dB per unit length, including recall and use of the expression *number of decibels* (dB) = 10 lg (P_1 /P_2) for the ratio of two powers.

(d) understand and use repeater gain measured in dB.

(e) estimate and use typical power levels and attenuations associated with different channels of communication.

T3. Radio Communication

Content

3.1 Propagation of radio waves

Learning Outcomes

Candidates should be able to:

(a) appreciate the effect of the Earth's surface on the propagation of radio waves over long distances, and the use of the ionosphere as a reflector if the waves are to be propagated over long distances.

(b) describe the use of satellites in radio communication and appreciate the importance of geostationary satellites.

(c) recall the wavelengths used in different modes of radio communication.

PRACTICAL ASSESSMENT

Practical Test

The assessment of experimental skills consists of both practical experiments and design questions. The Examiners will not be strictly bound by the syllabus in setting questions. Where appropriate, candidates will be told exactly what to do and how to do it; only knowledge of theory and experimental skills within the syllabus will be expected.

Candidates will be assessed on the following skills:

- **A** Planning
- **B** Implementing
- **C** Interpreting and Concluding

There are **six** assessment criteria for each skill. Skill descriptions and assessment criteria are detailed on pages 42 to 44.

It should be appreciated that all 18 assessment criteria will not be tested in any one examination.

Candidates should be directed towards the practice of experimental skills throughout the whole period of their course of study. As a guide, candidates should expect to spend at least 20% of their time on practical work and its assessment.

Further guidance

The aim of this section is to provide Centres with further guidance on the standard expected in the assessment of the practical test.

Experimental Questions

Experimental Method
A number of marks are awarded for the successful execution of the experiment. The candidate should be able to assemble the apparatus without help and take the prescribed number, or suitable number, of readings over a specified, or a suitable large range. It is expected that all readings will be recorded and repeated where appropriate, for example in the timing of oscillations. Calculations derived from raw readings should be correct and given to an appropriate number of significant figures, governed by the number of significant figures in the raw data. Generally, the number of significant figures in the calculated values should be equal in number to, or possibly one more than, the number of significant figures in the raw data. Results should be obtained of a high quality: this is often judged by looking at the scatter of points about the candidate's graph line.

Presentation of Results
Marks are also awarded for the presentation of results. Numerical data and values should be presented in a single table. It is expected that candidates will draw the table in advance of taking any readings: it should not be necessary for candidates to copy up their results. The table should include raw data and values calculated from them, for example logarithms of values. Column headings should conform to normal practice. If the quantity being measured is current, then the following would be allowed:
I / mA; I in mA; I (mA); $\frac{I}{\text{mA}}$. The quantity or unit may be written in words. Conventional symbols or abbreviations may be used without further explanation, for example p.d. In cases of doubt, the quantity's name should be written in full. Headings such as 'I mA' or plain 'mA' are not acceptable. It is expected that all recorded raw readings of a quantity will be given to the same degree of accuracy. If one measurement of length in a set is given to the nearest millimetre, then all the measured lengths should be given to the nearest millimetre. Candidates will be penalised if the degree of precision used is incompatible with the measuring instrument used: an example would

be a length measured on a millimetre scale, but recorded as '2 cm'. Calculated quantities must be given to the same number of significant figures as (or one more than) the measured quantity of least accuracy. For example, if values of a potential difference and of a current are measured to 2 and 3 significant figures respectively, then the corresponding quotient (resistance) should be given to 2 or 3 significant figures, but not 1 or 4. If both were measured to 3 significant figures, then the resistance could be given to 3 (or 4) significant figures. It is, however, as a special case, acceptable for a periodic time to be given to 3 (or 4) significant figures, when measured on a centisecond stopwatch, to allow for errors in starting and stopping this device.

Graphical Work

Graphical work contributes much to the assessment of the practical exercises. Candidates should be able to rearrange expressions to allow straight-line graphs to be plotted. Candidates should be familiar with the appropriate mathematical processes for taking logarithms and dealing with exponential functions. Graph axes should be clearly labelled with quantity and unit; drawn in conventional directions; occupy at least half the grid in both *x*- and *y*-directions; use convenient scales (e.g. 1, 2 or 5 units to a 2 cm square) and have clear numerical labels, not more than 6 cm (on the grid) apart. There should be no holes on the scale on a graph axis (i.e. labels which run, at 2 cm intervals, 0,1,3,4). All data points should be plotted on the grid: no credit is given for points drawn on the white margin to the grid. Points should be plotted to an accuracy of better than half a small (2 mm) square and must be finely drawn with a sharp pencil, yet still be visible. A fine cross or encircled dot is suitable. Thick pencil dots will be penalised. The line of best fit should show an even distribution of points either side of the line along its whole length. Thick or kinked lines do not gain credit. It is expected that the line will be drawn through the number of points specified in the question. Straight lines drawn where curves are expected will not gain any marks. When a gradient is to be measured, it is important that the points on the line chosen for the calculation are sufficiently separated; it is expected that the hypotenuse of the triangle (whether the triangle is actually drawn or not) should be at least half the length of the candidate's line. Read-offs from the graph should be accurate. If data points from the table are used, they must lie within half a small square of the line drawn, and fulfil the criteria for separation. Any intercept must be read to better than half a small square. Candidates should be taught how to determine the intercept from a graph with a false origin.

Analysis

Experimental questions often conclude with some analysis, using the results from the graph. At this stage, it is important that candidates realise the importance of using the correct number of significant figures and the correct units, where appropriate.

Design Questions

The design question provides candidates with the opportunity to demonstrate their mastery of Skill A on page 42. The best preparation for this question can be achieved by candidates designing some of their own experiments, under close, safe supervision, during their A Level course and by practising on questions from past papers. The context of the question will often be unfamiliar to candidates, although it is expected that they will have used or learnt about suitable apparatus for completing the task. Details of unfamiliar apparatus may be given in the question paper: candidates will typically be asked to select apparatus, describe the experimental arrangement and state the variables to be measured and those to be kept constant. Further detail of the procedure to be followed may be required, together with an outline of how the readings are to be treated, for example by means of a specified graph. Good marks can often be gained on relatively short answers, supported by clearly labelled diagrams.

Administration of the Practical Test

The list below gives some of the items regularly used in the practical test. To instil some variation in the questions set, some novel items are usually required. Details of the apparatus required are usually sent to Centres about six weeks before the date of the examination. Centres should contact the Despatch Department at CIE if they believe Instructions have not been received. These Instructions contain sufficient details to allow complete testing of the apparatus. Access to the question paper itself is not permitted in advance of the examination session. It is essential that absolute confidentiality be maintained in advance of the examination date. Further instructions are included in the Handbook for Centres.

A copy of the Report, supplied as part of the Instructions should be completed and enclosed in each envelope of scripts. A sample set of results may also be helpful for the Examiner, especially if there was any local difficulty with the apparatus. A missing Report can impede the marking process.

Apparatus that is used regularly

Electrical
Ammeter: (digital or analogue) f.s.d. 100 mA and 1 A
Voltmeter: (digital or analogue) f.s.d. 5 V, 10 V
Power supply: variable up to 12 V d.c. (low resistance)
Cells: 1.5 V
Lamp and holder: 6 V 60 mA; 2.5 V 0.3 A
Rheostat
Switch
Leads and crocodile clips
Wire: constantan 26, 28, 30, 32, 36, 38 s.w.g. or metric equivalents

Heat
Long stem thermometer: -10 °C to 110 °C x 1 °C
Metal calorimeter
Plastic or polystyrene cup 200 cm^3
Means to heat water safely to boiling
Stirrer

Mechanics and General items
Card
Pendulum bob
Wood or metal jaws
Stand, boss and clamp
G-clamp
Rule (1 m, 0.5 m, 300 mm)
Stopclock or stopwatch (candidates may use their own, reading to 0.1 s or better)
Balance to 0.1 g*
Beaker: 100 cm^3, 200 cm^3 or 250 cm^3
Plasticine
Blu-Tack
Wire cutters
Bare copper wire: 18, 26 s.w.g.
Stout pin or round nail
Scissors
Sellotape
Micrometer screw gauge*
String/thread/twine
Slotted 100 g masses or alternative
Spring
Protractor
Vernier calipers

* item may often be shared between sets of apparatus

Skill A **Planning**

(a) Defining a problem by

(i) applying knowledge and understanding of principles, theories and models,

(ii) developing and formulating testable hypotheses,

(iii) considering appropriate methods.

(b) Planning investigations including

(i) deciding which variables to control,

(ii) identifying and ordering the steps involved,

(iii) selecting appropriate apparatus and materials, including appropriate recording and analysis methods,

(iv) considering effective and safe procedures.

Assessment Criterion	Requirement
A1 APPLICATION	Appropriate methods considered in approaching a stated problem.
A2 DEFINITION	Development of a hypothesis which can be tested experimentally.
A3 VARIABLES	Appropriate variables selected which are consistent with the stated problem.
A4 ORGANISATION	Plan involving a series of well-ordered steps.
A5 APPARATUS	Appropriate apparatus/materials selected.
A6 PROCEDURES	Plan would be effective in testing the stated hypothesis.

Skill B **Implementing**

(a) Following instructions and carrying out experimental work in a methodical and organised way with due regard for safety.

(b) Using apparatus and materials in an appropriate way including

- (i) correctly setting up apparatus (for example, alignment),
- (ii) choosing appropriate scales,
- (iii) checking operation of apparatus (for example, zero errors),
- (iv) modifying procedures in the light of experience.

(c) Making and recording

- (i) accurate and detailed observations,
- (ii) measurements to the appropriate degree of precision allowed by the apparatus.

	Assessment Criterion	Requirement
B1	CARRYING OUT	Experiment carried out in a careful and organised way, with apparatus set up and all relevant instructions followed.
B2	SAFETY	Sensible conduct, with concern shown for safety of self and others and/or for equipment.
B3	MANIPULATIVE SKILLS	Apparatus used skilfully.
B4	MAKING OBSERVATIONS	Sufficient number of readings obtained fully covering the range which is appropriate to the procedure and the apparatus.
B5	RECORDING OBSERVATIONS	Relevant readings presented in a suitable format.
B6	PRECISION / ACCURACY	All measurements made are accurate and to the appropriate degree of precision and, where relevant, there is appropriate validation.

Skill C **Interpreting and Concluding**

(a) Assessing the reliability and accuracy of experimental data and techniques by identifying and assessing errors including

(i) knowing the likely orders of magnitude of physical quantities,

(ii) distinguishing between systematic and random errors,

(iii) recognising and responding to serious sources of error,

(iv) estimating likely errors in individual measurements,

(v) estimating the effect of errors on the final calculated quantity.

(b) Processing experimental data so that it can be used to achieve the stated aim, including the use of observations, to solve both routine and unfamiliar problems and to test hypotheses.

(c) Applying knowledge to

(i) explain and interpret experimental results to reach valid conclusions,

(ii) evaluate the experiment and suggest modifications to procedures.

(d) Communicating information, results, conclusions and ideas in clear, appropriate ways, including verbally continuous prose, tabulation and line graphs.

	Assessment Criterion	**Requirement**
C1	PROCESSING	Processing of measurements.
C2	RELIABILITY	Reliability and accuracy of own experimental data and/or techniques assessed, including appropriate treatment of errors.
C3	MODIFICATION	Modifications suggested to procedures or justification offered for no modification.
C4	INTERPRETATION	Processed data interpreted appropriately.
C5	CONCLUSION	Conclusion drawn consistent with processed data.
C6	COMMUNICATION	Written account well presented with a clear logical structure.

SAFETY IN THE LABORATORY

Responsibility for safety matters rests with Centres. Attention is drawn to the following UK publications:

(a) The requirements, as published in October 1989, of COSHH (the Committee on Safety of Substances Hazardous to Health).

(b) Safe Practices in Chemical Laboratories, the Royal Society of Chemistry, 1989.

(c) Safety in Science Laboratories, DES Safety Series, 2, HMSO, 1976.

(d) Hazards in the Chemical Laboratory, ed. L. Bretherick, The Royal Society of Chemistry, 4th ed., 1986.

(e) Safeguards in the School Laboratory, ASE, 9th ed., 1988.

(f) Hazards, as published by CLEAPSS Development Group, Brunel University, Uxbridge UB8 3PH.

MATHEMATICAL REQUIREMENTS

Arithmetic

Candidates should be able to:

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

(b) recognise and use binary notation.

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

(d) take account of accuracy in numerical work and handle calculations so that significant figures are neither lost unnecessarily nor carried beyond what is justified.

(e) make approximate evaluations of numerical expressions (e.g. $\pi^2 \approx 10$) and use such approximations to check the magnitude of machine calculations.

Algebra

Candidates should be able to:

(a) change the subject of an equation. Most relevant equations involve only the simpler operations but may include positive and negative indices and square roots.

(b) solve simple algebraic equations. Most relevant equations are linear but some may involve inverse and inverse square relationships. Linear simultaneous equations and the use of the formula to obtain the solutions of quadratic equations are included.

(c) substitute physical quantities into physical equations using consistent units and check the dimensional consistency of such equations.

(d) formulate simple algebraic equations as mathematical models of physical situations, and identify inadequacies of such models.

(e) recognise and use the logarithmic forms of expressions like ab, a/b, x^n, e^{kx}; understand the use of logarithms in relation to quantities with values that range over several orders of magnitude.

(f) express small changes or errors as percentages and vice versa.

(g) comprehend and use the symbols $<$, $>$, $\leqslant$, $\geqslant$, $\ll$, $\gg$, $\approx$, /, $\propto$, $\langle x \rangle$ (= $\bar{x}$), Σ , Δx, δx, $\surd$.

Geometry and trigonometry

Candidates should be able to:

(a) calculate areas of right-angled and isosceles triangles, circumference and area of circles, areas and volumes of rectangular blocks, cylinders and spheres.

(b) use Pythagoras' theorem, similarity of triangles, the angle sum of a triangle.

(c) use sines, cosines and tangents (especially for 0°, 30°, 45°, 60°, 90°). **Use the trigonometric relationships for triangles:**

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

(d) use sin $\theta \approx$ tan $\theta \approx \theta$ and cos $\theta \approx 1$ for small θ; $\sin^2\theta + \cos^2\theta = 1$.

(e) understand the relationship between degrees **and radians (defined as arc/radius), translate from one to the other and use the appropriate system in context**.

Vectors

Candidates should be able to:

(a) find the resultant of two coplanar vectors, recognising situations where vector addition is appropriate.

(b) obtain expressions for components of a vector in perpendicular directions, recognising situations where vector resolution is appropriate.

Graphs

Candidates should be able to:

(a) translate information between graphical, numerical, algebraic and verbal forms.

(b) select appropriate variables and scales for graph plotting.

(c) for linear graphs, determine the slope, intercept and intersection.

(d) choose, by inspection, a straight line which will serve as the best straight line through a set of data points presented graphically.

(e) recall standard linear form $y = mx + c$ and rearrange relationships into linear form where appropriate.

(f) sketch and recognise the forms of plots of common simple expressions like $1/x$, x^2, $1/x^2$, sin x, cos x, $\mathbf{e}^{-x}$.

(g) **use logarithmic plots to test exponential and power law variations**.

(h) **understand, draw and use the slope of a tangent to a curve as a means to obtain the gradient, and use notation in the form d*y*/d*x* for a rate of change.**

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

GLOSSARY OF TERMS USED IN PHYSICS PAPERS

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

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

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

3. *Explain* may imply reasoning or some reference to theory, depending on the context.

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

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

6. *Describe* requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena. The amount of description intended should be interpreted in the light of the indicated mark value.

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

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

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

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

11. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.

12. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. the Young modulus, relative molecular mass.

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

14. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned. Candidates should make such simplifying assumptions as may be necessary

about points of principle and about the values of quantities not otherwise included in the question.

15. *Sketch,* when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct. However, candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value. On a sketch graph it is essential that candidates clearly indicate what is being plotted on each axis.

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

17. *Compare* requires candidates to provide both similarities and differences between things or concepts.

SUMMARY OF KEY QUANTITIES, SYMBOLS AND UNITS

The following list illustrates the symbols and units which will be used in question papers. This list is not differentiated between the AS and full A Level qualifications.

Corresponding lists of symbols and units have not been provided for the Options. Where possible, conventional, well-established symbols and units will be used in Options questions, i.e. as given in the current ASE publication.

Quantity	Usual symbols	Usual unit
Base Quantities		
mass	m	kg
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
Other Quantities		
distance	d	m
displacement	s, x	m
area	A	m^2
volume	V, v	m^3
density	ρ	kg m^{-3}
speed	u, v, w, c	m s^{-1}
velocity	u, v, w, c	m s^{-1}
acceleration	a	m s^{-2}
acceleration of free fall	g	m s^{-2}
force	F	N
weight	W	N
momentum	p	N s
work	w, W	J
energy	E, U, W	J
potential energy	E_p	J
kinetic energy	E_k	J
heating	q, Q	J
change of internal energy	ΔU	J
power	P	W
pressure	p	Pa
torque	T	N m
gravitational constant	G	N kg^{-2} m^2
gravitational field strength	g	N kg^{-1}
gravitational potential	ϕ	J kg^{-1}
angle	θ	°, rad
angular displacement	θ	°, rad
angular speed	ω	rad s^{-1}
angular velocity	ω	rad s^{-1}
period	T	s
frequency	f	Hz
angular frequency	ω	rad s^{-1}
wavelength	λ	m
speed of electromagnetic waves	c	m s^{-1}
electric charge	Q	C
elementary charge	e	C
electric potential	V	V
electric potential difference	V	V

Quantity	Usual symbols	Usual unit
electromotive force	E	V
resistance	R	Ω
resistivity	ρ	Ω m
electric field strength	E	N C^{-1} , V m^{-1}
permittivity of free space	ε_o	F m^{-1}
capacitance	C	F
time constant	τ	s
magnetic flux	Φ	Wb
magnetic flux density	B	T
permeability of free space	μ_o	H m^{-1}
stress	σ	Pa
strain	ε	
force constant	k	N m^{-1}
Young modulus	E	Pa
Celsius temperature	θ	°C
specific heat capacity	c	J kg^{-1} K^{-1}
molar heat capacity	C_m	J mol^{-1} K^{-1}
specific latent heat	L	J kg^{-1}
molar gas constant	R	J mol^{-1} K^{-1}
Boltzmann constant	k	J K^{-1}
Avogadro constant	N_A	mol^{-1}
number	N, n, m	
number density (number per unit volume)	n	m^{-3}
Planck constant	h	J s
work function energy	Φ	J
activity of radioactive source	A	Bq
decay constant	λ	s^{-1}
half-life	$t_{1/2}$	s
relative atomic mass	A_r	
relative molecular mass	M_r	
atomic mass	m_a	kg, u
electron mass	m_e	kg, u
neutron mass	m_n	kg, u
proton mass	m_p	kg, u
molar mass	M	kg
proton number	Z	
nucleon number	A	
neutron number	N	

DATA AND FORMULAE

Data

speed of light in free space,	c	$= 3.00 \times 10^{8}$ m s^{-1}
permeability of free space,	μ_o	$= 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	ε_o	$= 8.85 \times 10^{-12}$ F m^{-1}
elementary charge,	e	$= 1.60 \times 10^{-19}$ C
the Planck constant,	h	$= 6.63 \times 10^{-34}$ J s
unified atomic mass constant,	u	$= 1.66 \times 10^{-27}$ kg
rest mass of electron,	m_e	$= 9.11 \times 10^{-31}$ kg
rest mass of proton,	m_p	$= 1.67 \times 10^{-27}$ kg
molar gas constant,	R	$= 8.31$ J K^{-1} mol^{-1}
the Avogadro constant,	N_A	$= 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant,	k	$= 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant,	G	$= 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
acceleration of free fall,	g	$= 9.81$ m s^{-2}

Formulae

uniformly accelerated motion	s	$= ut + \frac{1}{2}at^2$
	v^2	$= u^2 + 2as$
work done on/by a gas	W	$= p\Delta V$
gravitational potential	ϕ	$= -\frac{Gm}{r}$
simple harmonic motion	a	$= -\omega^2 x$
velocity of particle in s.h.m.	v	$= v_o \cos \omega t$
	v	$= \pm\omega\sqrt{(x_o^2 - x^2)}$
resistors in series	R	$= R_1 + R_2 + ...$
resistors in parallel	$1/R$	$= 1/R_1 + 1/R_2 + ...$
electric potential	V	$= \frac{Q}{4\pi\varepsilon_0 r}$
capacitors in series	$1/C$	$= 1/C_1 + 1/C_2 + ...$
capacitors in parallel	C	$= C_1 + C_2 + ...$
energy of charged capacitor	W	$= \frac{1}{2}QV$
alternating current/voltage	x	$= x_o \sin \omega t$
hydrostatic pressure	p	$= \rho g h$
pressure of an ideal gas	p	$= \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
radioactive decay	x	$= x_o \exp(-\lambda t)$
decay constant	λ	$= \frac{0.693}{t_{\frac{1}{2}}}$
equation of continuity	Av	$=$ *constant*
critical mean density of matter in the Universe	ρ_o	$= \frac{3H_o^2}{8\pi G}$
Bernoulli equation (simplified)	$p_1 + \frac{1}{2}\rho v_1^2$	$= p_2 + \frac{1}{2}\rho v_2^2$
Stokes' law	F	$= Ar\eta v$
drag force in turbulent flow	F	$= Br^2\rho v^2$

RESOURCE LIST

Teachers may find reference to the following books helpful.

Advanced Physics, edited by J. Ling, published by Longman, ISBN 0-582-35596-6
Understanding Physics for Advanced Level (Third Edition), by J. Breithaupt, published by Stanley Thornes, ISBN 0-7487-1579-7
Accessible Physics, by F. Azzopardi & B. Stewart, published by Macmillan,
ISBN 0-333-2780-6
Advanced Physics (4th Edition), by T. Duncan, published by John Murray, ISBN 0-7195-5199-4
Physics in Focus, by M. Brimicombe, published by Nelson, ISBN 0-17-448174-8
(ELBS version, 0-17-448179-9)
Physics, by P. Fullick, published by Heinemann, ISBN 0-435-57078-1
Advanced Physics (2nd Edition), by K. Gibbs, published by Cambridge University Press,
ISBN 0-521-39985-8
Physics, by R. Hutchings, published by Nelson, ISBN 0-17-438510-2
Cambridge Problems in Physics (2nd Edition), by P.P. Dendy, R. Tuffnell & C.H.B. Mee, published by Cambridge University Press, ISBN 0-521-40956-X

Cambridge Modular Sciences Series (Cambridge University Press)

Foundation Physics, by K. Gibbs & R. Hutchings, ISBN 0-521-42197-7
Basic Physics 1 and 2, by D. Sang, ISBN 0-521-48502-9
Further Physics, by D. Sang, ISBN 0-521-55606-6
Health Physics, by A. McCormick & A. Elliott, ISBN 0-521-42155-1
Cosmology, by B. Milner, ISBN 0-521-42162-4

These titles represent some of the texts available in the UK at the time of printing this booklet. Teachers are encouraged to choose texts for class use which they feel will be of interest to their students and will support their own teaching style.
The Option Booklets are available from the Publications Office at CIE, using the appropriate order form.

IT USAGE IN A LEVEL PHYSICS

Information Technology (IT) is a term used to cover a number of processes which have nowadays become an indispensible part of modern life. These processes are almost all based on the ability of the microprocessor chip to handle and manipulate large volumes of binary data in a short time. The use of IT is now an important factor in Physics education and it is hoped that all A Level candidates will have the opportunity to experience something of each of the following five processes:

1. Data Capture (Hardware)

Sensors and Data Loggers can be used in any experiment to measure and store a number of physical quantities which vary with time. The sensor usually converts the quantity (e.g. temperature, light/sound intensity, position, count rate, magnetic flux density) into a voltage and the data logger samples this voltage at regular intervals from a few microseconds to a few hours depending on the duration of the 'experiment'. Each sample is converted into a binary/digital number and then stored in memory. The number of samples which are taken and stored depends on the particular data logger in use but it is usually several hundred. This large number has the effect that when the stored data is subsequently plotted graphically, the data points are so close together that the physical quantity appears to vary continuously over the timescale of the experiment.

Sensors and Data Loggers are invaluable where the timescale of the 'experiment' is either very long (e.g. the variation of temperature over several days) or very short (e.g. the microphone signal of a handclap).

Although most suppliers of Sensors and Data Loggers will indicate the type of experiment in which they may be used, the following are some examples of their use in standard A Level Physics experiments:

the variation of voltage in capacitor charge/discharge circuits

the variation of temperature in a latent heat demonstration

the variation of induced e.m.f. in a coil as a magnet falls through it

the variation of count rate in radioactive half-life measurement

the variation of the position of an oscillator in simple harmonic motion

2. Data Analysis (Software)

The most important type of program which allows the analysis of data is the SPREADSHEET into which data may be added manually (via the keyboard) or automatically (via the data logger). These programs have a number of different functions.
One of the most important uses of the spreadsheet is that it allows its data to be analysed graphically. Two or more sets of corresponding data can be plotted as histograms or as pie charts or as simple line graphs or as X~Y scattergraphs (with or without a best-fit line).

Once a spreadsheet has some starting point, it can calculate further data by applying a formula to the existing information. For example, if the spreadsheet started with a column of voltages and another column of corresponding currents it could then calculate a third column of the product of the voltage and current (i.e. the power) and a fourth column of the quotient of voltage and current (i.e. the resistance).

A spreadsheet allows alphanumeric and mathematical analysis of its data. For example, one column of a spreadsheet could contain the names of students in a class while neighbouring columns could contain their raw scores for the various skills in a number of assessed practicals. The program could sort the names into alphabetical order or it could calculate mean or total values or apply some scaling factor to the different scores.

A spreadsheet may also be used to build mathematical models of physical situations by calculating and plotting the necessary data. For example, the dynamic model of the two dimensional flight of a ball subject to air resistance may be examined without resorting to the calculus of sophisticated differential equations. Here, the positions of the ball after successive increments of time would be calculated algebraically and added to successive cells in the spreadsheet. These positions can then be plotted to reveal the ball's trajectory.

There are a number of general spreadsheet programs available and there are also some dedicated to the process of graph plotting and graphical analysis. For example:

EXCEL is a general spreadsheet for use with MACs and PCs and commonly used in education.

LOTUS 123 is a general spreadsheet for use with PCs and commonly used in business.

3. Teaching Aids and Resources (Software)

There are now many software packages available which have been designed to assist the teaching of almost every topic in A Level Physics. Some of these can be used as self-learning programs for an individual student to work through at their own pace while others can be used as computer generated images for classroom demonstrations and simulations. For example, 'Moving Molecules' illustrates basic kinetic theory by allowing students to visualise what is happening to the molecules in gases, liquids and solids as temperature and pressure are changed.

Although there are at present very few CD-ROMs of direct relevance to A Level Physics, this is a potential growth area and it is likely that in the near future much more use will be made of this resource.

The videocassette and the laser disc are two further sources of sometimes excellent demonstrations of various topics in Physics.

4. World Wide Web (WWW)

The WWW is a huge resource for teachers and students as it provides a huge database of information/resources. Websites that have been carefully reviewed for its content and suitability may be incorporated in the teaching of physics or given as reference materials for students. The WWW offers pictures, video clips and data bases on science, slides of lecture material, lesson plans, concept maps and test questions that could be used as additional teaching aids. Perhaps one of the greatest advantage of the WWW is its abundance of JAVA applets which could be used to illustrate effectively a specific scientific concept.

One desirable feature of the Internet is its capability to facilitate communication and dissemination of information electronically. Students may post questions on a topic of interest to a forum page. They may consult experts and communicate with others on the topic of study through e-mail.

5. Open Tools

Students should be encouraged to communicate scientific concepts using effective and appropriate Open Tools when making presentation. Word-processor, graphic organiser and spreadsheet may be utilised to organise and present text, tables, charts or graphical information.

Learning Outcomes

Finally, students must develop an awareness of the many possible applications and limitations of IT. They should be able to judge when to use IT to collect, handle and analyse scientific investigation. Students must be aware of the need to be critical of information produced using IT and that the results may be affected by the use of inaccurate data or careless entry. Most importantly, students will, in the process, learn to adopt a critical and creative approach to problem solving that would enable them to meet the challenges of the new knowledge-based economy.

Certain Learning Outcomes of the Syllabus have been marked with an asterisk (*) to indicate the possibility of the application of IT. A brief commentary on some of these objectives follows. In some cases, software is available commercially; in others, teachers may be able to develop their own. References in the notes below are to Learning Outcomes.

2. MEASUREMENT TECHNIQUES

2(*a*) and *(b)* introduce candidates to the presentation of data in analogue and digital forms. In *(c),* calibration data may be stored on disc, as well as being read from hard copy. Data-capture techniques may be used in the measurement of magnetic flux density *{(a)}*. The treatment of uncertainties in *(f)* may be illustrated using IT simulation methods.

3. KINEMATICS

3(b), (c), (d), (e), (*g*) and (*i*) offer an opportunity to use computer programs to simulate particle motion, and to demonstrate how quantities such as displacement, velocity and acceleration are related. Data-capture techniques may also be used in practical work on kinematics.

4. DYNAMICS

In *(f)*, some examples of the application of Newton's second law may be presented through computer simulations. Likewise, collision problems {*(h), (i)* and (*j*)} may be presented very effectively using IT simulations. Experimental investigations of collisions lend themselves to data-capture techniques.

6. WORK, ENERGY, POWER

6(c), (*g*) and *(l)* may be approached using simulation methods.

7. MOTION IN A CIRCLE

Computer simulation techniques may be used effectively in the analysis of circular orbits {*(d)*}.

8. GRAVITATIONAL FIELD

Theoretical predictions from Newton's law of gravitation and the concept of gravitational potential may be presented through computer simulations {*(b), (d), (g)* and *(i)*}. Information on the orbits of planets in the Solar System could be stored on a spreadsheet.

12. TEMPERATURE

Data-capture methods may be used with certain types of thermometer {*(d)*}.

14. OSCILLATIONS

The relations between acceleration, velocity and displacement in simple harmonic motion {*(b)* and *(g)*}, and in damped and forced oscillation {*(i)* and *(k)}* may be demonstrated using computer simulations.

15. WAVES

The graphical representation of transverse and longitudinal waves {*(h)*} may be illustrated using computer simulations. Data capture may be applied in the measurement of the frequency and wavelength of sound {*(j)* and *(k)*}.

16. SUPERPOSITION

Computer simulations may be used to help students to model the concept of superposition {*(a)*}, and to investigate stationary waves {*(b)* and *(c)*}.

17. ELECTRIC FIELDS

Theoretical predictions from Coulomb's law and the concept of electric potential may be presented through computer simulations {*(f), (g)* and *(j)*}.

18. CAPACITANCE

Computer simulations may be used to illustrate *(f)*.

19. CURRENT OF ELECTRICITY

19(*i*), on the current-voltage characteristics of a number of devices, may be presented through computer simulations and data-capture.

20. D.C. CIRCUITS
The characteristics of thermistors and light-dependent resistors {*(k)*} may be presented using computer simulation techniques and data-capture.

23. ELECTROMAGNETIC INDUCTION
Computer simulations may be used to illustrate the phenomena of electromagnetic induction {*(d)*}.

24. ALTERNATING CURRENTS
Computer simulations, or demonstrations using a cathode-ray oscilloscope, are powerful methods of demonstrating alternating currents {*(b), (c), (g)* and *(j)*}.

25. CHARGED PARTICLES
The classic experiments on the determination of e {*(a)*} and e/m_e {*(e)*} may be presented through computer simulations. Theoretical predictions of the motion of charged particles in electric and magnetic fields may also be presented in this way {*(c)*}.

26. QUANTUM PHYSICS
Important concepts of the quantum theory may be presented using simulation techniques, and theoretical predictions may be demonstrated {*(c)* and *(h)*}. The relation of spectral lines to systems of discrete electron energy levels {*(j)*} may also be presented in this way.

27. NUCLEAR PHYSICS
Computer simulations of an α-particle scattering experiment {*(a)*} may be very effective. Simple models of the nuclear atom {*(b)*} may be presented using computer simulations. Data-capture methods may be used in experiments on radioactive decay {*(j)* and*(o)*}.

A LEVEL OPTIONS

A2. THE STANDARD MODEL OF THE UNIVERSE
Observations of the redshift {*(a)*} may be presented through computer simulations.

A3. TECHNIQUES OF OBSERVATION
3(*b*) may lead to an appreciation of the need for IT techniques in observational astronomy.

F2. NON-VISCOUS FLUID FLOW
Computer simulations may be useful to illustrate applications of the Bernoulli effect {*(i)*}.

F3. VISCOUS FLUIDS
3*(f)*, on Stokes' law, lends itself to a presentation through computer simulation. Data capture may be used in experimental work on terminal velocity. 3*(l)* suggests the use of computer simulations and predictions of drag coefficients.

M1. MEDICAL IMAGING
1*(e)*, on the exponential attenuation of X-rays in matter, may be presented using computer simulations and predictions. 1*(h)* allows the discussion of the use of IT techniques in displays and in data storage.

M4. THE PHYSICS OF HEARING
The concept of the decibel scale {*(e)*} may be introduced using computer simulations.

P1. POWER SOURCES
The discussion of *(e)* might involve computer simulations of changes in resources and reserves. Computer simulations could be used to model the operation of a nuclear reactor {*(h)*}.

P3. HEAT ENGINES
The four-stroke petrol-engine cycle {*(e)*} can be presented using computer simulations.

T1. COMMUNICATION PRINCIPLES
1*(a)*, *(b)*, *(c)* and *(g)* may be presented effectively using computer simulations.