ASSESSMENT and QUALIFICATIONS ALLIANCE

General Certificate of Education

Physics

Specification A

Special Features

- Maintains continuity with existing AQA (NEAB) syllabus
- Provides sound foundation for further study
- Includes optional topics
- Provides coursework and practical examination alternatives

Material accompanying this Specification

Specimen Assessment Units and Marking Schemes
Teachers' Guide

AQA ADVANCED SUBSIDIARY GCE 5451
AQA ADVANCED GCE 6451

Further copies of this specification booklet are available from:

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Background Information

1 New Advanced Subsidiary and Advanced Level for 2001/2002

Following the Dearing *'Review of Qualifications for 16-19 Year Olds'* and the subsequent consultation *'Qualifying for Success'*, all the unitary awarding bodies have introduced new Advanced Subsidiary and revised Advanced Level specifications for the award of the first qualification in 2001.

1.1 Advanced Subsidiary (AS)

Advanced Subsidiary courses will be introduced from September 2000 for the award for first qualification in August 2001. They may be used in one of two ways:

- as a final qualification, allowing candidates to broaden their studies and to defer decisions about specialism;
- as the first half (50%) of an Advanced Level qualification, which must be completed before an Advanced Level award can be made.

Advanced Subsidiary is designed to provide an appropriate assessment of knowledge, understanding and skills expected of candidates who have completed the first half of a full Advanced Level qualification. The level of demand of the AS examination is that expected of candidates half-way through a full A Level course of study.

1.2 Advanced Level (AS+A2)

The Advanced Level examination is in two parts:

- Advanced Subsidiary (AS) -- 50% of the total award;
- a second examination, called A2 -- 50% of the total award.

Most Advanced Subsidiary and Advanced Level courses will be modular. The AS will comprise three teaching and learning modules and the A2 will comprise a further three teaching and learning modules. Each teaching and learning module will normally be assessed through an associated assessment unit. The specification gives details of the relationship between the modules and assessment units.

With the two-part design of Advanced Level courses, centres may devise an assessment schedule to meet their own and candidates' needs. For example:

- assessment units may be taken at stages throughout the course, at the end of each year or at the end of the total course;
- AS may be completed at the end of one year and A2 by the end of the second year;
- AS and A2 may be completed at the end of the same year.

Details of the availability of the assessment units for each specification are provided in Section 3.

2 Specification at a Glance
Physics

Award	AS Examination 5451	
	Unit 1	
	Written Paper	30% of the total AS mark
	1½hours	15% of the total A Level mark
	Short structured questions on Module 1	
	Unit 2	
	Written Paper	30% of the total AS mark
	1½hours	15% of the total A Level mark
	Short structured questions on Module 2	
Year 2001 or 2002 Advanced Subsidiary Award 5451 ←	**Unit 3**	
	Written Paper	25% of the total AS mark
	1¼ hours	12½% of the total A Level mark
	Short structured questions on module 3	
	+	
	Either	Or
	Practical Examination	Coursework
	1½hours	
	15% of the total AS mark	15% of the total AS mark
	7½% of the total A level mark	7½% of the total A level mark

+

Award	A2 Examination 6451	
	Unit 4	
	Written Paper	
	1½hours	15% of the total A Level mark
	Multiple choice and structured questions on Module 4	
	Unit 5	
	Written Paper	
	1¼ hours	10% of the total A Level mark
	Structured questions on module 5 and module 6 options	
	+	
	Either	Or
	Practical Examination	Coursework
	1½ hours	
	5% of the total A level mark	5% of the total A level mark
Year 2002 Advanced Level Award 6451 ←	**Unit 6**	
	Written Paper	
	2 hours	20% of the total A Level mark
	Structured synoptic questions on Modules 1-5	

3 Availability of Assessment Units and Entry Details

3.1 Availability of Assessment Units

Examinations based on this specification are available as follows:

	Availability of Units		Availability of Qualification	
	AS	**A2**	**AS**	**A Level**
January 2001	1, 2		—	—
June 2001	1, 2 and 3		✓	—
January 2002	1, 2 and 3	4, 5	✓	—
June 2002	1, 2 and 3	4, 5 and 6	✓	✓
January 2003	1, 2 and 3	4, 5 and 6	✓	✓

3.2 Sequencing of Units

It is recommended that the units are taken in the sequence 1, 2, 3, 4, 5 and 6. Centres are recommended to read this section in conjunction with Paragraph 3.1, Availability of Assessment Units.

3.3 Entry Codes

Normal entry requirements apply, but the following information should be noted.

The following unit entry codes should be used:

AS	**A2**
Unit 1 - *PA01* Unit 2 - *PA02* Unit 3 - *PA3C*	Unit 4 - *PA04* Unit 5 - *PA5C* Unit 6 - *PA6C*

The **Subject Code** for entry to the AS only award is *5451*

The **Subject Code** for entry to the Advanced Level award is *6451*

3.4 Prohibited Combinations

Candidates entering for this examination are prohibited from entering for any GCE Physics (5451 and 6451) specification in the same examination series. This does not preclude candidates from taking AS and A2 units with AQA in the same examination series.

Every specification is assigned to a national classification code indicating the subject area to which it belongs. Centres should be aware that candidates who enter for more than one GCE qualification with the same classification code, will have only one grade (the highest counted for the purposes of the School and College Performance Tables .The classification code for this specification is 1210

3.5 Private Candidates	This specification is available to private candidates. Private candidates should write to the AQA for a copy *of 'Supplementary Guidance for Private Candidates'*. Private candidates must offer the Practical Examination alternative in Units 3 and 5.
3.6 Special Consideration	Special consideration may be requested for candidates whose work has been affected by illness or other exceptional circumstances. The appropriate form and all relevant information should be forwarded to the AQA office which deals with such matters for the centre concerned. Special arrangements may be provided for candidates with special needs. Details are available from AQA and centres should ask for a copy of *Candidates with Special Assessment Needs, Special Arrangements and Special Consideration: Regulations and Guidance.*
3.7 Language of Examinations	All Assessment Units in this subject are provided in English only.

Scheme of Assessment

4

Introduction

AQA has developed two Physics Specifications, Physics A and Physics B. This is the Physics A Specification.

Physics A, like Physics B, reflects modern developments in Physics and its applications. Additionally, it offers continuity from the existing NEAB syllabus and provides a sound foundation for further study. Further, there is the provision of optional topic areas in A2 and coursework and practical examinations as alternatives in both AS and A2.

The GCE Physics A specification complies with:

- the Subject Criteria for Physics;
- the GCSE and GCE A/AS Code of Practice;
- the GCE Advanced Subsidiary and Advanced Level Qualification-Specific Criteria;
- the arrangements for the Statutory Regulation of External Qualifications in England, Wales and Northern Ireland. Common Criteria

The aim of this specification is to attract candidates to study Physics post-16 and the provision of optional areas for study has been made to enhance this aim. The specification has been designed to foster a variety of teaching and assessment styles and the provision of a practical examination and coursework as options contributes to this.

Further, the specification also provides opportunities for students to develop the six Key Skills.

The general objectives of the specification are for candidates to:

- develop positive attitudes towards learning and applying Physics principles;
- develop ability and confidence in the subject;
- acquire a sound base of the knowledge, skills and attitudes required for further study in Physics, in other subjects and in employment;
- develop skills of generalisation and interpretation of results relevant to application and development in Physics;
- recognise the value of Physics in society;
- develop a rigorous approach to Physics and a precision in using those terms unique to the subject;
- develop practical skills including those of dexterity and organisation.

Prior level of attainment and recommended prior learning

The Advanced Subsidiary and A level specifications build on the knowledge, understanding and skills set out in the National Curriculum Key Stage 4 programme of study for Double Award Science. It is assumed that candidates have achieved Grade C or better in GCSE Science (Double Award) or GCSE Science: Physics. The specification provides progression for entry to higher education and employment.

5 Aims

The AS and A level specifications in Physics are intended to encourage candidates to:

a. develop essential knowledge and understanding in Physics and, where appropriate, the applications of Physics, and the skills needed for the use of this in new and changing situations;

b. develop an understanding of the link between theory and experiment;

c. appreciate how Physics has developed and is used in present day society;

d. show the importance of Physics as a human endeavour which interacts with social, philosophical, economic and industrial matters;

e. sustain and develop their enjoyment of, and interest in, Physics;

f. recognise the quantitative nature of Physics and understand how mathematical expressions relate to physical principles.

In addition, the A level specification is intended to encourage candidates to:

g. bring together knowledge of ways in which different areas of Physics relate to each other;

h. study how scientific models develop.

6 Assessment Objectives

Knowledge, understanding and skills are closely linked. Candidates are required to demonstrate the following Assessment Objectives in the context of the content and skills described.

At AS and A Level

Candidates should be able to :

6.1 Knowledge with Understanding (AO1)

a. recognise, recall and show understanding of specific physical facts, terminology, principles, relationships, concepts and practical techniques;

b. draw on existing knowledge to show understanding of the ethical, social, economic, environmental and technological implications and applications of Physics;

c. select, organise and present relevant information clearly and logically, using specialist vocabulary where appropriate.

6.2 Application of knowledge and understanding, synthesis and evaluation (AO2)

a. describe, explain and interpret phenomena and effects in terms of physical principles and concepts, presenting arguments and ideas clearly and logically, using specialist vocabulary where appropriate;

b. interpret and translate, from one form to another, data presented as continuous prose or in tables, diagrams and graphs;

c. carry out relevant calculations;

d. apply physical principles and concepts to unfamiliar situations including those which relate to the ethical, social, economic and technological implications and applications of Physics;

e. assess the validity of physical information, experiments, inferences and statements.

6.3 Experiment and investigation (AO3)

a. devise and plan experimental activities, selecting appropriate techniques;

b. demonstrate safe and skilful practical techniques;

c. make observations and measurements with appropriate precision and record these methodically;

d. interpret, explain, and evaluate the results of experimental activities, using knowledge and understanding of Physics and to communicate this information clearly and logically in appropriate forms *eg prose, tables and graphs*, using appropriate specialist vocabulary.

At A level

6.4	Synthesis of knowledge, understanding and skills (AO4)	a.	bring together principles and concepts from different areas of physics and apply them in a particular context, expressing ideas clearly and logically and using appropriate specialist vocabulary;
		b.	use the skills of physics in contexts which bring together different areas of the subject.

6.5 Quality of Written Communication

The quality of written communication is assessed in all assessment units where candidates are required to produce extended written material. Candidates will be assessed according to their ability to:

- select and use a form and style of writing appropriate to purpose and complex subject matter;
- organise relevant information clearly and coherently, using specialist vocabulary when appropriate;
- ensure text is legible, and spelling, grammar and punctuation are accurate, so that meaning is clear.

The assessment of the quality of written communication is included in all four Assessment Objectives.

7 Scheme of Assessment – *Advanced Subsidiary (AS)*

The Scheme of Assessment has a modular structure. The Advanced Subsidiary (AS) award comprises three assessment units. Assessment Units 1 and 2 are compulsory for all candidates. Assessment Unit 3 comprises a written paper which is compulsory for all candidates and **either** centre-assessed coursework **or** a practical examination.

7.1 Assessment Units

Unit 1 30% of the total AS marks	Written Paper 60 marks	 1½ hours

The written paper comprises short structured questions and assesses Module 1 of the AS Subject Content. All questions are compulsory.

Unit 2 30% of the total AS marks	Written Paper 60 marks	 1½ hours

The written paper comprises short structured questions and assesses Module 2 of the AS Subject Content. All questions are compulsory.

Unit 3 40% of the total AS marks	Written Paper 50 marks 25% of the total AS marks	 1¼ hours
	+	
Either	Centre –assessed coursework 30marks 15% of the total AS marks	
Or	Practical Examination 1½ hours 30 marks 15% of the total AS marks	

The written paper comprises short structured questions and assesses Module 3 of the AS Subject Content. All questions are compulsory.

The *centre-assessed coursework* requires candidates to submit evidence for each of the four skills listed in Section 18: Planning, Implementing, Analysing evidence and drawing conclusions, Evaluating evidence and procedures. It is assessed by the teacher(s) and moderated by AQA.

The *Practical Examination* comprises a planning exercise and a practical exercise to permit assessment of each of the 4 skills listed in Section 18: Planning, Implementing, Analysing evidence and drawing conclusions, Evaluating evidence and procedures. Both exercises are compulsory.

The design and experimental activities will be based on the specification content areas listed for AS.

The structure of the examination is as follows

Question	Type of Question	Skill(s) tested	Marks
1	Design and Planning: written exercise, no practical activity	Planning	8
2	A single experimental exercise; no choice of activity	Implementing Analysing Evaluating	8 8 6
		Total	30

Candidates are advised to spend approximately 30 minutes on Question 1 and 60 minutes on Question 2.

In Question 1, Planning, candidates will be asked to design an experiment or plan a procedure in order to investigate aspects of a given situation in Physics. Candidates may be asked to consider such matters as

- measurement of variables
- expected outcomes
- difficulties encountered and possible solutions

In Question 2 candidates will be required to perform an experiment according to given instructions.

They will not be asked to describe the experiment. They will however, be required to perform activities such as

- making measurements
- adjusting the apparatus in order to repeat the experiment under different conditions
- plotting graphs
- explaining procedures

Details of the apparatus and materials required for the Practical Examination will be sent to centres in advance of the date of the examination.

Candidates choosing the coursework alternative or the practical examination at AS do not have to follow the same form of assessment at A2.

7.2 Weighting of Assessment Objectives for AS

The approximate relationship between the relative percentage weighting of the Assessment Objectives (AOs) and the overall Scheme of Assessment is shown in the following table:

Assessment Objectives	**Unit Weightings (%)**			**Overall Weighting of AOs (%)**
	1	**2**	**3**	
Knowledge with understanding (AO1)	19.5	17.5	16	53
Application of knowledge and understanding, synthesis and evaluation (AO2)	10.5	12.5	9	32
Experiment and Investigation (AO3)	-	-	15	15
Overall Weighting of Units (%)	30	30	40	100

Candidates' marks for each assessment unit are scaled to achieve the correct weightings.

8 Scheme of Assessment – *Advanced Level (AS+A2)*

The Scheme of Assessment has a modular structure. The A Level award comprises three assessment units from the AS Scheme of Assessment and three assessment units from the A2 scheme of assessment. Assessment Units 4 and 6 are compulsory for all candidates. Assessment Unit 5 comprises a written paper on Module 5 and one of the five options from Module 6. Additionally, assessment unit 5 comprises **either** centre-assessed coursework **or** a practical examination.

8.1 AS Assessment Units

Unit 1 15% of the total A Level marks	Written Paper 60 marks	1½ hours

Unit 2 15% of the total A Level marks	Written Paper 60 marks	1½ hours

Unit 3 20% of the total A Level marks	Written Paper 50 marks 12½% of the total A level marks	1¼ hours
	+	
Either	Coursework 30 marks 7½% of the total A level marks	
Or	Practical 30 marks 7½% of the total A level marks	1½ hours

8.2 A2 Assessment Units

Unit 4 15% of the total A Level marks	Written Paper 60 marks	1½ hours

The written paper is made up of two sections.

Section A (30 marks) comprises 15 compulsory multiple choice questions.

Section B (30 marks) comprises short structured questions. All questions are compulsory.

Unit 5 15% of the total A Level marks		Written Paper 1¼ hours 40 marks 10% of the total A level marks
	+	
Either		Centre–assessed coursework 30 marks 5% of the total A level marks
Or		Practical Examination 1½ hours 30 marks 5% of the total A level marks

The written paper for each option consists of a question or questions on Nuclear Instability (Module 5) and questions from **one** of the options A, B, C, D, E from module 6 of the A2 Subject Content. Questions will be structured. All questions are compulsory.

The *centre-assessed coursework* requires candidates to submit evidence for each of the 4 skills listed in section 18: Planning, Implementing, Analysing evidence and drawing conclusions, Evaluating evidence and procedures. It is assessed by the teacher(s) and moderated by AQA.

The *Practical Examination* comprises a planning exercise and a practical exercise to permit assessment of each of the 4 skills, listed in section 18: Planning, Implementing, Analysing evidence and drawing conclusions, Evaluating evidence and procedures.

The design and experimental activities will be based on the specification content areas listed for A2 with the exception of the optional module areas.

The structure of the examination is as follows

Question	Type of question	Skill(s) tested	Marks
1	Design and Planning: written exercise, no practical activity	Planning	8
2	A single experimental exercise; no choice of activity	Implementing Analysing Evaluating	8 8 6
		Total	30

Candidates are advised to spend approximately 30 minutes on Question 1 and 60 minutes on Question 2.

In Question 1, Planning, candidates will be asked to design an experiment or plan a procedure in order to investigate aspects of a given situation in Physics. Candidates may be asked to consider such matters as

- measurement of variables
- expected outcomes
- difficulties encountered and possible solutions

In Question 2 candidates will be required to perform an experiment according to given instructions. They will not be asked to describe the experiment. They will, however, be required to perform activities such as

- making measurements
- adjusting the apparatus in order to repeat the experiment under different conditions
- plotting graphs
- evaluating and calculating
- explaining procedures
- discussing different approaches

Details of the apparatus and materials required for the Practical Examination will be sent to centres in advance of the date of the examination.

Candidates choosing the coursework alternative or the practical examination at AS do not have to follow the same form of assessment at A2.

Unit 6	Written Paper	2 hours
20% of the total A Level marks	80 marks	

This paper consists of structured questions and examines Modules 1-5. It embodies the synoptic assessment for the specification. All questions are compulsory.

8.3 Synoptic Assessment

The Advanced Subsidiary and Advanced Level Criteria state that A Level specifications must include synoptic assessment (representing at least 20% of the total A Level marks). In Unit 6 all marks are allocated to synoptic assessment (20% of the total A level marks).

8.4 Weighting of Assessment Objectives for A Level

The approximate relationship between the relative percentage weighting of the Assessment Objectives (AOs) and the overall Scheme of Assessment is shown in the following table.

A Level Assessment Units (AS + A2)

Assessment Objectives	**Unit Weightings (%)**						**Overall Weighting of AOs (%)**
	1	2	3	4	5	6	
Knowledge with Understanding (AO1)	10	9	8	7	5	-	39
Application of knowledge and understanding, synthesis and evaluation (AO2)	5	6	4.5	8	5	-	28.5
Experiment and Investigation (AO3)	-	-	7.5	-	5	-	12.5
Synthesis of knowledge, understanding and skills (AO4)	-	-	-	-	-	20	20
Overall Weighting of Units (%)	15	15	20	15	15	20	100

Candidates' marks for each assessment unit are scaled to achieve the correct weightings.

Subject Content

9 Summary of Subject Content

9.1 AS Modules

MODULE 1 - Particles, Radiation and Quantum Phenomena

Particles

Electromagnetic radiation and quantum phenomena

MODULE 2 - Mechanics and Molecular Kinetic Theory

Mechanics

Molecular kinetic theory model

MODULE 3 - Current Electricity and Elastic Properties of Solids

Current electricity

Elastic properties of solids

9.2 A2 Modules

MODULE 4 - Waves, Fields and Nuclear Energy

Oscillations and Waves

Capacitance

Gravitational and electric fields

Magnetic effects of currents

Nuclear Applications

MODULE 5 - Nuclear Instability

Nuclear Instability

MODULE 6A - Astrophysics

Lenses and Optical Telescopes

Radio Astronomy

Classification of Stars

Cosmology

MODULE 6B - Medical Physics

Physics of the Eye and Ear

Biological Measurement and Imaging

MODULE 6C - Applied Physics

Rotational Dynamics

Thermodynamics and Engines

MODULE 6D - Turning Points in Physics

The Discovery of the Electron

Wave Particle Duality

Special Relativity

MODULE 6E - Electronics

Basic Electrical Principles

Capacitors

Devices

Analogue Electronics

Summing Non-inverting Amplifier

10 AS Module 1
Particles, Radiation and Quantum Phenomena

Introduction	The two themes explored in this module are those of particles and of electromagnetic radiation and quantum phenomena. The concept of anti-particles is introduced as are quarks and anti-quarks. The particle and the wave models are brought together. Most of this module consists of material from the AS criteria for Physics and develops material studied in the Key Stage 4 science courses.

10.1 Particles

10.1.1	Constituents of the atom	Proton, neutron, electron Charges, relative masses. Atomic mass unit is not required
10.1.2	Evidence for existence of the nucleus, qualitative study of Rutherford scattering	Proton number Z, nucleon number A, isotopes
10.1.3	Particles, antiparticles and photons	Electron, positron Proton, antiproton Neutrino, antineutrino Photon model of electromagnetic radiation, the Planck constant, $E = hf$ Weak interaction, limited to changes in which a proton changes to a neutron or vice versa Pair production; annihilation of a particle and its antiparticle releases energy; the use of $E = mc^2$ is not required Concept of exchange particles to explain forces between elementary particles Simple Feynman diagrams to show how a reaction occurs in terms of particles going in and out and exchange particles: limited to β^- decay, β^+ decay, electron capture, neutrino – neutron collisions, antineutrino – proton collisions and electron – proton collisions
10.1.4	Classification of particles	Hadrons: baryons (proton, neutron) mesons (pion, kaon) Candidates should know that the proton is the only stable baryon into which other baryons eventually decay; in particular the decay of the neutron should be known Leptons: electron, muon, neutrino Candidates will not be required to remember, but will be expected to be familiar with, baryon and lepton numbers for individual particles and antiparticles

10.1.5	Quarks and antiquarks	Up (u), down (d) and strange (s) quarks only. Properties of quarks: charge, baryon number and strangeness Combinations of quarks and antiquarks are required for baryons (proton and neutron only) and for mesons (pion and kaon only) Change of quark character in β^- decay and β^+ decay Application of the conservation laws for charge, baryon number and strangeness to particle interactions

10.2 Electromagnetic radiation and quantum phenomena

10.2.1	Refraction at a plane surface	Refractive index, *n*; candidates are not expected to recall methods for determining refractive indices Snell's law of refraction $${}_1n_2 = \frac{\sin\theta_1}{\sin\theta_2} = \frac{c_1}{c_2}$$ $${}_1n_2 = \frac{n_2}{n_1}$$ Total internal reflection including calculations of critical angle, θ_c $$\sin\theta_c = \frac{1}{n}$$ Simple treatment of fibre optics including function of cladding with lower refractive index around central core limited to step index only; candidates should be familiar with modern applications of fibre optics, e.g. endoscopy, communications, etc.
10.2.2	The photoelectric effect	Treatment limited to energy considerations only; the stopping potential experiment is not required; work function ϕ, photoelectric equation $hf = \phi + E_k$
10.2.3	Collisions of electrons with atoms Ionisation, excitation	The electronvolt Understanding of the role of ionisation and excitation in the fluorescent tube; line spectra (e.g. of atomic hydrogen) as evidence of transitions between discrete energy levels
	Energy levels, photon emission	$hf = E_1 - E_2$
10.2.4	Wave-particle duality	Candidates should know that electron diffraction suggests the wave nature of particles and the photoelectric effect suggests the particle nature of electromagnetic waves; details of particular methods of showing particle diffraction are not expected de Broglie wavelength $$\lambda = \frac{h}{mv}$$

11 AS Module 2
Mechanics and Molecular Kinetic Theory

Introduction

This module contains principally simple mechanics and initial ideas on the molecular kinetic theory model. Most of the module consists of material from the AS criteria for Physics and some topics which have been introduced in Key Stage 4 Science courses.

11.1 Mechanics

11.1.1 Scalars and vectors

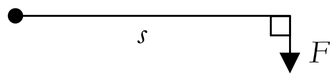
The addition and subtraction of vectors by calculation or scale drawing; calculations limited to two perpendicular vectors
The resolution of vectors into two components at right angles to each other

11.1.2 Conditions for equilibrium for two or three coplanar forces acting at a point

Problems may be solved either by using resolved forces or by using a closed triangle

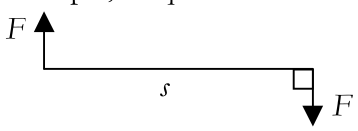
11.1.3 Turning effects

Moment of a force



moment = Fs

Couple, torque



couple = Fs

The principle of moments and its applications in simple balanced situations e.g. see–saw.
The centre of mass; calculations of the position of centre of mass of a regular lamina are not expected.

11.1.4 Displacement, speed, velocity and acceleration

$$v = \frac{\Delta s}{\Delta t}$$

$$a = \frac{\Delta v}{\Delta t}$$

11.1.5 Uniform and non-uniform acceleration, representation and interpretation by graphical methods

Interpretation of velocity-time and displacement-time graphs for motion with non-uniform acceleration and uniform acceleration; significance of areas and gradients

Equations for uniform acceleration

$$v = u + at$$

$$s = \left(\frac{u + v}{2}\right)t$$

		$s = ut + \frac{at^2}{2}$ $v^2 = u^2 + 2as$ Acceleration due to gravity g, terminal speed; detailed experimental methods of measuring g are not required
11.1.6	Independence of vertical and horizontal motion	Calculations involving projectile equations will not be set
11.1.7	Momentum, conservation of linear momentum	Recall and use of $p = mv$ Conservation calculations for elastic and inelastic collisions limited to one dimension Candidates should have experience of analysing motion using datalogging techniques involving data capture with appropriate sensors e.g. light gates Candidates will require understanding of the application of the principles of the conservation of linear momentum e.g. space vehicles
11.1.8	Newton's laws of motion	Candidates are expected to know and to be able to apply the three laws in appropriate situations Force as the rate of change of momentum $F = \frac{\Delta(mv)}{\Delta t}$ For constant mass: $F = ma$
11.1.9	Work, energy, power	$W = Fs\cos\theta$ $P = \frac{\Delta W}{\Delta t}$ $P = Fv$
11.1.10	Conservation of energy	Application of the principle of the conservation of energy to determine whether a collision is elastic or inelastic. Application of the conservation of energy to examples involving gravitational potential energy and kinetic energy Recall and use of $\Delta E_p = mg\Delta h$ Recall and use of $E_k = \frac{1}{2}mv^2$
11.1.11	Calculations involving change of energy	$\Delta Q = mc\Delta\theta$, where c is specific heat capacity $\Delta Q = ml$, where l is specific latent heat

11.2 Molecular kinetic theory model

11.2.1	The equation of state for an ideal gas	Recall and use of $pV = nRT$
11.2.2	The molar gas constant R, The Avogadro constant N_A	Concept of absolute zero of temperature $T \propto$ average kinetic energy of molecules for an ideal gas
11.2.3	Pressure of an ideal gas	Assumptions leading to and derivation of $pV = \frac{1}{3}Nm\overline{c^2}$

11.2.4	Internal energy Relation between temperature and molecular kinetic energy. The Boltzmann constant	Random distribution of energy amongst particles in a body Thermal equilibrium $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT = \frac{3RT}{2N_A}$

12 AS Module 3
Current Electricity and Elastic Properties of Solids

Introduction	This module contains principally simple current electricity including alternating currents and the use of the oscilloscope. Some work on elastic properties of solids is also included. Most of this module consists of material from the AS Criteria for Physics.

12.1 Current electricity

12.1.1	Charge, current, potential difference	Electrical current as the rate of flow of charge Recall and use of $I = \dfrac{\Delta Q}{\Delta t}$ $\quad V = \dfrac{W}{Q}$
	Resistance	Resistance is defined by $R = \dfrac{V}{I}$
12.1.2	Current/voltage characteristics	For an ohmic conductor, a semiconductor diode and a filament lamp Candidates should have experience of the use of a current sensor and a voltage sensor with a datalogger to capture data from which to determine $V - I$ curves
12.1.3	Ohm's law	Ohm's law understood as a special case where $I \propto V$
12.1.4	Resistivity ρ	Recall and use of $\rho = \dfrac{AR}{l}$ Description of the qualitative effect of temperature on the resistance of metal conductors and thermistors. Applications, e.g. temperature sensors
12.1.5	Series and parallel resistor circuits	$R_T = R_1 + R_2 + R_3$ $\quad \dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}$
12.1.6	Energy and power in d.c. circuits	Recall and use of $E = VIt$ $\quad P = VI$ $\quad P = I^2R$ Application, e.g. understanding of high current requirement for a starter motor in a motor car
12.1.7	Kirchhoff's laws	Conservation of charge and energy in simple d.c. circuits The relationships between currents, voltages and resistances in series and parallel circuits; questions will not be set which require the use of simultaneous equations to calculate currents or potential difference
12.1.8	Potential divider	The potential divider used to supply variable p.d. e.g. application as a hi-fi volume control
12.1.9	Electromotive force $\in$ Internal resistance r	$\in = \dfrac{E}{Q}$ $\quad \in = I(R + r)$

12.1.10	Alternating currents	Sinusoidal voltages and currents only; root mean square, peak and peak-to-peak values, for sinusoidal waveforms: $I_{\mathrm{rms}} = \frac{I_0}{\sqrt{2}}$ $\quad V_{\mathrm{rms}} = \frac{V_0}{\sqrt{2}}$ Application to calculation of mains electricity peak and peak-to-peak voltage values
12.1.11	Oscilloscope	Use of an oscilloscope as a d.c. and a.c. voltmeter, to measure time intervals and frequencies, and to display waveforms

12.2 Elastic properties of solids

12.2.1	Bulk properties of solids	Density ρ. Recall and use of $\rho = \frac{m}{V}$ Hooke's law, elastic limit, experimental investigations Tensile strain and tensile stress Elastic strain energy, breaking stress Derivation of $energy\ stored = \frac{1}{2}Fe$ Description of plastic behaviour, fracture and brittleness and interpretation of simple stress-strain curves
12.2.2	The Young modulus	$The\ Young\ modulus = \frac{tensile\ \ stress}{tensile\ \ strain} = \frac{F}{A}\frac{l}{e}$ One simple method of measurement Use of stress-strain graphs to find the Young modulus and strain energy per unit volume

13 A2 Module 4
Waves, Fields and Nuclear Energy

Introduction	This is the first A2 module building on the key ideas and knowledge covered in AS. The properties of waves are covered, gravitational and electric fields are introduced, as are the magnetic effects of currents. Candidates will also study the practical application of nuclear fission as a source of energy.

13.1 Oscillations and Waves

13.1.1	Simple harmonic motion: graphical and analytical treatments	Characteristic features of simple harmonic motion Exchange of potential and kinetic energy in oscillatory motion Understanding and use of the following equations $a = -(2\pi f)^2 x$ $x = A\cos 2\pi ft$ $v = \pm 2\pi f\sqrt{A^2 - x^2}$ Graphical representations linking displacement, velocity, acceleration , time and energy Velocity as gradient of displacement/time graph Simple pendulum and mass-spring as examples and use of the equations $T = 2\pi\sqrt{\frac{l}{g}}$ $T = 2\pi\sqrt{\frac{m}{k}}$ Candidates should have experience of the use of datalogging techniques in analysing mechanical and oscillatory systems
13.1.2	Free and forced vibration	Qualitative treatment of free and forced vibration Resonance and the effects of damping Examples of these effects from more than one branch of Physics e.g. production of sound in a pipe instrument or mechanical vibrations in a moving vehicle
13.1.3	Progressive waves	Oscillation of the particles of the medium Amplitude, frequency, wavelength, speed, phase, path difference Recall and use of $c = f\lambda$
13.1.4	Longitudinal waves and transverse waves	Examples including sound and electromagnetic waves Polarisation as evidence for the nature of transverse waves; applications, e.g. polaroid sunglasses
13.1.5	Superposition of waves, stationary waves	The formation of stationary waves by two waves of the same frequency travelling in opposite directions; no mathematical treatment required Simple graphical representations of stationary waves, nodes and antinodes on strings and in pipes

13.1.6	Interference	The concepts of path difference and coherence Requirements of two source and single source double-slit systems for the production of fringes The appearance of the interference fringes produced by a double slit system. $\lambda = \frac{ws}{D}$
13.1.7	Diffraction	Appearance of the diffraction pattern from a single slit The plane transmission diffraction grating at normal incidence Optical details of the spectrometer will not be required Derivation of $d\sin\theta = n\lambda$ Applications, e.g. to spectral analysis of light from stars

13.2 Capacitance

13.2.1	Capacitance	Recall and use of $C = \frac{Q}{V}$
13.2.2	Energy stored by capacitor	Derivation and use of $E = \frac{1}{2}QV$ and interpretation of area under a graph of charge against p.d.
13.2.3	Graphical representation of charging and discharging of capacitors through resistors	*time constant* $= RC$ Calculation of time constants including their determination from graphical data
13.2.4	Quantitative treatment of capacitor discharge	$Q = Q_0 e^{-t/RC}$ Candidates should have experience of the use of a voltage sensor and datalogger to plot discharge curve for a capacitor

13.3 Gravitational and electric fields

13.3.1	Uniform motion in a circle	$\omega = \frac{v}{r}$ $\quad \omega = 2\pi f$ $\quad a = \frac{v^2}{r} = r\omega^2$ where ω is angular speed
13.3.2	Centripetal force equation	Recall and use of $F = \frac{mv^2}{r}$
13.3.3	Gravity, Newton's law, the gravitational constant G	Recall and use of $F = -\frac{Gm_1m_2}{r^2}$ Methods for measuring G are **not** included
13.3.4	Gravitational field strength g	$g = \frac{F}{m}$ $\quad g = -\frac{GM}{r^2}$ (radial field) $g = -\frac{\Delta V}{\Delta r}$
13.3.5	Gravitational potential V	$V = -\frac{GM}{r}$ (radial field) Graphical representations of variations of g and V with r

13.3.6	Motion of masses in gravitational fields	Circular motion of planets and satellites including geo-synchronous orbits
13.3.7	Coulomb's law, permittivity of free space ε_0	Recall and use of $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$
13.3.8	Electric field strength E	Application, e.g. estimation of forces at closest approach in Rutherford alpha particle scattering $E = \frac{F}{Q}$ $\quad E = \frac{V}{d}$ (uniform field) $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ (radial field)
13.3.9	Electric potential V	$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$
13.3.10	Motion of charged particles in an electric field	Trajectory of particle beams
13.3.11	Similarities and differences between electric and gravitational fields	No quantitative comparisons required

13.4 Magnetic effects of currents

13.4.1	Force on a current carrying wire in a magnetic field	$F = BIl$ (field perpendicular to current)
13.4.2	Motion of charged particles in a magnetic field	$F = BQv$ (field perpendicular to velocity) Circular path of particles; application, e.g. charged particles in a cyclotron
13.4.3	Magnetic flux density B, flux Φ flux linkage $N\,\Phi$	$\Phi = BA$, B normal to A
13.4.4	Electromagnetic induction	Simple experimental phenomena, Faraday's and Lenz's laws For a flux change at a uniform rate $\textit{magnitude of induced e.m.f.} = N\frac{\Delta\Phi}{\Delta t}$ Applications, e.g. p.d. between wing-tips of aircraft in flight

13.5. Nuclear applications

13.5.1	Mass and energy	Simple calculations on nuclear transformations; mass difference; binding energy Atomic mass unit, u Conversion of units; 1u = 931.1 Mev $E = mc^2$ Appreciation that $E = mc^2$ applies to all energy changes Graph of average binding energy per nucleon against nucleon number, A Fission and fusion processes

13.5.2	Induced fission	Induced fission by thermal neutrons Possibility of a chain reaction Critical mass Need for a moderator in thermal reactors Control of the reaction rate Factors influencing choice of material for moderator, control rods and coolant Examples of materials
13.5.3	Safety aspects	Fuel used, shielding, emergency shut-down Production, handling and disposal of active wastes
13.5.4	Artificial transmutation	Production of man-made nuclides and examples of their practical applications, e.g. in medical diagnosis

14 A2 Module 5 *Nuclear Instability*

Introduction	This A2 module builds on the ideas introduced in Module 1. Students will gain knowledge and understanding of the present-day views of the particle nature of matter.

14.1 Nuclear instability

14.1.1 Radioactivity	α, β and γ radiation; their properties and experimental identification; applications, e.g. to relative hazards of exposure to humans The experimental investigation of the inverse square law for γ rays $I = k\dfrac{I_0}{x^2}$ Applications, e.g. to safe handling of radioactive sources Background radiation; its origins and experimental elimination from calculations
14.1.2 Exponential law of decay	Random nature of decay $\dfrac{\Delta N}{\Delta t} = -\lambda N \quad N = N_0 e^{-\lambda t}$ Half-life and decay constant and their determination from graphical decay data $T_{\frac{1}{2}} = \dfrac{\ln 2}{\lambda}$ Applications, e.g. relevance to storage of waste radioactive materials; radioactive dating
14.1.3 Variation of N with Z for stable and unstable nuclei	Graph of N against Z for stable and unstable nuclei
14.1.4 Possible modes of decay of unstable nuclei	α, β^+, β^-, nucleon emission, electron capture Changes of Z and A caused by decay and representation in simple decay equations
14.1.5 Existence of nuclear excited states	γ ray emission Application, e.g. use of technetium–99m as a gamma source in medical diagnosis
14.1.6 Probing matter	Scattering as a means of probing matter, including a qualitative discussion of the choice of bombarding radiation or particle, the physical principles involved in the scattering process, the processing and interpretation of data
14.1.7 Nuclear radius	Estimation of radius from closest approach of alpha particles and determination of radius from electron diffraction; knowledge of typical values Dependence of radius on nucleon number $R = r_o A^{\frac{1}{3}}$ derived from experimental data

15

A2 Module 6A
Astrophysics

In this option, fundamental physical principles are applied to the study and interpretation of the Universe. Students will gain deeper insight into the behaviour of objects at great distances from Earth and discover the ways in which information from these objects can be gathered. The underlying physical principles of the optical and other devices used are covered and some indication given of the new information gained by the use of radio astronomy. Details of particular sources and their mechanisms are not required.

15.1 Lenses and optical telescopes

15.1.1 Lenses

Principal focus, focal length of converging lens

$$power = \frac{1}{f}$$

Formation of images by a converging lens

Ray diagrams

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

15.1.2 Astronomical telescope consisting of two converging lenses

Ray diagram to show the image formation in normal adjustment
Angular magnification in normal adjustment

$$M = \frac{angle\ \ subtended\ \ by\ \ image\ \ at\ \ eye}{angle\ \ subtended\ \ by\ \ object\ \ at\ \ unaided\ \ eye}$$

Focal lengths of the lenses

$$M = \frac{f_o}{f_e}$$

15.1.3 Reflecting telescopes

Focal point of concave mirror
Cassegrain arrangement, ray diagram to show path of rays through the telescope as far as the eyepiece
Relative merits of reflectors and refractors including a qualitative treatment of spherical and chromatic aberration

15.1.4 Resolving power

Appreciation of diffraction pattern produced by circular aperture, Airy disc
Resolving power of telescope, Rayleigh criterion,

$$\theta \approx \frac{\lambda}{D}$$

15.1.5 Charge coupled device

Structure and operation of the charge coupled device

Quantum efficiency of pixel > 70%

15.2 Radio astronomy

15.2.1	Single dish radio telescopes, general principles and resolving power	Similarities with optical telescopes: objective, mirror, detector, $power \propto diameter^2$, tracking of source Differences from optical telescopes: resolving power, limit of resolution $\theta \approx \frac{\lambda}{D}$, need for scanning to build up image Objective diameter, precision of about $\lambda/20$ needed in shape of dish. Use of wire mesh

15.3 Classification of stars

15.3.1	Classification by luminosity	Relation between brightness and apparent magnitude
15.3.2	Apparent magnitude, m	Relation between intensity and apparent magnitude Measurement of m from photographic plates and distinction between photographic and visual magnitude not required
15.3.3	Absolute magnitude, M	Parsec and light year Definition of M, relation to m $m - M = 5 \log \frac{d}{10}$
15.3.4	Classification by temperature, black body radiation	Stefan's law and Wien's displacement law General shape of black body curves, experimental verification is not required Use of Wien's displacement law to estimate black-body temperature of sources $\lambda_{max} T = \text{constant} = 0.0029 \text{ mK}$ Inverse square law, assumptions in its application Use of Stefan's law to estimate area needed for sources to have same power output as the sun $P = \sigma A T^4$ Assumption that a star is a black body Problem of detector response as a function of wavelength and atmospheric effects
15.3.5	Principles of the use of stellar spectral classes	Description of the main classes, O B A F G K M Temperature required: need for excitation Helium absorption (O): need for higher temperature Hydrogen Balmer absorption lines (B, A): need for atoms in $n = 2$ state Metals absorption (F, G): occurs at lower temperature Molecular bands (K, M): occur at lowest temperature
15.3.6	The Hertzsprung-Russell diagram	General shape: main sequence, dwarfs and giants Stellar evolution: path of a star similar to our Sun on the Hertzsprung-Russell diagram from formation to white dwarf

15.3.7	Supernovae, neutron stars and black holes	General properties Calculation of the radius of the event horizon for a black hole Schwarzchild radius (R_s) $R_s \approx \frac{2GM}{c^2}$

15.4 Cosmology

15.4.1	Doppler effect	$\frac{\Delta f}{f} = \frac{v}{c}$ and $\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$ for $v \ll c$ applied to optical and radio frequencies Calculations on binary stars viewed in the plane of orbit
15.4.2	Hubble's law	Red shift $v = Hd$ Simple interpretation as expansion of universe; estimation of age of universe, assuming H is constant Qualitative treatment of Big Bang theory
15.4.3	Quasars	Quasars as the most distant measurable objects Discovery as bright radio sources Controversy concerning distance and power – use of inverse square law Quasars show large optical red shifts; estimation of distance

15 A2 Module 6B
Medical Physics

Introduction	This option offers an opportunity for students with an interest in biological and medical topics to study some of the applications of physical principles and techniques in medicine.

15.5 Physics of the eye and ear

15.5.1	Physics of vision	Simple structure of the eye The eye as an optical refracting system; including ray diagrams of image formation
15.5.2	Sensitivity of the eye	Spectral response as a photodetector
15.5.3	Spatial resolution	Explanation in terms of the behaviour of rods and cones
15.5.4	Persistence of vision	Excluding a physiological explanation
15.5.5	Depth of field	
15.5.6	Lenses	Properties of converging and diverging lenses; principal focus, focal length and power, $\text{power} = \frac{1}{f}$ $\quad \frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ and $\quad m=\frac{v}{u}$
15.5.7	Ray diagrams	Image formation
15.5.8	Defects of vision	Myopia, hypermetropia and astigmatism
15.5.9	Correction of defects of vision using lenses	Ray diagrams and calculations of powers (in dioptres) of correcting lenses for myopia and hypermetropia The format of prescriptions for astigmatism
15.5.10	Physics of hearing	Speed of sound in solid and gaseous media
15.5.11	Acoustic impedance	Definitions of intensity and attenuation
15.5.12	The ear as a sound detection system	Simple structure of the ear, transmission processes
15.5.13	Sensitivity and frequency response	Production and interpretation of equal loudness curves Human perception of relative intensity levels and the need for a logarithmic scale to reflect this
15.5.14	Relative intensity levels of sounds	Measurement of sound intensity levels and the use of dB and dBA scales
15.5.15	The threshold of hearing	$I_0 = 1.0\times10^{-12}\ \text{Wm}^{-2}$ $\textit{intensity level} = 10\log\frac{I}{I_0}$

15.5.16	Defects of hearing	The effect on equal loudness curves and the changes experienced in terms of hearing loss of: injury resulting from exposure to excessive noise; deterioration with age (excluding physiological changes)

15.6 Biological measurement and imaging

15.6.1	Basic structure of the heart	The heart as a double pump with identified valves
15.6.2	Electrical signals and their detection	The biological generation and conduction of electrical signals; methods of detection of electrical signals at the skin surface
15.6.3	Action potentials	The response of the heart to the action potential originating at the sino-atrial node
15.6.4	Simple ECG machines and the normal ECG waveform	Principles of operation for obtaining the ECG waveform; explanation of the characteristic shape of a normal ECG waveform
15.6.5	Ultrasound imaging	Reflection and transmission characteristics of sound waves at tissue boundaries, acoustic impedance Advantages and disadvantages of ultrasound imaging in comparison with alternatives including safety issues and resolution
15.6.6	Piezoelectric devices	Principles of generation and detection of ultrasound pulses
15.6.7	A-scan and B-scan	Examples of applications
15.6.8	Fibre optics and lasers	Properties of fibre optics and applications in medical physics; including total internal reflection at the core-cladding interface
15.6.9	Endoscopy	Physical principles of the optical system of a flexible endoscope; the use of coherent and non-coherent fibre bundles; examples of use for internal imaging and related advantages
15.6.10	Properties of laser radiation	Absorption by tissue
15.6.11	Uses of lasers in medicine	Safety issues
15.6.12	X-ray imaging	The physics of diagnostic X-rays
15.6.13	Physical principles of the production of X-rays	Rotating-anode X-ray tube; methods of controlling the beam intensity, the photon energy, the image sharpness and contrast and the patient dose
15.6.14	Differential tissue absorption of X-rays	Excluding details of the absorption processes
15.6.15	Exponential attenuation	Linear coefficient μ, mass attenuation coefficient μ_m and half-value thickness $I = I_0 e^{-\mu x}$ $\quad \mu_m = \dfrac{\mu}{\rho}$
15.6.16	Image contrast enhancement	Use of X-ray opaque material as illustrated by the barium meal technique
15.6.17	Radiographic image detection	Photographic detection with intensifying screen and fluoroscopic image intensification; reasons for using these

15 A2 Module 6C
Applied Physics

The option offers opportunities for students to reinforce and extend the work of modules PH01, PH02 and PH04 of the previous NEAB syllabus by considering applications in areas of engineering and technology. It embraces rotational dynamics and thermodynamics.

The emphasis should be on an understanding of the concepts and the application of Physics. Questions may be set in novel or unfamiliar contexts, but in all such cases the scene will be set and all relevant information will be given.

15.7 Rotational dynamics

15.7.1 Concept of moment of inertia

$$I = \sum mr^2$$

Expressions for moment of inertia will be given where necessary

15.7.2 Rotational kinetic energy

$$E_k = \tfrac{1}{2} I\omega^2$$

Factors affecting the energy storage capacity of a flywheel
Use of flywheels in machines

15.7.3 Angular displacement, velocity and acceleration

Equations for uniformly accelerated motion:

$$\omega_2 = \omega_1 + \alpha t$$

$$\theta = \omega_1 t + \tfrac{1}{2}\alpha t^2$$

$$\omega_2^2 = \omega_1^2 + 2\alpha\theta$$

$$\theta = \tfrac{1}{2}(\omega_1 + \omega_2)t$$

15.7.4 Torque and angular acceleration

$T = I\alpha$

15.7.5 Angular momentum

$\textit{angular momentum} = I\omega$

Conservation of angular momentum

Angular impulse = change of angular momentum = Tt

15.7.6 Power

$W = T\theta \qquad P = T\omega$

Awareness that, in rotating machinery, frictional couples have to be taken into account

15.8 Thermodynamics and engines

15.8.1 First law of thermodynamics

$$\Delta Q = \Delta U + \Delta W$$

where ΔQ is heat entering the system, ΔU is increase in internal energy and ΔW is work done by the system
At constant pressure $\qquad \Delta W = p\Delta V$

15.8.2 Non-flow processes

Isothermal and adiabatic changes, constant pressure and constant volume changes

$$pV = nRT$$

$$pV^{\gamma} = constant$$

Application of first law of thermodynamics to the above processes

15.8.3 The $p - V$ diagram

Representation of processes on $p - V$ diagram

Estimation of work done in terms of area below the graph

Expressions for work done are not required except for the constant pressure case, $W = p\Delta V$

Extension to cyclic processes:

$$\textit{work done per cycle} = \textit{area of loop}$$

15.8.4 Engine cycles

Understanding of a four-stroke petrol cycle and a Diesel engine cycle, and of the corresponding indicator diagrams; comparison with the theoretical diagrams for these cycles; a knowledge of engine constructional details is not required; where questions are set on other cycles, they will be interpretative and all essential information will be given; indicator diagrams predicting and measuring power and efficiency

$$\textit{input power} = \textit{calorific value} \times \textit{fuel flow rate}$$

Indicated power as

$$(\textit{area of } p - V \textit{ loop}) \times (\textit{no. of cycles/s}) \times (\textit{no. of cylinders})$$

Output or brake power $\qquad P = T\omega$

$$\textit{friction power} = \textit{indicated power} - \textit{brake power}$$

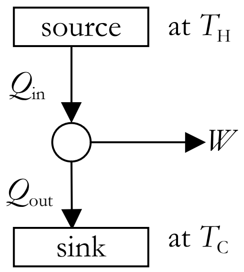
Engine efficiency; overall, thermal and mechanical efficiencies

15.8.5 Second Law and engines

Need for an engine to operate between a source and a sink

$$\textit{efficiency} = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$$

$$\textit{maximum theoretical efficiency} = \frac{T_H - T_C}{T_H}$$



Reasons for the lower efficiencies of practical engines

15 A2 Module 6D
Turning Points in Physics

This option is intended to enable key developments in Physics to be studied in depth so that students can appreciate, from a historical viewpoint, the significance of major conceptual shifts in the subject both in terms of the understanding of the subject and in terms of its experimental basis. Many present day technological industries are the consequence of such key developments and the topics illustrate how unforeseen technologies develop from new discoveries.

15.9 The Discovery of the electron

15.9.1	Cathode rays	Production of cathode rays in a discharge tube
15.9.2	Thermionic emission of electrons	The principle of thermionic emission Work done on an electron accelerated through a p.d. $\frac{1}{2}mv^2 = eV$
15.9.3	Determination of the specific charge of an electron, e/m, by any one method	Significance of Thomson's determination of e/m Comparison with the specific charge of the hydrogen ion
15.9.4	Principle of Millikan's determination of e	Condition for holding a charged oil droplet stationary between oppositely charged parallel plates $\frac{eV}{d} = mg$ Motion of a falling oil droplet with and without an electric field; terminal speed, Stokes' Law for the viscous force on an oil droplet used to calculate the droplet radius $F = 6\pi\eta rv$
15.9.5	Significance of Millikan's results	Quantisation of electric charge

15.10 Wave particle duality

15.10.1	Newton's corpuscular theory of light	Comparison with Huygens' wave theory in general terms The reasons why Newton's theory was preferred
15.10.2	Significance of Young's double slits experiment	Explanation for fringes in general terms, no calculations are expected Delayed acceptance of Huygens' wave theory of light
15.10.3	Electromagnetic waves	Nature of electromagnetic waves Maxwell's formula for the speed of electromagnetic waves in a vacuum $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ Hertz's discovery of radio waves
15.10.4	The discovery of photoelectricity	The failure of classical wave theory to explain photoelectricity The significance of Einstein's explanation of photoelectricity

15.10.5	Wave particle duality	de Broglie's hypothesis supported by electron diffraction experiments $p = \frac{h}{\lambda}$ $\lambda = \frac{h}{\sqrt{2meV}}$
15.10.6	Electron microscopes	Estimate of anode voltage needed to produce wavelengths of the order of the size of the atom Principle of operation of the transmission electron microscope (T.E.M.) Principle of operation of the scanning tunnelling microscope (S.T.M.)

15.11 Special relativity

15.11.1	The Michelson-Morley experiment	Principle of the Michelson-Morley interferometer Outline of the experiment as a means of detecting absolute motion Significance of the failure to detect absolute motion The invariance of the speed of light
15.11.2	Einstein's theory of special relativity	The concept of an inertial frame of reference The two postulates of Einstein's theory of special relativity: (i) physical laws have the same form in all inertial frames, (ii) the speed of light in free space is invariant
15.11.3	Time dilation	Proper time and time dilation as a consequence of special relativity Time dilation $t = t_0\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}$ Evidence for time dilation from muon decay
15.11.4	Length contraction	Length of an object having a speed v $l = l_0\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}}$
15.11.5	Mass and energy	Equivalence of mass and energy $E = mc^2$ $E = \frac{m_0c^2}{\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}}}$

15 A2 Module 6E *Electronics*

15.12 Basic electrical principles

15.12.1 Measurement of current, voltage and resistance	Multimeters: digital and analogue, relative advantages and disadvantages
15.12.2 Impedance	$Z = \dfrac{V_{\mathrm{rms}}}{I_{\mathrm{rms}}}$

15.13 Capacitors

15.13 Capacitors	Maximum working voltage, temperature coefficient, polarisation and leakage current Use of data sheets
15.13.1 Different types of capacitors	Relative advantages and disadvantages
15.13.2 Capacitors in series and in parallel	$\dfrac{1}{C_{\mathrm{T}}} = \dfrac{1}{C_1} + \dfrac{1}{C_2}$ and $C_{\mathrm{T}} = C_1 + C_2$
15.13.3 Charging and discharging, time constant	5*RC* as a measure of the time taken to charge and to discharge completely
15.13.4 Capacitative reactance	Sinusoidal waveforms only Calculation of reactance defined as $X_{\mathrm{C}} = \dfrac{1}{2\pi fC}$ Awareness of its variation with frequency Sketch graph showing the variation of X_{C} with frequency
15.13.5 RC filters	Simple *RC* filters treated as a frequency dependent voltage divider
15.13.6 Square waveforms	Pulsed waveforms applied to simple *RC* circuits Effect of the time constant on the output waveform
15.13.7 Oscilloscope	Vertical sensitivity settings and time base settings Interpretation of a wave trace on an oscilloscope in terms of period, frequency and amplitude Use of the wave trace, determinations of period and frequency Use of oscilloscope, determinations of I and V
15.13.8 Rectification	Half-wave and full-wave rectification Bridge rectifier Choice of suitable diodes from specifications
15.13.9 Capacitative smoothing	Effect of a capacitor on output waveform from a bridge rectifier Dependence of ripple voltage and current on capacitance

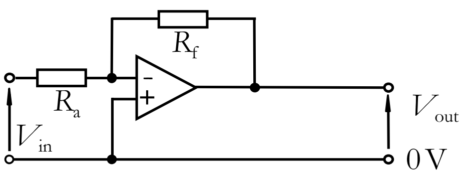
15.14 Devices

15.14.1 Data sheets	Use and interpretation of data sheets for the components listed below
15.14.2 Diodes, zener diodes	Characteristics, including forward voltage drop (0.7 V), maximum forward current and reverse breakdown voltage Regulation of an output voltage by a zener diode

15.14.3	LEDs, photodiodes	Characteristics of LEDs Forward voltage drop and reverse breakdown voltage Calculation of value of series resistor
15.14.4	Junction transistors used as switches	
15.14.5	Resistive transducers	
15.14.6	LDR, negative temperature coefficient thermistors	Characteristic curves Use in bridge circuit and potential dividers
15.14.7	Electromagnetic relay	Construction details not required NO and NC notation Circuit protection by a diode in parallel with a relay

15.15 Analogue electronics

15.15.1	Amplifiers	Voltage gain and phase relationship between input and output voltages
15.15.2	Bandwidth	In terms of voltage gain and power Input and output impedances
15.15.3	Feedback	
15.15.4	Positive feedback	Instability and oscillation (qualitative treatment only)
15.15.5	Negative feedback	Effect on amplification and frequency response
15.15.6	Operational amplifier	Characteristics of ideal operational amplifier Open-loop gain and variation of gain with frequency Inverting and non-inverting inputs Output saturation
15.15.7	The operational amplifier as a voltage comparator	Use in bridge circuits
15.15.8	Negative feedback amplifiers	

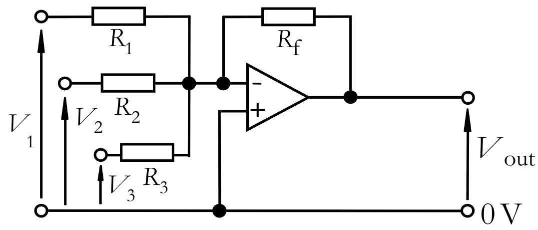


Candidates should be able to use

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_a}$$

15.16 Summing non-inverting amplifier

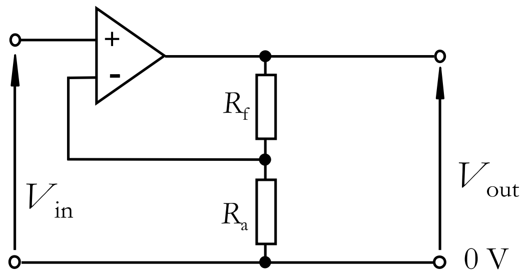
Summing amplifier



Candidates should be able to use

$$V_{out} = -R_f\left[\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}\right]$$

Non-inverting amplifier



Candidates should be able to use

$$\frac{V_{out}}{V_{in}}=1+\frac{R_f}{R_a}$$

Key Skills and Other Issues

16 Key Skills – Teaching, Developing and Providing Opportunities for Generating Evidence

16.1 Introduction

The Key Skills Qualification requires candidates to demonstrate levels of achievement in the Key Skills of *Application of Number*, *Communication* and *Information Technology*.

The units for the 'wider' Key Skills of *Improving own Learning and Performance*, *Working with Others* and *Problem-Solving* are also available. The acquisition and demonstration of ability in these 'wider' Key Skills is deemed highly desirable for all candidates, but they do not form part of the Key Skills Qualification.

Copies of the Key Skills Units may be downloaded from the QCA web site (http://www.qca.org.uk/keyskills)
The units for each Key Skill comprise three sections:

A. What you need to know
B. What you must do
C. Guidance

Candidates following a course of study based on this specification for Physics can be offered opportunities to develop and generate evidence of attainment in aspects of the Key Skills of *Application of Number, Communication, Information Technology, Improving own Learning and Performance, Working with Others and Problem Solving.* Areas of study and learning that can be used to encourage the acquisition and use of Key Skills, and to provide opportunities to generate evidence for Part B of the units, are signposted below. More specific guidance on integrating the delivery of Key Skills in courses based upon this specification is given in the AQA specification support material.

16.2 Key Skills Opportunities in Physics A

The broad and multi-disciplinary nature of Physics, that calls upon candidates' abilities to demonstrate the transferability of their knowledge, understanding and skills, make it an ideal vehicle to assist candidates to develop their knowledge and understanding of the Key Skills and to produce evidence of their application. The matrices below signpost the opportunities for the acquisition, development and production of evidence for Part B of the six Key Skills units at ***Level 3***, in the teaching and learning modules of this specification. The degree of opportunity in any one module will depend upon a number of centre-specific factors, including teaching strategies and level of resources.

Communication

What you must do:	**Signposting of Opportunities for Generating Evidence in Modules**					
	1	**2**	**3**	**4**	**5**	**6**
C3.1a Contribute to discussions	✓	✓	✓	✓	✓	✓
C3.1b Make a presentation	✓	✓	✓	✓	✓	✓
C3.2 Read and synthesise information	✓	✓	✓	✓	✓	✓
C3.3 Write different types of documents	✓	✓	✓	✓	✓	✓

Application of Number

What you must do:	**Signposting of Opportunities for Generating Evidence in Modules**					
	1	**2**	**3**	**4**	**5**	**6**
N3.1 Plan and interpret information from different sources	✓	✓	✓	✓	✓	✓
N3.2 Carry out multi-stage calculations	✓	✓	✓	✓	✓	✓
N3.3 Present findings, explain results and justify choice of methods	✓	✓	✓	✓	✓	✓

Information Technology

What you must do:	**Signposting of Opportunities for Generating Evidence in Modules**					
	1	**2**	**3**	**4**	**5**	**6**
IT3.1 Plan and use different sources to search for and select information	✓	✓	✓	✓	✓	✓
IT3.2 Explore, develop and exchange information, and derive new information	✓	✓	✓	✓	✓	✓
IT3.3 Present information including text, numbers and images			✓		✓	

Working with Others

What you must do	Signposting of Opportunities for Generating Evidence in Modules					
	1	2	3	4	5	6
WO3.1 Plan the activity			✓		✓	
WO3.2 Work towards agreed objectives			✓		✓	
WO3.3 Review the activity			✓		✓	

Improving own Learning and Performance

What you must do	Signposting of Opportunities for Generating Evidence in Modules					
	1	2	3	4	5	6
LP3.1 Agree and plan targets			✓		✓	
LP3.2 Seek feedback and support			✓		✓	
LP3.3 Review progress			✓		✓	

Problem Solving

What you must do	Signposting of Opportunities for Generating Evidence in Modules					
	1	2	3	4	5	6
PS3.1 Recognise, explain and describe the problem			✓		✓	
PS3.2 Generate and compare different ways of solving problems			✓		✓	
PS3.3 Plan and implement options			✓		✓	
PS3.4 Agree and review approaches to tackling problems			✓		✓	

NB The signposting in the six tables above, represents the opportunities to acquire and produce evidence of the Key Skills which are possible through this specification. There may be other opportunities to achieve these and other aspects of Key Skills via this specification, but such opportunities are dependent on the detailed course of study delivered within centres.

16.3 Key Skills in the Assessment of Physics A

Physics Specification A may contribute to the assessment of the Key Skills of *Application of Number* and Communication. *Communication* is an intrinsic part of all Assessment Objectives. Aspects of *Application of Number* will form an intrinsic part of the assessment requirements for all modules. Both Key Skills will form part of the assessment for Units 1, 2, 3, 4, 5, 6.

16.4 Further Guidance

More specific guidance and examples of tasks that can provide evidence of single or composite tasks that can provide evidence of more than one Key Skill are given in the AQA specification support material.

17 Spiritual, Moral, Ethical, Social, Cultural and Other Issues

17.1 Spiritual, Moral, Ethical, Social and Cultural Issues

The general philosophy of the subject is rooted in an ethical approach, in particular to the social, economic, moral and cultural effects of advances in this branch of science.

The following sections of the specification may be particularly apposite for analysis and discussion of spiritual, moral, ethical, social and cultural issues:

- implication of nuclear power, nuclear waste and environmental effects (Module 4);
- production of man-made nuclides (Module 4);
- nuclear fuel reprocessing (Module 4);
- the study of cosmology and the Big Bang theory (Module 6A – Astrophysics);
- determination of charge of electron, quantum theory and relativity (Module 6D – Turning Points in Physics).

17.2 European Dimension

AQA has taken account of the 1988 Resolution of the Council of the European Community in preparing this specification and associated specimen papers. The specification is designed to improve candidates' knowledge and understanding of the international debates surrounding developments in Physics and to foster responsible attitudes to them.

17.3 Environmental Education

AQA has taken account of the 1988 Resolution of the Council of the European Community and the Report *"Environmental Responsibility: An Agenda for Further and Higher Education"* 1993 in preparing this specification and associated specimen papers. The study of Physics as described in this specification can encourage a responsible attitude towards the environment.

17.4 Avoidance of Bias

AQA has taken great care in the preparation of this specification and associated specimen papers to avoid bias of any kind.

17.5 Terminology

Questions will be set in SI units. It will be assumed that candidates are familiar with the electron volt and the atomic mass unit. Whenever letter symbols, signs and abbreviations are used they will follow the recommendations in the ASE booklet *Signs Symbols and Systematics* (published 1995).

Questions may be set on the use of any units in the specification.

17.6 Health and Safety

AQA recognises the need for safe practice in laboratories and tries to ensure that experimental work required for this specification and associated examination papers complies with up-to-date safety recommendations.

Nevertheless, centres are primarily responsible for the safety of candidates and teachers should carry out their own risk assessment.

17.7 Mathematical Requirements

In order to be able to develop the knowledge, understanding and skills, candidates need to have been taught and to have acquired competence in the areas of mathematics set out below. Material given in bold type is for A level only.

Arithmetic and computation

Students should be able to:

- recognise and use expressions in decimal and standard form;
- use ratios, fractions and percentages;
- use calculators to find and use $x^n, \frac{1}{x}, \sqrt{x}, \log_{10} x, e^x$ ln, x
- use calculators to handle $\sin x, \cos x, \tan x$ when x is expressed in degrees or **radians**.

Handling Data

Students should be able to:

- make order of magnitude calculations;
- use an appropriate number of significant figures;
- find arithmetic means.

Algebra

Students should be able to:

- change the subject of an equation by manipulation of the terms, including positive, negative, integer and fractional indices;
- solve simple algebraic equations;
- substitute numerical values into algebraic equations using appropriate units for physical quantities;
- understand and use the symbols: $=, <, >, \ll, \gg, \propto, \approx$.

Geometry and Trigonometry

Students should be able to:

- calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres;
- use Pythagoras' theorem, and the angle sum of a triangle;
- use sines, cosines and tangents in physical problems;
- **understand the relationship between degrees and radians and translate from one to the other.**

Graphs

Students should be able to:

- translate information between graphical, numerical and algebraic forms;
- plot two variables from experimental or other data;
- understand that $y = mx + c$ represents a linear relationship;
- determine the slope and intercept of a linear graph;
- draw and use the slope of a tangent to a curve as a measure of rate of change;
- understand the possible physical significance of the area between a curve and the x axis and be able to calculate it or measure it by counting squares as appropriate;

- **use logarithmic plots to test exponential and power law variations;**
- **sketch simple functions including**

$y = \frac{k}{x}$, $y = kx^2$, $y = \frac{k}{x^2}$, $y = \sin x$, $y = \cos x$, $y = e^{-kx}$;

Vectors

Students should be able to

- find the resultant of two coplanar vectors;
- resolve a vector in two perpendicular directions.

17.8 Data and equations

Each candidate will be provided with a data sheet (Appendix D), a copy of which will be printed at the beginning of each assessment unit written paper. Except for barred equations and relationships (see 17.10), equations will either be provided on the data sheet or given in the question.

In order to achieve a proper understanding of the Physics involved it is expected that candidates will derive many of the equations during the course but questions requiring derivations will be set only for those equations so specified in the specification.

17.9 Calculators

It is assumed that candidates will have the use of calculators which have at least the functions of addition (+), subtraction (–), multiplication (×), division (÷), square root (√), sine, cosine, tangent, natural logarithms and their inverses, and a memory.

17.10 Barred relationships

The following formulae for relationships between physical quantities cannot be provided for AS and A level candidates and they should therefore know them by heart.

(i) the relationship between speed, distance and time:

$$\textit{speed} = \frac{\textit{distance}}{\textit{time taken}}$$

(ii) the relationship between force, mass and acceleration:

$$\textit{force} = \textit{mass} \times \textit{acceleration} \qquad F = ma$$

$$\textit{acceleration} = \frac{\textit{change in velocity}}{\textit{time taken}}$$

(iii) the relationship between density, mass and volume:

$$\textit{density} = \frac{\textit{mass}}{\textit{volume}}$$

(iv) the concept of momentum and its conservation:

$$\textit{momentum} = \textit{mass} \times \textit{velocity} \qquad p = mv$$

(v) the relationship between force, distance, work, power and time:

$$work\ done = force \times distance\ moved\ in\ direction\ of\ force$$

$$power = \frac{energy\ transfered}{time\ taken} = \frac{work\ done}{time\ taken}$$

(vi) the relationships between mass, weight, potential energy and kinetic energy:

$$weight = mass \times gravitational\ field\ strength$$

$$kinetic\ energy = \tfrac{1}{2} \times mass \times speed^2$$

$$change\ in\ potential\ energy = mass \times gravitational\ field\ strength \times change\ in\ height$$

(vii) the relationship between an applied force, the area over which it acts and the resulting pressure:

$$pressure = \frac{force}{area}$$

(viii) the Gas Law:

$$pressure \times volume = number\ of\ moles \times molar\ gas\ constant \times absolute\ temperature$$

$$pV = nRT$$

(ix) the relationships between charge, current, potential difference, resistance and electrical power:

$charge = current \times time$ $\quad \Delta Q = I\Delta t$

$potential\ difference = current \times resistance$ $\quad V = IR$

$electrical\ power = potential\ difference \times current$ $\quad P = VI$

(x) the relationship between potential difference, energy and charge:

$$potential\ difference = \frac{energy\ transfered}{charge} \qquad V = \frac{W}{Q}$$

(xi) the relationship between resistance and resistivity:

$$resistance = \frac{resistivity \times length}{cross\ sectional\ area} \qquad R = \frac{\rho l}{A}$$

(xii) the relationship between charge flow and energy and energy transfer in a circuit:

$energy = potential\ difference \times current \times time$ $\quad E = VIt$

(xiii) the relationship between speed, frequency and wavelength:

$wave\ speed = frequency \times wavelength$ $\quad v = f\lambda$

(xiv) the relationship between centripetal force, mass, speed and radius:

$$centripetal\ force = \frac{mass \times speed^2}{radius} \qquad F = \frac{mv^2}{r}$$

(xv) the inverse square laws for force in radial electric and gravitational fields:

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2} \qquad F = -\frac{Gm_1m_2}{r^2}$$

(xvi) the relationship between capacitance, charge and potential difference:

$$\textit{capacitance} = \frac{\textit{charge stored}}{\textit{potential difference}} \qquad C = \frac{Q}{V}$$

(xvii) relationship between the potential difference across the coils in a transformer and the number of turns in them:

$$\frac{\textit{potential difference across coil 1}}{\textit{potential difference across coil 2}} = \frac{\textit{number of turns in coil 1}}{\textit{number of turns in coil 2}} \qquad \frac{V_1}{V_2} = \frac{N_1}{N_2}$$

Centre-Assessed Component

18 Nature of Centre-Assessed Component

18.1 Introduction

Within the Scheme of Assessment, the optional coursework elements are alternatives within parts of each of Unit 3 of the AS and Unit 5 of the A2. Coursework (Unit 3) contributes 15% of the AS and, together with the coursework in Unit 5, contributes 12½% of the A level.

The skills comprising the coursework components are as follows:

A Planning
B Implementing
C Analysing evidence and drawing conclusions
D Evaluating evidence and procedures

It is intended that the internal assessment of candidates' performance in the four skills is made during normal coursework activity and should, therefore, be an integral part of the scheme of work for both the AS and the A2. It is a continuous process and not separate or additional to the normal teaching programme. It is important therefore that the teaching programme should include activities designed to develop the skills and that assessments should arise naturally from coursework activities rather than from a series of practical tasks.

18.2 Relationship of Coursework Skills to Assessment Objectives

Experiment and Investigation AO3	AS	A2	Total in A Level
	15%	10%	12½%

18.3 Subject Content

Coursework for AS must be based on the subject content for AS; coursework for A2 must be based on the Subject Content for A2.

18.4 Early Notification

Centres must advise AQA of their intention to enter candidates using Form A (Early Information) so that early contact can be made with new centres.

19 Guidance on Setting Centre-Assessed Component

It is important that teachers consider carefully the types of activities which will provide valid evidence of positive achievement for the purpose of assessment. The activities in which candidates are involved should be chosen to make reasonable demands and to enable positive achievements to be demonstrated in relation to the assessment criteria.

Guidance on suitable activities is available on request from AQA. Centres which require advice as to whether their proposed activities are appropriate should contact AQA.

AQA does not intend to specify the number, type and length of activities. Individual activities will depend on the scheme of work adopted by an individual centre. However, it is expected that the range of assessment activities will reflect and emphasise the scientific approach to the study of the subject content of the AS and the A2 specification. The links between the coursework skills and the knowledge, skills and understanding described in the subject content are fundamental in designing the activities.

20 Assessment Criteria

20.1 Introduction

Marks should be awarded for the four skills listed below for both the AS and the A2. Standards are set by the use of mark criteria which describe the performance for a particular mark in each skill area. The marks submitted to AQA should be awarded using only the scales defined by the mark criteria printed in Section 20.2 of this specification.

The skills comprising the coursework components are as follows:

A Planning
B Implementing
C Analysing evidence and drawing conclusions
D Evaluating evidence and procedures

The same criteria should be applied at both AS and A2 level. Some evidence of attainment is, however, not required for AS. In such cases, it will be indicated that only A2 candidates need demonstrate evidence. Each skill should be assessed in the context of a complete activity but each skill need not be assessed in every activity. This allows for the assessment of *planning* in an activity such as spectroscopy or particle Physics where it is not possible actually to implement the plan in most centres.

The assessment criteria allow the four skills to be assessed individually or for them to be assessed together. It is important to note that not all candidates need to be assessed on any one activity. Where more than one skill is assessed in one activity, care must be taken to ensure that a candidate's performance in one skill does not adversely affect the performance in another.

20.2 Criteria for each skill area

A Planning

2 marks

The candidate can:

suggest an appropriate experimental plan with some relevant procedures.

The following evidence will be present:

- **a.** an outline plan or testable hypothesis
- **b.** a sketch or partial diagram of the practical set-up
- **c.** consideration of safety aspects of the plan
- **d.** a list of some appropriate apparatus.

4 marks

The candidate can:

design a plan for the investigation or problem to be solved and outline most (if not all) of the appropriate procedures.

The following evidence will be present:

- **a.** a detailed plan or testable hypothesis
- **b.** identification of an appropriate variable
- **c.** a labelled diagram of the full practical set-up and/or a circuit diagram (where appropriate)
- **d.** a comprehensive list of apparatus.

6 marks

The candidate can:

design a plan for the investigation or problem to be solved, outlining the appropriate experimental procedures in a sensible sequence.

The following evidence will be present:

a. identification of variable to be kept constant
b. number and range of readings to be taken
c. logical sequence of readings to be taken
d. full instrument or apparatus specification. (e.g. instrument ranges)

8 marks

The candidate can:

design a plan for the investigation or problem to be solved, outlining clearly and succinctly the appropriate experimental procedures and providing sound reasons for design choices.

The following evidence will be present:

a. at least one reason for procedures based on evidence of knowledge and understanding (e.g. why range / number / sequence of readings should give good/more accurate results)
b. justification for design based on supporting theory (e.g. supporting formulae or calculations)
c. aspects of the plan based on reasoned predictions (A2 only)
d. use of relevant information from secondary sources or preliminary work (A2 only).

B Implementing

2 marks

The candidate can:

make and record some units given correctly.

The following evidence will be present:

a. demonstration of the safe and correct use of some equipment
b. some appropriate readings or observations made
c. some readings or observations recorded
d. two or more correct units used.

4 marks

The candidate can:

make and record an adequate number of appropriate measurements correctly, with most units given correctly, including the repeat of measurements where appropriate.

The following evidence will be present:

a. all equipment used safely and correctly
b. majority of readings accurate and appropriately recorded
c. sufficient readings taken including, where appropriate, repeat readings
d. all units correct (except occasional omissions).

6 marks

The candidate can:

meet the criteria for 4 marks above with measurements made to a suitable degree of precision within the limits set by the apparatus, identify significant source(s) of error.

The following evidence will be present:

a. readings given to appropriate number of significant figures
b. readings taken with suitable precision
c. clear, organised and accurate presentation of results and observations
d. identification of significant source(s) of error.

8 marks

The candidate can:

meet the criteria for 6 marks above and discuss appropriate ways to minimise experimental error, and where possible, implement these.

The following evidence will be present:

a. description of action proposed to minimise errors
b. implementation of plan to minimise errors where possible (A2 only).
c. checks of readings or observations which appear to be inconsistent or suspect (A2 only)
d. calculation of mean values of repeat readings.

C Analysing Evidence and Drawing Conclusions

2 marks

The candidate can:

produce a report of the major aspects of the investigation in a logical sequence, tabulate results as appropriate and process data in preparation for analysis by graphical or other methods of interpretation.

The following evidence will be present:

a. record of major aspects of the investigation including observations and raw data
b. demonstration of the use of the equations and/or some calculations
c. tabulated processed data and/or organised observations
d. some awareness of how to analyse data or observations (e.g. intention to draw a graph).

4 marks

The candidate can:

meet the criteria for 2 marks above and, in addition, correctly use scientific conventions, including table headings, graph headings and axes, diagrams, labels and significant figures and produce appropriate graph(s).

The following evidence will be present:

a. data and/or observations processed and organised in a logical sequence
b. data presented in appropriate tables with correct headings and units
c. appropriate graphs drawn with correct headings and labelled axes
d. accurate plotting of points on a graph.

6 marks

The candidate can:

interpret processed data by finding the gradient or intercept of a graph and reach a valid conclusion consistent with the data obtained.

The following evidence will be available:

a. best fit line (or curve) drawn

b. large Δy and Δx shown

c. correct values read and recorded from graph

d. $\Delta y/\Delta x$ calculated or intercept read or formula manipulation.

8 marks

The candidate can:

analyse and interpret the results and explain how these support or contradict the original prediction or expectation (when one has been made) and/or explain clearly and succinctly the results in the light of established knowledge and theory, drawing a reasoned conclusion about the whole investigation.

The following evidence will be available:

a. statement of established theory or knowledge relating to the investigation

b. reasoned conclusion or statement about the outcome of the investigation

c. final numerical value, relationship with correct significant figures and units where appropriate

d. explanation of how the results support or contradict the original prediction or expected outcome and established theory or knowledge (A2 only).

D Evaluating Evidence and Procedures

2 marks

The candidate can:

identify some possible sources of errors and anomalies in the experimental evidence and data.

The following evidence will be available:

a. possible sources of errors

b. observations about discrepancies or anomalies in the experimental data

c. variation in repeat readings or repeated observations indicating an uncertainty in the data

d. comment on discrepancies between expected results or outcomes and the experimental evidence.

4 marks

The candidate can:

identify the most significant (or error-sensitive) measurements, make reasonable estimates of the errors in all measurements; use these to assess the suitability of the techniques used and the reliability of the conclusions drawn.

The following evidence will be available:

a. identification of the most significant measurement(s) (e.g. a value to be squared in processing or the measurement of a very small quantity)
b. estimate of error of uncertainty in all measurements based on experimental data or evidence
c. comment on the suitability of the techniques used
d. comment on the reliability of the conclusions drawn.

6 marks

The candidate can:

identify possible sources of systematic errors and assess the implications of these for the reliability of the outcome of the investigation; discuss clearly and succinctly appropriate ways to minimise experimental error and, where possible, how to implement these and hence improve reliability of final "answer" or conclusions.

The following evidence will be available:

a. identification of possible sources of systematic errors in addition to the identified random errors
b. critical analysis of techniques used and associated errors and suggestions for improvement in experimental plan or technique(s) to minimise errors (A2 only)
c. critical assessment of reliability of conclusions and/or final quantitative "answer" in the light of error-estimates and critical analysis of experimental technique(s) (A2 only)
d. proposals for improvements, or further work, to provide additional or more reliable evidence for the conclusion or to extend the investigation in a different or potentially more successful direction.

20.3 Evidence to Support the Award of Marks

The precise evidence to be presented to support the award of marks under each mark band for each skill is given in Paragraph 20.2 above

Coursework must be presented in a clear and helpful form for the moderator. It must be annotated to identify, as precisely as possible, where in the work the relevant assessment criteria have been met so that the reasons why marks have been awarded are clear.

An indication must also be given at the appropriate part in the work of any further guidance given by the teacher which has significant assessment implications.

The work must contain a completed Candidate Record Form, a Coursework Cover Sheet and a Candidate Record of Supervision Form. (See Appendix B)

21 Supervision and Authentication

21.1 Supervision of Candidates' Work

Candidates' work for assessment must be undertaken under conditions which allow the teacher to supervise the work and enable the work to be authenticated. As much work as possible must be conducted in the laboratory under the direct supervision of the teacher. If it is necessary for some assessed work to be done outside the centre, sufficient work must take place under direct supervision to allow the teacher to authenticate each candidate's whole work with confidence.

21.2 Guidance by the Teacher

The work assessed must be solely that of the candidate concerned. Any assistance given to an individual candidate which is beyond that given to the group as a whole must be recorded on the Coursework Cover Sheet.

It is acceptable for parts of a candidate's coursework to be taken from other sources provided they are clearly indicated in the test and acknowledged on the Coursework Cover Sheet

21.3 Unfair Practice

At the start of the course, the supervising teacher is responsible for informing candidates of the AQA Regulations concerning malpractice. Candidates must not take part in any unfair practice in the preparation of coursework to be submitted for assessment, and must understand that to present material copied directly from books or other sources without acknowledgement will be regarded as deliberate deception. Centres must report suspected malpractice to AQA. The penalties for malpractice are set out in the AQA Regulations.

21.4 Authentication of Candidates' Work

Both the candidate (on the Candidate Cover Sheet) and the teacher(s) (on the Centre Declaration Sheet) are required to sign declarations, confirming that the work submitted for assessment is the candidate's own. The teacher declares that the work was conducted under the specified conditions, and requires the teacher to record details of any additional assistance.

22 Standardisation

22.1 Annual Standardisation Meetings

Annual standardisation meetings will usually be held in the autumn term. Centres entering candidates for the first time must send a representative to the meetings. Attendance is also mandatory in the following cases:

- where there has been a serious misinterpretation of the specification requirements;
- where the nature of coursework tasks set by a centre has been inappropriate;
- where a significant adjustment has been made to a centre's marks in the previous year's examination.

Otherwise attendance is at the discretion of centres. At these meetings support will be provided for centres in the development of appropriate coursework tasks and assessment procedures.

22.2 Internal Standardisation of Marking

The centre is required to standardise the assessments across different teachers and teaching groups to ensure that all candidates at the centre have been judged against the same standards. If two or more teachers are involved in marking a component, one teacher must be designated as responsible for internal standardisation. Common pieces of work must be marked on a trial basis and differences between assessments discussed at a training session in which all teachers involved must participate. The teacher responsible for standardising the marking must ensure that the training includes the use of reference and archive materials such as work from a previous year or examples provided by AQA. The centre is required to send to the moderator a signed Centre Declaration Sheet confirming that the marking of centre-assessed work at the centre has been standardised. If only one teacher has undertaken the marking, that person must sign this form.

23 Administrative Procedures

23.1 Recording Assessments

The candidates' work must be marked according to the assessment criteria set out in Section 20.2. Teachers should keep records of their assessments during the course in a form which facilitates the complete and accurate submission of the final overall assessments at the end of the course.

The candidate's records of coursework carried out for the purposes of assessment are to be kept in a loose-leaf A4 size folder. These records are to be prefaced by a Coursework Cover Sheet. A sample of these records will be requested from each centre to assist in the moderation process. They should be available on request to the moderator.

At the beginning of the course, centres must inform AQA on Form A (Early Information) of the approximate number of candidates to be entered for the examination so that the appropriate number of Coursework Cover Sheets and other forms may be sent.

23.2 Submitting Marks and Sample Work for Moderation

The total component mark for each candidate must be submitted to AQA on the mark sheets provided or by Electronic Data Interchange (EDI) by the specified date. Centres will be informed which candidates' work is required in the samples to be submitted to the moderator.

23.3 Problems with Individual Candidates

Teachers should be able to accommodate the occasional absence of candidates by ensuring that the opportunity is given for them to make up missed assessments.

Special consideration should be requested for candidates whose work has been affected by illness or other exceptional circumstances. Information about the procedure is issued separately. Details are available from AQA and centres should ask for a copy of *Candidates with Special Assessment Needs, Special Arrangements and Special Consideration: Regulations and Guidance.*

If work is lost, AQA should be notified immediately of the date of the loss, how it occurred, and who was responsible for the loss. AQA will advise on the procedures to be followed in such cases.

Where special help which goes beyond normal learning support is given, AQA must be informed so that such help can be taken into account when assessment and moderation take place.

Candidates who move from one centre to another during the course sometimes present a problem for a scheme of internal assessment. Possible courses of action depend on the stage at which the move takes place. If the move occurs early in the course the new centre should take responsibility for assessment. If it occurs late in the course it may be possible to accept the assessments made at the previous centre. Centres should contact AQA at the earliest possible stage for advice about appropriate arrangements in individual cases.

23.4 Retaining Evidence and Re–using Marks

The centre must retain the work of all candidates, with Coursework Cover Sheets attached, under secure conditions, from the time it is assessed, to allow for the possibility of an enquiry upon results. The work may be returned to candidates after the issue of results provided that no enquiry upon result is to be made which will include re-moderation of the coursework component. If an enquiry upon result is to be made, the work must remain under secure conditions until requested by AQA.

Candidates repeating the examination may carry forward their moderated mark for the coursework component once only and within a 12-month period.

24 Moderation

24.1 Moderation Procedures

Moderation of the coursework is by inspection of a sample of candidates' work, sent by post from the centre to a moderator appointed by AQA. The centre marks must be submitted to AQA and the sample of work must reach the moderator by (to be confirmed) in the year in which the qualification is awarded.

Following the re-marking of the sample work, the moderator's marks are compared with the centre marks to determine whether any adjustment is needed in order to bring the centre's assessments into line with standards generally. In some cases it may be necessary for the moderator to call for the work of other candidates. In order to meet this possible request, centres must have available the coursework and Coursework Cover Sheet of every candidate entered for the examination and be prepared to submit it on demand. Mark adjustments will normally preserve the centre's order of merit, but where major discrepancies are found, AQA reserves the right to alter the order of merit.

24.2 Post-Moderation Procedures

On publication of the GCE results, the centre is supplied with details of the final marks for the coursework component.

The candidates' work is returned to the centre after the examination with a report form from the moderator giving feedback to the centre on the appropriateness of the tasks set, the accuracy of the assessments made, and the reasons for any adjustments to the marks.

Some candidates' work may be retained by AQA for archive purposes.

Awarding and Reporting

25 Grading, Shelf-Life and Re-Sits

25.1 Qualification Titles

The qualifications based on these specifications have the following titles:

AQA Advanced Subsidiary GCE in Physics A
AQA Advanced Level GCE in Physics A

25.2 Grading System

Both the AS and the full A Level qualifications will be graded on a five-grade scale: A, B, C, D and E. Candidates who fail to reach the minimum standard for grade E will be recorded as U (unclassified) and will not receive a qualification certificate.

Individual assessment unit results will be certificated.

25.3 Shelf-Life of Unit Results

The shelf-life of individual unit results, prior to the award of the qualification, is limited only by the shelf-life of the specification.

25.4 Assessment Unit Re-Sits

Each assessment unit may be re-sat once only. The better result will count towards the final award. Candidates may, however, re-sit the whole qualification more than once.

An AS result can be converted into a full A Level award by taking the A2 examination at any examination series when Physics is available.

Marks for individual AS or A2 units may be counted once only towards an AS and/or an A Level award

25.5 Carrying Forward of Coursework Marks

Candidates who wish to re-sit the whole qualification and carry-forward the mark for the coursework assessment unit(s) must do so within a 12-month period of the original award.

25.6 Minimum Requirements

Candidates will be graded on the basis of work submitted for the award of the qualification.

25.7 Awarding and Reporting

The regulatory authorities, in consultation with GCE awarding bodies, will develop a new GCE Code of Practice for new GCE qualifications, to be introduced in September 2000. This specification will comply with the grading, awarding and certification requirements of the revised GCE Code of Practice for courses starting in September 2000.

Appendices

A Grade Descriptions

The following grade descriptors indicate the level of attainment characteristic of the given grade at A Level. They give a general indication of the required learning outcomes at each specific grade. The descriptors should be interpreted in relation to the content outlined in the specification; they are not designed to define that content.

The grade awarded will depend in practice upon the extent to which the candidate has met the assessment objectives (as in section 6) overall. Shortcomings in some aspects of the examination may be balanced by better performances in others.

Grade A

Candidates recall and use knowledge of Physics from the whole specification with few significant omissions and show good understanding of the principles and concepts they use. They select appropriate information from which to construct arguments or techniques with which to solve problems. In the solution of some problems, candidates bring together fundamental principles from different content areas of the common specification and demonstrate a clear understanding of the relationships between these.

Candidates apply knowledge and physical principles contained within the specification in both familiar and unfamiliar contexts. In questions requiring numerical calculations, candidates demonstrate good understanding of the underlying relationships between physical quantities involved and carry out all elements of extended calculations correctly, in situations where little or no guidance is given.

In experimental activities, candidates identify a problem, independently formulate a clear and effective plan, using knowledge and understanding of Physics, and use a range of relevant techniques with care and skill. They make and record measurements which are sufficient and with a precision which is appropriate to the task. They interpret and explain their results with sound use of physical principles and evaluate critically the reliability of their methods.

Grade C

Candidates recall and use knowledge of Physics from most parts of the specification and demonstrate understanding of a significant number of the main principles and concepts within it. They select and make good use of information that is presented in familiar ways to solve problems, and make some use of the concepts and terminology of Physics in communicating their answers. In their answers to some questions, candidates demonstrate some knowledge of the links between different areas of Physics.

Candidates apply knowledge and physical principles contained within the specification when the context provides some guidance on the required area of work. They show some understanding of the physical principles involved and the magnitudes of common physical quantities when carrying out numerical work. Candidates carry out calculations in most areas of Physics correctly when these calculations are of a familiar kind or when some guidance is provided, using correct units for most physical quantities.

In experimental activities, candidates formulate a clear plan. They make and record measurements with skill and care and show some awareness of the need for appropriate precision. They interpret and explain their experimental results, making some use of fundamental principles of Physics and mathematical techniques.

Grade E

Candidates recall knowledge of Physics from parts of the specification and demonstrate some understanding of fundamental principles and concepts. Their level of knowledge and understanding may vary significantly across major areas of the specification. They select discrete items of knowledge in structured questions and make some use of the terminology of Physics in communicating answers.

Candidates apply knowledge and principles of Physics contained within the specification to material presented in a familiar or closely related context. They carry out straightforward calculations where guidance is given, usually using the correct units for physical quantities. They use some fundamental skills of Physics in contexts which bring together different areas of the subject.

In experimental activities, candidates formulate some aspects of a practical approach to a problem. They make and record some appropriate measurements, showing care and appropriate procedure in implementation. They present results appropriately and provide some descriptive interpretation of the outcomes of the investigation.

B

AQA

ASSESSMENT and QUALIFICATIONS ALLIANCE

Record Forms

Centre-assessed work

Centre Declaration Sheet

June 2002

Specification Title...Unit Code ....

Centre Name.. **Centre No.**

Authentication

This is to certify that marks have been awarded in accordance with the requirements of the specification and that every reasonable step has been taken to ensure that the work presented is that of the candidates named. Any assistance given to candidates beyond that given to the class as a whole and beyond that described in the specification has been recorded on the Candidate Record Form(s) and has been taken into account. The marks given reflect accurately the unaided achievement of the candidates.

Signature(s) of teacher(s) responsible for assessment

Teacher 1.. Teacher 2..

Teacher 3.. Teacher 4..

Teacher 5.. Teacher 6 ....

(continue overleaf if necessary)

Internal standardisation of marking

Each centre must standardise the assessments for this unit across different teachers and teaching groups to ensure that all candidates at the centre have been judged against the same standards. If two or more teachers are involved in marking a unit, one of them must be designated as responsible for standardising the marking of all teachers at the centre who mark that unit.

The following declaration must be signed by the teacher responsible for ensuring standardisation. If all the work has been marked by the same person, that person should sign below.

I confirm that

(a) *I have marked the work of all candidates for this component

(b) *the procedure described in the specification has been followed at this centre to ensure that the marking is of the same standard for all candidates.

(*delete as applicable)

Signed...Date...

Signature of Head of Centre...Date...

This form should be completed and sent to the moderator with the sample of centre-assessed work.

AQA
ASSESSMENT and QUALIFICATIONS ALLIANCE

Centre-assessed work

Candidate Record Form

June 2002

A Level Physics 5451/6451

Centre Name.. Centre No. | | | | | |

Candidate Name.. Candidate No. | | | | |

This side is to be completed by the candidate

Sources of advice and information

1. Have you received any help or information from anyone other than your subject teacher(s) in the production of this work? .... (Write YES or NO)

2. If you have answered YES, give details. Continue on a separate sheet if necessary.

....

....

3. If you have used **any** books, information leaflets or other materials (e.g. videos, software packages or information from the Internet) to help you complete this work, you must list these below unless they are clearly acknowledged in the work itself. To present material copied from books or other sources without acknowledgement will be regarded as deliberate deception.

....

....

NOTICE TO CANDIDATE

The work you submit for assessment must be your own.

If you copy from someone else or allow another candidate to copy from you, or if you cheat in any other way, you may be disqualified from at least the subject concerned.

Declaration by candidate

I have read and understood the **Notice to Candidate** (above). I have produced the attached work without any help apart from that which I have stated on this sheet.

Signed... Date...
(Candidate)

This form should be completed and attached to the candidate's work and retained at the Centre or sent to the moderator as required.

[redacted]

This side is to be completed by the teacher.

Marks must be awarded in accordance with the instructions and criteria in Section 20 of the specification.

Supporting information to show how the marks have been awarded should be given in the form of annotations on the candidate's work but additional comments may be given in the spaces provided below.

Please complete the boxes to show the marks awarded and use the spaces to make any summative comments which seem appropriate.

Criteria for award of marks	Max. mark	Mark awarded	Teacher's supporting statement
A Planning	8		
B Implementing	8		
C Analysing evidence and drawing conclusions	8		
D Evaluating evidence and procedures	6		
Total	30		

Concluding Comments

Details of additional assistance given (if any)

Record here details of any assistance given to this candidate which is beyond that given to the class as a whole and beyond that described in the specification. Continue on a separate sheet if necessary.

Teacher's signature

Date ....

C

Overlaps with other Qualifications

The AQA GCE Physics Specification A overlaps peripherally with AQA GCE Electronics through its optional module 6E, Electronics. There is marginal overlap with AQA GCE Design and Technology.

The overlap with AQA GCE Mathematics A and B rests only on the use and application of those formulae and equations given in the Subject Criteria for Physics. There is marginal overlap with AQA GCE Biology A and Biology B and Chemistry.

Overlap with AQA Physics B is subject to a prohibited combination.

D Data Sheet

Fundamental constants and values

Quantity	*Symbol*	*Value*	*Units*
speed of light in vacuo	c	3.00×10^{8}	$\mathrm{m\,s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\,m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\,m^{-1}}$
charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\mathrm{N\,m^{2}\,kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\,K^{-1}\,mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\,K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\,m^{-2}\,K^{-4}}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4}u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	e/m_e	1.76×10^{11}	$\mathrm{C\,kg^{-1}}$
proton rest mass (equivalent to 1.00728u)	m_p	1.67×10^{-27}	kg
proton charge/mass ratio	e/m_p	9.58×10^{7}	$\mathrm{C\,kg^{-1}}$
neutron rest mass (equivalent to 1.00867u)	m_n	1.67×10^{-27}	kg
gravitational field strength	g	9.81	$\mathrm{N\,kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\,s^{-2}}$
atomic mass unit (1u is equivalent to 931.3 MeV)	u	1.661×10^{-27}	kg

Fundamental particles

Class	*Name*	*Symbol*	*Rest energy* MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^{\pm}$	0.511004
	muon	$\mu^{\pm}$	105.659
mesons	pion	$\pi^{\pm}$	139.576
		π^{0}	134.972
	kaon	$K^{\pm}$	493.821
		K^{0}	497.762
baryons	proton	$p^{\pm}$	938.257
	neutron	n	939.551

Properties of quarks

Type	*Charge*	*Baryon number*	*Strangeness*
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}$	$+\frac{1}{3}$	−1

Geometrical equations

$\text{arc length} = r\theta$

$\text{circumference of circle} = 2\pi r$

$\text{area of circle} = \pi r^2$

$\text{area of cylinder} = 2\pi rh$

$\text{volume of cylinder} = \pi r^2 h$

$\text{area of sphere} = 4\pi r^2$

$\text{volume of sphere} = \frac{4}{3}\pi r^3$

Mechanics and Applied Physics

$v = u + at$

$s = \left(\frac{u+v}{2}\right)t$

$s = ut + \frac{at^2}{2}$

$v^2 = u^2 + 2as$

$F = \frac{\Delta(mv)}{\Delta t}$

$P = Fv$

$\text{efficiency} = \frac{\text{power output}}{\text{power input}}$

$\omega = \frac{v}{r} = 2\pi f$

$a = \frac{v^2}{r} = r\omega^2$

$I = \sum mr^2$

$E_k = \frac{1}{2}I\omega^2$

$\omega_2 = \omega_1 + \alpha t$

$\theta = \omega_1 t + \frac{1}{2}\alpha t^2$

$\omega_2^2 = \omega_1^2 + 2\alpha\theta$

$\theta = \frac{1}{2}(\omega_1 + \omega_2)t$

$T = I\alpha$

$\text{angular momentum} = I\omega$

$W = T\theta$

$P = T\omega$

$\text{angular impulse} = \text{change of angular momentum} = Tt$

$\Delta Q = \Delta U + \Delta W$

$\Delta W = p\Delta V$

$PV^\gamma = \text{constant}$

$\text{work done per cycle} = \text{area of loop}$

$\text{input power} = \text{calorific value} \times \text{fuel flow rate}$

$\text{indicated power as (area of } p - V \text{ loop)} \times \text{(no. of cycles/s)} \times \text{(no. of cylinders)}$

$\text{friction power} = \text{indicated power} - \text{brake power}$

$$efficiency = \frac{W}{Q_{\text{in}}} = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}}$$

$$maximum\ possible\ efficiency = \frac{T_H - T_C}{T_H}$$

Fields, Waves, Quantum Phenomena

$$g = \frac{F}{m}$$

$$g = -\frac{GM}{r^2}$$

$$g = -\frac{\Delta V}{\Delta x}$$

$$V = -\frac{GM}{r}$$

$$a = -(2\pi f)^2 x$$

$$v = \pm 2\pi f \sqrt{A^2 - x^2}$$

$$x = A \cos 2\pi ft$$

$$T = 2\pi \sqrt{\frac{m}{k}}$$

$$T = 2\pi \sqrt{\frac{l}{g}}$$

$$\lambda = \frac{\omega s}{D}$$

$$d \sin\theta = n\lambda$$

$$\theta \approx \frac{\lambda}{D}$$

$${}_1n_2 = \frac{\sin\theta_1}{\sin\theta_2} = \frac{c_1}{c_2}$$

$${}_1n_2 = \frac{n_2}{n_1}$$

$$\sin\theta_c = \frac{1}{n}$$

$$E = hf$$

$$hf = \phi + E_k$$

$$hf = E_1 - E_2$$

$$\lambda = \frac{h}{p}$$

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

Electricity

$$\in = \frac{E}{Q}$$

$$\in = I(R + r)$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$R_T = R_1 + R_2 + R_3$$

$$P = I^2 R$$

$$E = \frac{F}{Q} = \frac{V}{d}$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

$$E = \tfrac{1}{2} QV$$

$$F = BIl$$

$$F = BQv$$

$$Q = Q_0 e^{-t/RC}$$

$$\Phi = BA$$

$$\textit{magnitude of induced e.m.f.} = N\frac{\Delta\Phi}{\Delta t}$$

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

Mechanical and Thermal Properties

$$\textit{the Young modulus} = \frac{\textit{tensile stress}}{\textit{tensile strain}} = \frac{F}{A}\frac{l}{e}$$

$$\textit{energy stored} = \tfrac{1}{2} Fe$$

$$\Delta Q = mc\,\Delta\theta$$

$$\Delta Q = ml$$

$$pV = \tfrac{1}{3} N m\overline{c^2}$$

$$\tfrac{1}{2} m\overline{c^2} = \tfrac{3}{2} kT = \frac{3RT}{2N_A}$$

Nuclear Physics and Turning Points in Physics

$$\textit{force} = \frac{eV_p}{d}$$

$$\textit{force} = Bev$$

$$\textit{radius of curvature} = \frac{mv}{Be}$$

$$\frac{eV}{d} = mg$$

$$\textit{work done} = eV$$

$$F = 6\pi\eta r v$$

$$I = k\frac{I_0}{x^2}$$

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$N = N_0 e^{-\lambda t}$$

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

$$R = r_0 A^{\frac{1}{3}}$$

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

$$l = l_0 \left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}$$

$$t = \frac{t_0}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

Astrophysics and Medical Physics

Body	*Mass* kg	*Mean radius* m
Sun	2.00×10^{30}	7.00×10^{8}
Earth	6.00×10^{24}	6.40×10^{6}

1 astronomical unit = 1.50×10^{11} m

1parsec = 206265 AU = 3.08×10^{16} m = 3.26 ly

1 light year = 9.45×10^{15} m

Hubble constant (H) = 65 km s^{-1} Mpc^{-1}

$$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$$

$$M = \frac{f_o}{f_e}$$

$$m - M = 5 \log \frac{d}{10}$$

$$\lambda_{max} T = \text{constant} = 0.0029\,\text{mK}$$

$$v = Hd$$

$$P = \sigma A T^4$$

$$\frac{\Delta f}{f} = \frac{v}{c}$$

$$\frac{\Delta \lambda}{\lambda} = -\frac{v}{c}$$

$$R_s \approx \frac{2GM}{c^2}$$

Medical Physics

$$power = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad \text{and} \quad m = \frac{v}{u}$$

$$intensity\ level = 10 \log \frac{I}{I_0}$$

$$I = I_0 e^{-ux}$$

$$\mu_m = \frac{\mu}{\rho}$$

Electronics

Resistors

Preferred values for resistors (E24) Series:
1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2 2.4 2.7 3.0
3.3 3.6 3.9 4.3 4.7 5.1 5.6 6.2 6.8 7.5 8.2 9.1 ohms
and multiples that are ten times greater

$$Z = \frac{V_{\mathrm{rms}}}{I_{\mathrm{rms}}}$$

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$C_T = C_1 + C_2 + C_3$$

$$X_C = \frac{1}{2\pi f C}$$

Alternating Currents

$$f = \frac{1}{T}$$

Operational amplifier

$$G = \frac{V_{\mathrm{out}}}{V_{\mathrm{in}}} \quad \text{voltage gain}$$

$$G = -\frac{R_f}{R_1} \quad \text{inverting}$$

$$G = 1 + \frac{R_f}{R_1} \quad \text{non-inverting}$$

$$V_{\mathrm{out}} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) \quad \text{summing}$$