IBO

INTERNATIONAL BACCALAUREATE ORGANIZATION

DIPLOMA PROGRAMME

Physics

For first examinations in 2003

Physics
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International Baccalaureate Organization
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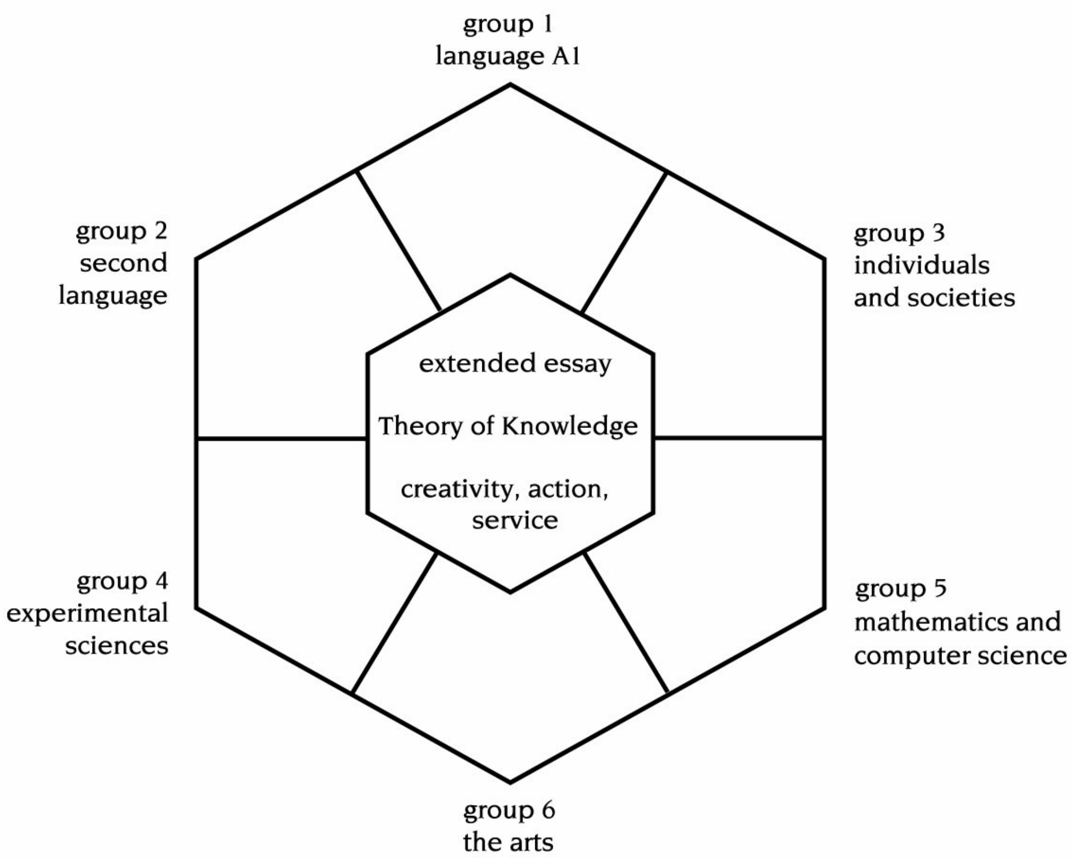
INTRODUCTION

The International Baccalaureate Diploma Programme is a rigorous pre-university course of studies, leading to examinations, that meets the needs of highly motivated secondary school students between the ages of 16 and 19 years. Designed as a comprehensive two-year curriculum that allows its graduates to fulfill requirements of various national education systems, the Diploma Programme model is based on the pattern of no single country but incorporates the best elements of many. The programme is available in English, French and Spanish.

The curriculum is displayed in the shape of a hexagon with six academic areas surrounding the core. Subjects are studied concurrently and students are exposed to the two great traditions of learning: the humanities and the sciences.



Diploma Programme candidates are required to select one subject from each of the six subject groups. At least three and not more than four are taken at higher level (HL), the others at standard level (SL). Higher level courses represent 240 teaching hours; standard level courses cover 150 hours. By arranging work in this fashion, students are able to explore some subjects in depth and some more broadly over the two-year period; this is a deliberate compromise between the early specialization preferred in some national systems and the breadth found in others.

Distribution requirements ensure that the science-orientated student is challenged to learn a foreign language and that the natural linguist becomes familiar with science laboratory procedures. While overall balance is maintained, flexibility in choosing higher level combinations allows the student to pursue areas of personal interest and to meet special requirements for university entrance.

Successful Diploma Programme candidates meet three requirements in addition to the six subjects. The interdisciplinary Theory of Knowledge (TOK) course is designed to develop a coherent approach to learning which transcends and unifies the academic areas and encourages appreciation of other cultural perspectives. The extended essay of some 4000 words offers the opportunity to investigate a topic of special interest and acquaints students with the independent research and writing skills expected at university. Participation in the creativity, action, service (CAS) requirement encourages students to be involved in artistic pursuits, sports and community service work.

For first examinations in 2003

CURRICULUM MODEL

A common curriculum model applies to all the Diploma Programme group 4 subjects: biology, chemistry, environmental systems, physics and design technology. (There are some differences in this model for design technology and these arise from the design project, a unique feature of this subject. A double asterisk (**) indicates where these differences occur.) A core of material is studied by both higher level and standard level students in all subjects, and this is supplemented by the study of options. Higher level students also study additional higher level (AHL) material. Higher level students and SL students both study two options. There are three kinds of options: those specific to SL students, those specific to HL students and those which can be taken by both SL and HL students. Schools wishing to develop their own school-based option should contact the IBCA office in the first instance.

This curriculum model is not designed to favour the teaching of SL and HL students together. The IBO does not support the joint teaching of students at different levels as this does not provide the greatest educational benefit for either level.

Higher level students are required to spend 60 hours, and SL students 40 hours, on practical/ investigative work**. This includes 10 to 15 hours for the group 4 project.

Group 4 Curriculum Model HL **

HL	**Total teaching hours**	**240**
Theory		**180**
	Core	80
	Additional higher level (AHL)	55
	Options	45
Internal assessment (IA)		**60**
	Investigations	45–50
	Group 4 project	10–15

Group 4 Curriculum Model SL **

SL	Total teaching hours	150
Theory		**110**
	Core	80
	Options	30
Internal assessment (IA)		**40**
	Investigations	25–30
	Group 4 project	10–15

Format of the Syllabus Details

Note: The order in which the syllabus content is presented is not intended to represent the order in which it should be taught.

The format of the syllabus details section of the group 4 guides is the same for each subject. The structure is as follows.

Topics or Options

Topics are numbered and options are indicated by a letter (eg Topic 6: Nucleic Acids and Proteins or Option C: Cells and Energy).

Sub-topics

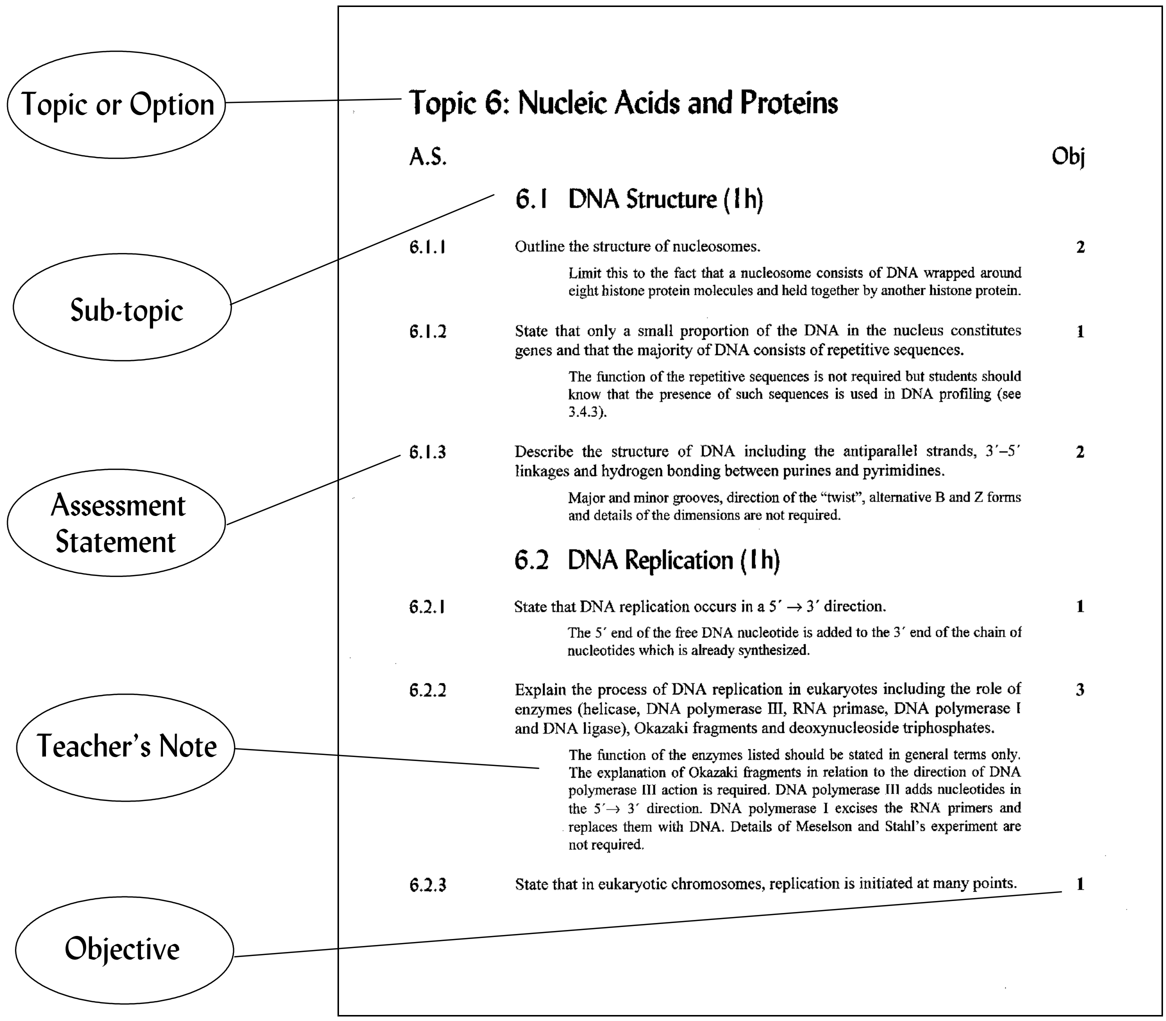
Sub-topics are numbered and the estimated teaching time required to cover the material is indicated (eg 6.1 DNA Structure (1h)). The times are for guidance only and do not include time for practical/investigative work.

Assessment Statements (A.S.)

Assessment statements, which are numbered, are expressed in terms of the outcomes that are expected of students at the end of the course (eg 6.1.1 Outline the structure of nucleosomes). These are intended to prescribe to examiners what can be assessed by means of the written examinations. Each one is classified as objective 1, 2 or 3 (see page 7) according to the action verb(s) used (see page 8). The objective levels are relevant for the examinations and for balance within the syllabus, while the action verbs indicate the depth of treatment required for a given assessment statement. It is important that students are made aware of the meanings of the action verbs since these will be used in examination questions.

Teacher's Notes

Teacher's notes, which are included below some assessment statements, provide further guidance to teachers.



AIMS

Through studying any of the group 4 subjects, students should become aware of how scientists work and communicate with each other. While the "scientific method" may take on a wide variety of forms, it will generally involve the formation, testing and modification of hypotheses through observation and measurement, under the controlled conditions of an experiment. It is this approach, along with the falsifiability of scientific hypotheses, that distinguishes the experimental sciences from other disciplines and characterizes each of the subjects within group 4.

It is in this context that all the Diploma Programme experimental science courses should aim to:

1. provide opportunities for scientific study and creativity within a global context which will stimulate and challenge students
2. provide a body of knowledge, methods and techniques which characterize science and technology
3. enable students to apply and use a body of knowledge, methods and techniques which characterize science and technology
4. develop an ability to analyse, evaluate and synthesize scientific information
5. engender an awareness of the need for, and the value of, effective collaboration and communication during scientific activities
6. develop experimental and investigative scientific skills
7. develop and apply the students' information technology skills in the study of science
8. raise awareness of the moral, ethical, social, economic and environmental implications of using science and technology
9. develop an appreciation of the possibilities and limitations associated with science and scientists
10. encourage an understanding of the relationships between scientific disciplines and the overarching nature of the scientific method.

OBJECTIVES

The objectives for all group 4 subjects reflect those parts of the aims that will be assessed. Wherever appropriate, the assessment will draw upon environmental and technological contexts and identify the social, moral and economic effects of science.

It is the intention of all the Diploma Programme experimental science courses that students should achieve the following objectives.

1. Demonstrate an understanding of:
   a. scientific facts and concepts
   b. scientific methods and techniques
   c. scientific terminology
   d. methods of presenting scientific information.
2. Apply and use:
   a. scientific facts and concepts
   b. scientific methods and techniques
   c. scientific terminology to communicate effectively
   d. appropriate methods to present scientific information.
3. Construct, analyse and evaluate:
   a. hypotheses, research questions and predictions
   b. scientific methods and techniques
   c. scientific explanations.
4. Demonstrate the personal skills of cooperation, perseverance and responsibility appropriate for effective scientific investigation and problem solving.
5. Demonstrate the manipulative skills necessary to carry out scientific investigations with precision and safety.

ACTION VERBS

These action verbs indicate the depth of treatment required for a given assessment statement. These verbs will be used in examination questions and so it is important that students are familiar with the following definitions.

Objective 1

Define	give the precise meaning of a word or phrase as concisely as possible
Draw	represent by means of pencil lines (add labels unless told not to do so)
List	give a sequence of names or other brief answers with no elaboration, each one clearly separated from the others
Measure	find a value for a quantity
State	give a specific name, value or other brief answer (no supporting argument or calculation is necessary)

Objective 2

Annotate	add brief notes to a diagram, drawing or graph
Apply	use an idea, equation, principle, theory or law in a new situation
Calculate	find an answer using mathematical methods (show the working unless instructed not to do so)
Compare	give an account of similarities and differences between two (or more) items, referring to both (all) of them throughout (comparisons can be given using a table)
Describe	give a detailed account, including all the relevant information
Distinguish	give the differences between two or more different items
Estimate	find an approximate value for an unknown quantity, based on the information provided and scientific knowledge
Identify	find an answer from a number of possibilities
Outline	give a brief account or summary (include essential information only)

Objective 3

Analyse	interpret data to reach conclusions
Construct	represent or develop in graphical form
Deduce	reach a conclusion from the information given
Derive	manipulate a mathematical equation to give a new equation or result
Design	produce a plan, object, simulation or model
Determine	find the only possible answer
Discuss	give an account including, where possible, a range of arguments, assessments of the relative importance of various factors or comparisons of alternative hypotheses
Evaluate	assess the implications and limitations
Explain	give a clear account including causes, reasons or mechanisms
Predict	give an expected result
Solve	obtain an answer using algebraic and/or numerical methods
Suggest	propose a hypothesis or other possible answer

INFORMATION AND COMMUNICATION TECHNOLOGY (ICT)

The role of computers in developing and applying scientific knowledge is well established. Scientists make measurements, handle information and model ideas. They need to process information and communicate it effectively.

Why Use Computers in Science?

Skills in handling information are clearly important life skills. The use of ICT will enhance learning, increase awareness of the technology scientists use for processing information and prepare students better for a rapidly changing situation in the real world. Computers enable students to become more active participants in learning and research and offer a valuable resource for understanding the processes of science. Development of ICT skills will allow students to explore rich materials, access information quickly and easily and lead them into areas previously experienced only through the possession of higher order skills. The computer also allows the teacher more flexibility in both approach and presentation of materials. Creating an ICT culture in classrooms is an important endeavour for all schools.

It is for these reasons that the IBO has incorporated a new aim related to ICT for group 4—aim 7: develop and apply the students' information technology skills in the study of science.

When Should Computers be Used?

The use of computers should complement rather than replace hands-on practical work. However computers can be used in areas where a practical approach is inappropriate or limited.

For example: sensors may be used in data-logging to obtain data over long or very short periods of time, or in experiments that otherwise would not be feasible. Simulation software may be used to illustrate concepts and models which are not readily demonstrable in laboratory experiments because they require expensive equipment or materials that are hazardous or difficult to obtain. The experiments may also involve skills not yet achieved by students or which require more time than is available.

What Sort of Technologies are Available?

The technology for processing information includes such tools as word processors, spreadsheets, database programs, sensors and modelling programs.

Spreadsheets

These multipurpose programs may be used for generating results tables from experimental data, data handling, sorting and searching pre-existing data, and producing graphs. Perhaps their most interesting feature is their use in calculations and mathematical modelling.

Databases

Scientists use database programs to handle the vast amounts of data which may be generated in experiments, or to retrieve other scientists' data. The database may be on disc, CD-Rom or downloaded from the Internet. Scientists use their skills and experience to collect, organize and analyse data, look for patterns and check for errors. To appreciate the value of databases to the scientific community, students should be familiar with using a database to store, sort and graph data.

Data-logging

Sensors and control technology can help scientists by monitoring very fast or very slow changes. Data-logging has the advantage that students can see the data recorded in real time. They can therefore focus on the trends and patterns that emerge rather than on the process of gathering the data. Sensors can also measure with more precision allowing students to have greater confidence in their results.

Software for Modelling and Simulations

A wide range of software programs exist to model (amongst other things) photosynthesis, control of blood sugar, chemical equilibria, the cardiovascular system and wave phenomena such as interference and diffraction. Generic programs are also available which allow students to construct models of, for example, motion and gravity, heat loss or populations in an ecosystem. Some of these programs are available via the Internet.

The Internet, CD-Roms, DVDs and Multimedia

The powerful combination of the spoken word, animation and video in these multimedia products clearly motivates and stimulates the user. Interactive multimedia has considerable potential to link different representations and ways of learning to facilitate understanding in science. It provides information that can be selected or rejected, and search facilities allow many different routes through the material which illustrate new links and patterns.

There is clearly added value in the use of interactive multimedia through visualization and differentiation. To be able to represent visually, for example, the dynamic aspects of kinetic theory or electron movements, helps students imagine the situation and aids the learning of difficult concepts. This complements more traditional teaching approaches.

Word Processing and Graphics

Word processing is not merely a means of writing in electronic form. It can improve the quality of written work from the initial listing of ideas, their development and reworking, through to the final product. Drawing programs, scanners, digital cameras, video cameras, desktop publishing, multimedia authoring and CAD/CAM software also have their place, particularly in design technology and perhaps more widely through the group 4 project.

Internationalism

The ease and widespread use of email should encourage the networking of teachers and students, and this replicates the networking activities of the science community. Email (and web sites) could be used to collaborate with other schools world wide, perhaps as part of the group 4 project, or in established collaborative ventures such as the Science Across the World and Globe programs.

Ethical and Moral Dimension

This dimension of the use of ICT need not be made explicit in the group 4 subjects as students will be exposed to it through Theory of Knowledge (TOK), and it will also emerge in the day-to-day experiences of students inside and outside school. Such issues as plagiarism of extended essays, firewalls to prevent access to undesirable web sites, hacking, anti-social behaviour in local networks and on the Internet, privacy of information in databases, freedom of information and web site subscriptions may be encountered.

How to Proceed

Because of the variability of both hardware and software between IB schools, the use of ICT will not be monitored or assessed. For this reason, there is no new objective related to ICT in group 4. However, it is vital to encourage ICT use and to stress its importance in any modern science curriculum. (One common element is the use of graphic calculators in some IB Diploma Programme mathematics courses. This allows for portable, low cost data-logging, modelling and graph plotting.) The IB community can help disseminate ideas and guidance through its workshops and the online curriculum centre.

For further information teachers should access:

- the online curriculum centre to find up-to-date and relevant resources and web site addresses, and to share experiences and resources with other IB teachers
- the web sites of national and international educational bodies promoting ICT
- the web sites of the main educational suppliers and specialized educational software and hardware suppliers, many of whom now operate internationally.

EXTERNAL ASSESSMENT

The external assessment consists of three written papers.

Paper 1

Paper 1 is made up of multiple-choice questions which test knowledge of the core and additional higher level (AHL) material for higher level (HL) students and the core only for standard level (SL) students. The questions are designed to be short, one- or two-stage problems which address objectives 1 and 2 (see page 7). No marks are deducted for incorrect responses. Calculators are not permitted, but students are expected to carry out simple calculations.

Paper 2

Paper 2 tests knowledge of the core and AHL material for HL students and the core only for SL students. The questions address objectives 1, 2 and 3 and the paper is divided into two sections.

In section A, there is a data-based question which will require students to analyse a given set of data. The remainder of section A is made up of short-answer questions.

In section B, students are expected to answer two questions from a choice of four at HL** or one question from a choice of three at SL. These extended response questions may involve writing a number of paragraphs, solving a substantial problem, or carrying out a substantial piece of analysis or evaluation. A calculator is required for this paper.

Paper 3

Paper 3 tests knowledge of the options and addresses objectives 1, 2 and 3. At HL, students will answer several short-answer questions and an extended response question in each of the two options studied. At SL, students answer several short-answer questions in each of the two options studied. A calculator is required for this paper. (In biology, students will also answer a data-based question in each of the two options studied.)

The assessment specifications at HL and SL are summarized on the next page.

There are some variations in external assessment requirements for design technology, arising from the design project. A double asterisk (**) indicates where these variations occur. See the design technology guide for details.

Note: Wherever possible teachers should use, and encourage students to use, the Système International d'Unites (International System of Units—SI units).

Assessment Specifications—Standard Level **

Component	Overall Weighting (%)	Approximate Weighting of Objectives 1+2	3	Duration (hours)	Format and Syllabus Coverage
Paper 1	20	20		¾	30 multiple-choice questions on the core
Paper 2	32	16	16	1¼	Section A: one data-based question and several short-answer questions on the core (all compulsory) Section B: one extended response question on the core (from a choice of three)
Paper 3	24	12	12	1	several short-answer questions in each of the two options studied (all compulsory)

Assessment Specifications—Higher Level **

Component	Overall Weighting (%)	Approximate Weighting of Objectives 1+2	3	Duration (hours)	Format and Syllabus Coverage
Paper 1	20	20		1	40 multiple-choice questions (± 15 common to SL plus about five more on the core and about 20 more on the AHL)
Paper 2	36	18	18	2¼	Section A: one data-based question and several short-answer questions on the core and the AHL (all compulsory) Section B: two extended response questions on the core and AHL (from a choice of four)
Paper 3	20	10	10	1¼	several short-answer questions and one extended response question in each of the two options studied (all compulsory)

For both SL and HL, calculators are not permitted in paper 1 but are required in papers 2 and 3, where programmable graphic display calculators are allowed.

INTERNAL ASSESSMENT

General Introduction

The internal assessment (IA) requirements are the same for all group 4 subjects, with the exception of design technology which has an additional element. The IA, worth 24% of the final assessment (design technology 36%) consists of an interdisciplinary project, a mixture of short- and long-term investigations (such as practicals and subject-specific projects) and, for design technology only, the design project

Student work is internally assessed by the teacher and externally moderated by the IBO. The performance in IA at both higher level and standard level is judged against assessment criteria each consisting of achievement levels 0–3.

Rationale for Practical Work

Although the requirements for IA are mainly centred on the assessment of practical skills, the different types of experimental work that a student may engage in serve other purposes, including:

- illustrating, teaching and reinforcing theoretical concepts
- developing an appreciation of the essential hands-on nature of scientific work
- developing an appreciation of the benefits and limitations of scientific methodology.

Therefore, there may be good justification for teachers to conduct further experimental work beyond that required for the IA scheme.

Practical Scheme of Work

The practical scheme of work (PSOW) is the practical course planned by the teacher and acts as a summary of all the investigative activities carried out by a student. Higher level and standard level candidates in the same subject may carry out some of the same investigations and, where more than one group of students is taught in a subject and level, common investigations are acceptable.

Syllabus Coverage

The range of investigations carried out should reflect the breadth and depth of the subject syllabus at each level, but it is not necessary to carry out an investigation for every syllabus topic. However, all candidates must participate in the group 4 project and the IA activities should ideally include a spread of content material from the core, options and, where relevant, AHL material. A minimum number of investigations to be carried out is not specified.

Choosing Investigations

Teachers are free to formulate their own practical schemes of work by choosing investigations according to the requirements outlined. Their choices will be based on:

- subjects, levels and options taught
- the needs of their students
- available resources
- teaching styles.

Teachers should not feel that all investigations must form part of the practical scheme of work, however their scheme must meet the IB requirements. Each scheme must include at least a few complex investigations which make greater conceptual demands on the students. A scheme made up entirely of simple experiments, such as ticking boxes or exercises involving filling in tables, will not provide an adequate range of experience for students.

Teachers are encouraged to use the online curriculum centre to share ideas about possible investigations by joining in the discussion forums and adding resources they use onto the relevant sections of the online subject guides.

Note: Any investigation or part investigation that is to be used to assess candidates should be specifically designed to match the relevant assessment criteria.

Flexibility

The IA model is flexible enough to allow a wide variety of investigations to be carried out. These could include:

- short laboratory practicals over one or two lessons and long-term practicals or projects extending over several weeks
- computer simulations
- data-gathering exercises such as questionnaires, user trials and surveys
- data analysis exercises
- general laboratory and fieldwork.

The Group 4 Project

The group 4 project is an interdisciplinary activity in which all Diploma Programme science students must participate. The intention is that students analyse a topic or problem which can be investigated in each of the science disciplines offered by a school. The exercise should be a collaborative experience where the emphasis is on the **processes** involved in scientific investigation rather than the **products** of such investigation.

In most cases all students in a school would be involved in the investigation of the same topic. Where there are large numbers of students, it is possible to divide them into several smaller groups containing representatives from each of the science subjects. Each group may investigate the same topic or different topics, ie there may be several group 4 projects in the same school.

Design Technology

In design technology, each student must carry out the design project in addition to several investigations and the group 4 project. Higher level students are required to spend 31 hours on the design project and SL students 19 hours.

Practical Work Documentation

Details of an individual student's practical scheme of work are recorded on **form 4/PSOW** provided in the *Vade Mecum*, section 4. Electronic versions may be used as long as they include all necessary information.

In design technology, each candidate must compile a log book. This is a candidate's record of his/her development of the design project and an informal personal record of investigative activities.

IA Time Allocation

The recommended teaching times for the IB Diploma Programme courses are 240 hours for HL and 150 hours for SL. Higher level students are required to spend 60 hours, and SL students 40 hours, on practical activities (excluding time spent writing up work). These times include 10 to 15 hours for the group 4 project.

> Note: For design technology, HL students are required to spend 81 hours, and SL students 55 hours, on practical activities.

The time allocated to IA activities should be spread throughout most of the course and not confined to just a few weeks at the beginning, middle or end. Only 2–3 hours of investigative work can be carried out after the deadline for submission of work to the moderator and still be counted in the total hours for the practical scheme of work.

Guidance and Authenticity

All candidates should be familiar with the requirements for IA. It should be made clear to them that they are entirely responsible for their own work. It is helpful if teachers encourage candidates to develop a sense of responsibility for their own learning so that they accept a degree of ownership and take pride in their own work. In responding to specific questions from candidates concerning investigations, teachers should (where appropriate) guide candidates into more productive routes of enquiry rather than respond with a direct answer.

When completing an investigation outside the classroom candidates should work independently where possible. Teachers are required to ensure that work submitted is the candidate's own. If in doubt, authenticity may be checked by one or more of the following methods:

- discussion with the candidate
- asking the candidate to explain the methods used and to summarize the results
- asking the candidate to repeat the investigation.

Safety

While teachers are responsible for following national or local guidelines which may differ from country to country, attention should be given to the mission statement below which was developed by the International Council of Associations for Science Education (ICASE) Safety Committee.

ICASE Safety Committee

Mission Statement

The mission of the ICASE Safety Committee is to promote good quality, exciting practical science, which will stimulate students and motivate their teachers, in a safe and healthy learning environment. In this way, all individuals (teachers, students, laboratory assistants, supervisors, visitors) involved in science education are entitled to work under the safest possible practicable conditions in science classrooms and laboratories. Every reasonable effort needs to be made by administrators to provide and maintain a safe and healthy learning environment and to establish and require safe methods and practices at all times. Safety rules and regulations need to be developed and enforced for the protection of those individuals carrying out their activities in science classrooms and laboratories, and experiences in the field. Alternative science activities are encouraged in the absence of sufficiently safe conditions.

It is a basic responsibility of everyone involved to make safety and health an ongoing commitment. Any advice given will acknowledge the need to respect the local context, the varying educational and cultural traditions, the financial constraints and the legal systems of differing countries.

Criteria and Aspects

There are eight assessment criteria which are used to assess the work of both higher level and standard level candidates:

- *planning (a)*—Pl (a)
- *planning (b)*—Pl (b)
- *data collection*—DC
- *data processing and presentation*—DPP
- *conclusion and evaluation*—CE
- *manipulative skills*—MS
- *personal skills (a)*—PS (a)
- *personal skills (b)*—PS (b)

Each candidate must be assessed at least twice on each of the eight criteria. The two marks for each of the criteria are added together to determine the final mark out of 48 for the IA component. This will then be scaled at IBCA to give a total out of 24%.

General regulations and procedures relating to IA can be found in the *Vade Mecum*.

Each of the assessment criteria can be separated into two or three **aspects** as shown on the following pages. Descriptions are provided to indicate what is expected in order to meet the requirements of a given aspect **completely (c)** and **partially (p)**. A description is also given for circumstances in which the requirements are not satisfied, **not at all (n)**.

Planning (a)

	ASPECTS		
LEVELS	Defining the problem or research question	Formulating a hypothesis or prediction	Selecting variables
Complete	Identifies a focused problem or research question.	Relates the hypothesis or prediction directly to the research question and explains it, quantitatively where appropriate.	Selects the relevant independent and controlled variable(s).
Partial	States the problem or research question, but it is unclear or incomplete.	States the hypothesis or prediction but does not explain it.	Selects some relevant variables.
Not at all	Does not state the problem or research question **or** repeats the general aim provided by the teacher.	Does not state a hypothesis or prediction.	Does not select any relevant variables.

Planning (b)

	ASPECTS		
LEVELS	Selecting appropriate apparatus or materials*	Designing a method for the control of variables	Designing a method for the collection of sufficient relevant data
Complete	Selects appropriate apparatus or materials.	Describes a method that allows for the control of the variables.	Describes a method that allows for the collection of sufficient relevant data.
Partial	Selects some appropriate apparatus or materials.	Describes a method that makes some attempt to control the variables.	Describes a method that allows for the collection of insufficient relevant data.
Not at all	Does not select any apparatus or materials.	Describes a method that does not allow for the control of the variables.	Describes a method that does not allow any relevant data to be collected.

* suitable diagrams are acceptable

Data Collection

	ASPECTS	
LEVELS	Collecting and recording raw data	Organizing and presenting raw data
Complete	Records appropriate raw data (qualitative and/or quantitative), including units and uncertainties where necessary.	Presents raw data clearly, allowing for easy interpretation.
Partial	Records some appropriate raw data.	Presents raw data but does not allow for easy interpretation.
Not at all	Does not record any appropriate raw data.	Does not present raw data **or** presents it incomprehensibly.

Data Processing and Presentation

	ASPECTS	
LEVELS	Processing raw data	Presenting processed data
Complete	Processes the raw data correctly.	Presents processed data appropriately, helping interpretation and, where relevant, takes into account errors and uncertainties.
Partial	Some raw data is processed correctly.	Presents processed data appropriately but with some errors and/or omissions.
Not at all	No processing of raw data is carried out **or** major errors are made in processing.	Presents processed data inappropriately **or** incomprehensibly.

Conclusion and Evaluation

	ASPECTS		
LEVELS	Drawing conclusions	Evaluating procedure(s) and results	Improving the investigation
Complete	Gives a valid conclusion, based on the correct interpretation of the results, with an explanation and, where appropriate, compares results with literature values.	Evaluates procedure(s) and results including limitations, weaknesses or errors.	Identifies weaknesses and states realistic suggestions to improve the investigation.
Partial	States a conclusion that has some validity.	Evaluates procedure(s) and results but misses some obvious limitations or errors.	Suggests only simplistic improvements.
Not at all	Draws a conclusion that misinterprets the results.	The evaluation is superficial **or** irrelevant.	Suggests unrealistic improvements.

Manipulative Skills

	ASPECTS	
LEVELS	Carrying out techniques safely	Following a variety of instructions*
Complete	Is competent and methodical in the use of the technique(s) and the equipment, and pays attention to safety issues.	Follows the instructions accurately, adapting to new circumstances (seeking assistance when required).
Partial	Requires assistance in the use of a routine technique. Works in a safe manner with occasional prompting.	Follows the instructions but requires assistance.
Not at all	Does not carry out the technique(s) **or** misuses the equipment, showing no regard for safety.	Does not follow the instructions **or** requires constant supervision.

* Instructions may be given in a variety of forms: oral, written worksheets, diagrams, photographs, videos, flowcharts, audiotapes, models, computer programs etc.

Personal Skills (a)

	ASPECTS		
LEVELS	Working within a team*	Recognizing the contributions of others	Exchanging and integrating ideas
Complete	Collaborates with others, recognizing their needs, in order to complete the task.	Expects, actively seeks and acknowledges the views of others.	Exchanges ideas with others, integrating them into the task.
Partial	Requires guidance to collaborate with others.	Acknowledges some views.	Exchanges ideas with others but requires guidance in integrating them into the task.
Not at all	Is unsuccessful when working with others.	Disregards views of others.	Does not contribute.

* A team is defined as two or more people.

Personal Skills (b)

	ASPECTS		
LEVELS	Approaching scientific investigations with self-motivation and perseverance	Working in an ethical manner	Paying attention to environmental impact
Complete	Approaches the investigation with self-motivation and follows it through to completion.	Pays considerable attention to the authenticity of the data and information, and the approach to materials (living or non-living).	Pays considerable attention to the environmental impact of the investigation.
Partial	Approaches the investigation with self-motivation or follows it through to completion.	Pays some attention to the authenticity of the data and information, and the approach to materials (living or non-living).	Pays some attention to the environmental impact of the investigation.
Not at all	Lacks perseverance and motivation.	Pays little attention to the authenticity of the data and information, and the approach to materials (living or non-living).	Pays little attention to the environmental impact of the investigation.

Achievement Level Matrixes

For a particular criterion, a piece of work is judged to see whether the requirements of each aspect have been fulfilled completely, partially or not at all. This can then be translated into an achievement level 0, 1, 2 or 3 using the achievement level matrixes below. The lowest level of achievement is represented by 0, and 3 represents the highest level of achievement.

Planning (a), Planning (b), Conclusion and Evaluation, Personal Skills (a), Personal Skills (b)

The matrix below refers to *planning (a)*, *planning (b)*, *conclusion and evaluation*, *personal skills (a)* and *personal skills (b)*, where each criterion has three aspects.

Level	3			2			2			2			1		
Completely	✓	✓	✓	✓	✓		✓	✓		✓					
Partially						✓					✓	✓	✓	✓	✓
Not at all									✓						
	Aspects			Aspects			Aspects			Aspects			Aspects		

Level	1			1			1			0			0		
Completely	✓			✓											
Partially		✓					✓	✓		✓					
Not at all			✓		✓	✓			✓		✓	✓	✓	✓	✓
	Aspects			Aspects			Aspects			Aspects			Aspects		

Data Collection, Data Processing and Presentation, Manipulative Skills

The matrix below applies to *data collection*, *data processing and presentation*, and *manipulative skills*, where each criterion has two aspects.

Level	3		2		1		1		0		0	
Completely	✓	✓	✓		✓							
Partially				✓			✓	✓	✓			
Not at all						✓				✓	✓	✓
	Aspects		Aspects		Aspects		Aspects		Aspects		Aspects	

Guidance on the Criteria

Planning (a)

It is generally not appropriate to assess *planning (a)* for most experiments or investigations found in standard textbooks, unless the experiments are modified. It is essential that students are given an open-ended problem to investigate. Although the general aim of the investigation may be provided by the teacher, students must be able to identify a focused problem or specific research question.

For example, the teacher might present the aim of the investigation generally in the form "investigate the factors that affect X". Students should be able to recognize that certain factors will influence X and clearly define the aim of the experiment or identify a focused research question. A hypothesis or prediction should then be formulated in the light of any independent variables that have been chosen. Such a hypothesis must contain more than just an expected observation. It must include a proposed relationship between two or more variables, or at least an element of rational explanation for an expected observation, the basis of which can be investigated experimentally. A typical formulation for a hypothesis might be "if y is done, then z will occur". Other variables that might affect the outcome should also be mentioned, even if they are not to be specifically investigated. Controlled variables should also be selected.

Planning (b)

The student must design a realistic and appropriate method that allows for the control of variables and the collection of sufficient relevant data. The experimental set-up and measurement techniques must be described.

Data Collection

Data collection skills are important in accurately recording observed events and are critical to scientific investigation. Data collection involves all quantitative or qualitative raw data, such as a column of results, written observations or a drawing of a specimen. Qualitative data is defined as those observed with more or less unaided senses (colour, change of state, etc) or rather crude estimates (hotter, colder, etc), whereas quantitative data implies actual measurements.

Investigations should allow students opportunities to deal with a wide range of observations and data. It is important that the practical scheme of work includes:

- the collection of qualitative and quantitative data
- various methods or techniques
- different variables (time, mass, etc)
- various conditions
- subject-specific methods of collection.

In addition:

- attention to detail should be reflected in the accuracy and precision of the data recorded
- use of data collection tables should be encouraged
- methods of collection and the measurement techniques must be appropriate to each other
- units of measurement must be relevant to the task at hand.

Data Processing and Presentation

The practical scheme of work should provide sufficient investigations to enable a variety of methods of data processing to be used.

Students should also be exposed to the idea of error analysis. That is not to say that error analysis must be carried out for every investigation, nor should it overshadow the purpose of an investigation.

Students should show that they can take raw data, transform it and present it in a form suitable for evaluation.

Processing raw data may include:

- subjecting raw data to statistical calculations (eg producing percentages or means), with the calculations correct and accurate to the level necessary for evaluation
- converting drawings into diagrams
- converting tabulated data into a graphical form
- correctly labelling drawings
- sketching a map from measurements and observations in land form
- proceeding from a sketched idea to a working drawing (eg orthographic projection or sectional views).

The data should be presented so that the pathway to the final result can be followed. Features which should be considered when presenting data include:

- quality of layout (eg choice of format, neatness)
- choice of correct presentation (eg leave as a table, convert to a graph, convert to a flow diagram)
- use of proper scientific conventions in tables, drawings and graphs
- provision of clear, unambiguous headings for drawings, tables or graphs.

Conclusion and Evaluation

Once the data has been processed and presented in a suitable form, the results can be interpreted, conclusions can be drawn and the method evaluated.

Students are expected to:

- analyse and explain the results of experiments and draw conclusions
- evaluate the results.

Analysis may include comparisons of different graphs or descriptions of trends shown in graphs.

Students are also expected to evaluate the procedure they adopted, specifically looking at:

- the processes
- use of equipment
- management of time.

Modifications to improve the investigation should be suggested.

Manipulative Skills

Indications of manipulative ability are the amount of assistance required in assembling equipment, the orderliness of carrying out the procedure(s), the ability to follow the instructions accurately and adherence to safe working practices.

Personal Skills (a)

Working in a team is when two or more students work on a task collaboratively, face-to-face, with individual accountability. Effective teamwork includes recognizing the contributions of others, which begins with each member of the team expecting every other member to contribute. The final product should be seen as something that has been achieved by all members of the team participating in the tasks involved. Encouraging the contributions of others implies not only recognizing, but also actively seeking, contributions from reluctant or less confident members of the team.

Personal Skills (b)

Issues such as plagiarism, the integrity of data collection and data analysis, may be considered here. Sources of data should be acknowledged and data must be reported accurately, even when anomalous or when an experiment has not given rise to the results expected. Due attention to environmental impact may be demonstrated in various ways including avoidance of wastage, using proper procedures for disposal of waste, and minimizing damage to the local environment when conducting experiments.

Assessing an Investigation

In assessing an investigation it must be noted that:

- the same standards must be applied to both HL and SL students
- level 3 does not imply faultless performance
- only whole numbers should be awarded, not fractions or decimals.

The work being assessed must be that of the student. For example in work on *planning (a)*, the student should define the problem, formulate the hypothesis and select the variables; this information should not be provided by the teacher. In work on *data collection*, the student must decide how to collect, record, organize and present the raw data. The teacher should not, for instance, specify how the data should be acquired or provide a table in which the data is recorded. This principle extends to the other criteria.

To illustrate the use of the achievement level matrixes, consider the following example. A student's work is assessed against the criterion *data processing and presentation*. The teacher feels that the first aspect, *processing raw data*, is met completely whereas the second aspect, *presenting processed data*, is only achieved partially. Using the achievement level matrix for *data processing and presentation*, this translates to a level of 2.

THE GROUP 4 PROJECT

Summary of the Group 4 Project

The group 4 project allows students to appreciate the environmental, social and ethical implications of science. It may also allow them to understand the limitations of scientific study, for example, the shortage of appropriate data and/or the lack of resources. The emphasis is on interdisciplinary cooperation and the processes involved in scientific investigation, rather than the products of such investigation.

The exercise should be a collaborative experience where concepts and perceptions from across the group 4 disciplines are shared. The intention is that students analyse a topic or problem which can be investigated in each of the science disciplines offered by a school. The topic can be set in a local, national or international context.

Project Stages

The 10–15 hours allocated to the group 4 project, which are part of the teaching time set aside for internal assessment, can be divided into four stages: planning, definition of activities, action and evaluation.

Planning

This stage is crucial to the whole exercise and should last 2–4 hours.

- The planning stage could consist of a single session, or two or three shorter ones.
- This stage must involve all science students meeting to “brainstorm” and discuss the central topic, sharing ideas and information.
- The topic can be chosen by the students themselves or selected by the teachers.
- Where large numbers of students are involved, it may be advisable to have more than one mixed discipline group.

After selecting a topic or issue, the activities to be carried out must be clearly defined before moving from the planning stage to the action and evaluation stages.

Definition of Activities

A possible strategy is that students define specific tasks for themselves, either individually or as members of groups, and investigate various aspects of the chosen topic. Contact with other schools, if a joint venture has been agreed, is an important consideration at this time.

Action

This stage should take 6–8 hours in total and may be carried out over one or two weeks in normal scheduled class time. Alternatively a whole day could be set aside if, for example, the project involves fieldwork.

- The students (as individuals, single subject groups or mixed subject groups) should investigate the topic from the perspective of the individual science disciplines.
- There should be collaboration in the action stage; findings of investigations should be shared with others working on the project. This may be difficult if the action stage takes place during normal lessons, but it is possible to use bulletin boards (either physical or electronic) to exchange information or to use times when students are together, such as lunchtimes. Enthusiastic students will no doubt share information informally.
- During this stage it is important to pay attention to safety, ethical and environmental considerations.

Evaluation

The emphasis during this stage, for which 2–4 hours is probably necessary, is on students sharing their findings, both successes and failures, with other students. How this is achieved can be decided by the teachers, the students or jointly.

- One solution is to devote a morning, afternoon or evening to a symposium where all the students, as individuals or as groups, give brief presentations (perhaps with the aid of an overhead projector, flip charts, posters, video player, computers, etc).
- Alternatively the presentation could be more informal and take the form of a science fair where students circulate around displays summarizing the activities of each student or group.

The symposium or science fair could also be attended by parents, members of the school board and the press. This would be especially pertinent if some issue of local importance has been researched. Some of the findings might influence the way the school interacts with its environment or local community.

In addition to the presentation, each student must show evidence of their participation in the project.

Preparation

The impact the project has on the organization of the school is an important consideration. The key is the formulation of an action plan, perhaps in the form of a list of questions, to help draw up a strategy for all the activities involved. The following are suggestions for such a list (these could be adapted to suit the needs of an individual school).

- How might a topic be selected? Possibilities are a questionnaire to students, discussions with students and/or teacher selection.
- Will teachers from other non-science departments be involved?
- Will people from outside the school be used as a source of ideas for the project? If so, what is their availability?
- What communication methods are available for the coordination of activities, exchange of data and joint presentations?
- When should the project be conducted, and over what time period?
- What are the implications in terms of staff and resources?

Strategies

Considerations

Teachers will find that there are many factors to consider when planning the project work, besides deciding at what point to carry out the project and what the starting and completion dates should be. These factors include:

- the way the school's year is organized into terms or semesters
- the number of sciences offered
- the number of IB students
- whether or not the school wishes to collaborate with other schools either locally, nationally or internationally.

The needs of the students should be of foremost importance when weighing up the advantages and disadvantages of the various possibilities.

Ensuring that carrying out the project is a group experience (not restricted to a single science in group 4) may present organizational problems for some schools. The options may be limited because, for example, there is a small number of students, only one science is offered or other IB schools are some distance away. Teachers should take into account factors specific to their school and the general points made in this section when planning their strategies.

Timing

The time-span for carrying out the project is not a full two years.

- The project must be finished, at the latest, 19 months after starting teaching. Therefore, allowing for the planning stages, there may only be 18 months during which the project can be carried out. In the case of those completing the course in one year, such as anticipated SL candidates, the time available is limited further.
- Before starting work on the project students should, ideally, have some experience of working in a team.
- It is very important that students have reached a point where they have a certain degree of scientific knowledge and skills, and have experience of experimental techniques, before undertaking the project.

The 10–15 hours that the IBO recommends should be allocated to the project may be spread over a number of weeks. The distribution of these hours needs to be taken into account when selecting the optimum time to carry out the project. However, it is possible for a group to dedicate a period of time exclusively to project work if all other school work is suspended.

Year 1

In the first year students' experience and skills may be limited and it would be inadvisable to start the project too soon in the course. However, doing the project in the final part of the first year may have the advantage of reducing pressure on students later on. This strategy provides time for solving unexpected problems.

Year 1–Year 2

The planning stage could start, the topic could be decided and provisional discussion in individual subjects could take place at the end of the first year. Students could then use the vacation to think about how they are going to tackle the project and would be ready to start work early in the second year.

Year 2

Delaying the start of the project until some point in the second year, particularly if left too late, increases pressure on students in many ways: the schedule for finishing the work is much tighter than for the other options; the illness of any student or unexpected problems will present extra difficulties. Nevertheless, this choice does mean students know one another and their teachers by this time, have probably become accustomed to working in a team and will be more experienced in the relevant fields than in the first year.

Combined HL and SL

Where circumstances dictate that the project is only carried out every two years, HL beginners and more experienced SL students are combined.

General Strategies

1. Collaborate with other IB schools, including:
   - direct contact with local schools
   - post, fax, telephone, email, video conferencing.

   This is particularly useful for small schools or those with a single science, and where schools have well-established contacts they wish to exploit, or new ones they wish to develop. Where schools in different countries are linked, the importance of internationalism can be reinforced.
2. Carry out the project only every two years so that first- and second-year students can work together to make a larger group, bearing in mind the restriction on timing. (This is perhaps only necessary for small schools and may be difficult in terms of timing.)
3. Encourage IB students to work with non-IB students in the school who may be following courses leading to national or other equivalent qualifications. (This may be useful for small schools or those with a single science.)
4. Encourage participation of local teachers or experts from local industries, businesses, colleges or universities. (This may be helpful to small schools or those distant from other IB schools.)
5. Collaborate with students taking group 3 subjects such as geography, psychology or economics. (This is only relevant to schools not offering the full IB Diploma Programme.)

Selecting a Topic

In most cases all students in a single school will be involved in the investigation of the same topic. Where there are large numbers of students, it is possible to divide them into several smaller groups, each undertaking their own project. The students may choose the topic or propose possible topics; teachers then decide which one is the most viable based on resources, staff availability etc. Alternatively, the teachers select the topic or propose several topics from which students make a choice.

Student Selection

Students are likely to display more enthusiasm and feel a greater sense of ownership for a topic that they have chosen themselves. A possible strategy for student selection of a topic, which also includes part of the planning stage, is outlined below. At this point, subject teachers may provide advice on the viability of proposed topics.

- Identify possible topics by using a questionnaire or a survey of the students.
- Conduct an initial “brainstorming” session of potential topics or issues.
- Discuss, for 10 minutes, two or three topics that seem interesting.
- Select one topic by consensus.
- Examine the topic. Students in each science subject write down relevant aspects that could be studied given the local circumstances, resources etc.
- Each subject group reads out their list and a master copy is made.
- Students in each discipline make a list of potential investigations that could be carried out. All students then discuss issues such as possible overlap and collaborative investigations.

Assessment

The group 4 project forms one part of a candidate's overall practical experience and does not contribute any fixed percentage to internal assessment. A school may choose:

- not to assess the project at all
- to assess the project according to the criteria for the school's local or national requirements
- to assess the project against one or more of the IB Diploma Programme internal assessment criteria.

The project may produce evidence for the full range of criteria, particularly *planning (a)* and *(b)*, and *personal skills (a)* and *(b)*.

Given the diverse nature of the activities associated with the project, it may be difficult for a single teacher to gain a fair overview of an individual student's contribution, especially in regard to *planning* and *personal skills*. It may be necessary for teachers to exchange observations and comments concerning student performance. Group, peer and self-evaluation can also contribute valuable extra information.

Participation

The evidence of a candidate's involvement in the project, required by the IBO in a moderation sample, can take a variety of forms. It must be accompanied by a copy of the written instructions and/or a summary of the verbal instructions given in relation to the project.

For each student in the moderation sample, the evidence may be:

- a statement written by the student about his/her own individual contributions
- a copy of a self-evaluation form
- a copy of a peer-evaluation form
- an individual laboratory report or complete project report
- rough work or a record of data collected by the student
- photographs, eg of a final poster produced by the group.

PART 2—PHYSICS

NATURE OF THE SUBJECT

Physics is the most fundamental of the experimental sciences as it seeks to explain the universe itself, from the very smallest particles—quarks (perhaps 10^{-17} m in size) which may be truly fundamental—to the vast distances between galaxies (10^{24} m).

Classical physics, built upon the great pillars of Newtonian mechanics, electromagnetism and thermodynamics, went a long way in deepening our understanding of the universe. From Newtonian mechanics came the idea of predictability in which the universe is deterministic and knowable. This led to Laplace's boast that by knowing the initial conditions—the position and velocity of every particle in the universe—he could, in principle, predict the future with absolute certainty. Maxwell's theory of electromagnetism described the behaviour of electric charge and unified light and electricity, while thermodynamics described the relation between heat and work and described how all natural processes increase disorder in the universe.

However, experimental discoveries dating from the end of the nineteenth century eventually led to the demise of the classical picture of the universe as being knowable and predictable. Newtonian mechanics failed when applied to the atom and has been superseded by quantum mechanics and general relativity. Maxwell's theory could not explain the interaction of radiation with matter and was replaced by quantum electrodynamics (QED). More recently, developments in chaos theory, in which it is now realized that small changes in the initial conditions of a system can lead to completely unpredictable outcomes, have led to a fundamental rethinking in thermodynamics.

While chaos theory shows that Laplace's boast is hollow, quantum mechanics and QED show that the initial conditions Laplace required are impossible to establish. Nothing is certain and everything is decided by probability. But there is still much that is unknown and there will undoubtedly be further paradigm shifts as our understanding deepens.

Despite the exciting and extraordinary development of ideas throughout the history of physics, certain things have remained unchanged. Observations remain essential at the very core of physics, and this sometimes requires a leap of imagination to decide what to look for. Models are developed to try to understand the observations and these themselves can become theories which attempt to explain the observations. Theories are not directly derived from the observations but need to be created. These acts of creation can sometimes compare to those in great art, literature and music, but differ in one aspect which is unique to science: the predictions of these theories or ideas must be tested by careful experimentation. Without these tests a theory is useless. A general or concise statement about how nature behaves, if found to be experimentally valid over a wide range of observed phenomena, is called a law or a principle.

The scientific processes carried out by the most eminent scientists in the past are the same ones followed by working physicists today and, crucially, are also accessible to students in schools. Early in the development of science physicists were both theoreticians and experimenters (natural philosophers). The body of scientific knowledge has grown in size and complexity and the tools and skills of theoretical and experimental physicists have become so specialized that it is difficult (if not impossible) to be highly proficient in both areas. While students should be aware of this, they should also know that the free and rapid interplay of theoretical ideas and experimental results in the public scientific literature maintains the crucial links between these fields.

At the school level both theory and experiments should be undertaken by all students. They should complement one another naturally, as they do in the wider scientific community. The Diploma Programme physics course allows students to develop traditional practical skills and techniques and increase facility in the use of mathematics, which is the language of physics. It also allows students to develop interpersonal skills, and information and communication technology skills which are essential in modern scientific endeavour and are important life-enhancing, transferable skills in their own right.

Alongside the growth in our understanding of the natural world, perhaps the more obvious and relevant result of physics to most of our students is our ability to change the world. This is the technological side of physics in which physical principles have been applied to construct and alter the material world to suit our needs, and have had a profound influence on the daily lives of all human beings; for good or bad. This raises the issue of the impact of physics on society, the moral and ethical dilemmas and the social, economic and environmental implications of the work of physicists. These concerns have become more prominent as our power over the environment has grown, particularly amongst young people for whom the importance of the responsibility of physicists for their own actions is self-evident.

Physics is therefore, above all, a human activity and students need to be aware of the context in which physicists work. Illuminating its historical development places the knowledge and the process of physics in a context of dynamic change in contrast to the static context in which physics has sometimes been presented. This can give students insights into the human side of physics: the individuals; their personalities, times and social milieux; and their challenges, disappointments and triumphs.

SYLLABUS OVERVIEW

The syllabus for the Diploma Programme physics course is divided into three parts: the core, the additional higher level (AHL) material and the options. A syllabus overview is provided below.

Core [80h]

Topics

		Teaching hours
1	Physics and physical measurement	11
2	Mechanics	24
3	Thermal physics	11
4	Waves	10
5	Electricity and magnetism	15
6	Atomic and nuclear physics	9

Additional Higher Level [55h]

Topics

		Teaching hours
7	Measurement and uncertainties	2
8	Mechanics	15
9	Thermal physics	6
10	Wave phenomena	8
11	Electromagnetism	9
12	Quantum physics and nuclear physics	15

Options

Options SL

		Teaching hours
A	Mechanics extension	15
B	Quantum physics and nuclear physics	15
C	Energy extension	15

Options SL/HL

D	Biomedical physics	15/22
E	The history and development of physics	15/22
F	Astrophysics	15/22
G	Relativity	15/22
H	Optics	15/22

Standard level candidates are required to study any **two** options from A–H.
The duration of each option is 15 hours.

Higher level candidates are required to study any **two** options from D–H.
The duration of each option is 22 hours.

SYLLABUS OUTLINE

Core [80h]

			Teaching hours
Topic 1	**Physics and physical measurement**		**[11]**
	1.1	The realm of physics	2
	1.2	Measurement and uncertainties	2
	1.3	Mathematical and graphical techniques	3
	1.4	Vectors and scalars	4
Topic 2	**Mechanics**		**[24]**
	2.1	Kinematics	6
	2.2	Forces and dynamics	5
	2.3	Inertial mass, gravitational mass and weight	1
	2.4	Momentum	4
	2.5	Work, energy and power	6
	2.6	Uniform circular motion	2
Topic 3	**Thermal physics**		**[11]**
	3.1	Thermal concepts	3
	3.2	Thermal properties of matter	5
	3.3	Ideal gases	3
Topic 4	**Waves**		**[10]**
	4.1	Travelling waves	3
	4.2	Wave properties	5
	4.3	Standing waves	2
Topic 5	**Electricity and magnetism**		**[15]**
	5.1	Electrostatics	6
	5.2	Electric current and electric circuits	6
	5.3	Magnetism	3
Topic 6	**Atomic and nuclear physics**		**[9]**
	6.1	The atom	2
	6.2	Radioactive decay	3
	6.3	Nuclear reactions, fission and fusion	4

Additional Higher Level [55h]

		Teaching hours
Topic 7	**Measurement and uncertainties**	**[2]**
7.1	Graphical analysis	1
7.2	Uncertainties	1
Topic 8	**Mechanics**	**[15]**
8.1	Projectile motion	3
8.2	Gravitation	5
8.3	Orbital motion	2
8.4	Friction	2
8.5	Statics	3
Topic 9	**Thermal physics**	**[6]**
9.1	Thermodynamic systems and concepts	1
9.2	Processes	4
9.3	Second law of thermodynamics and entropy	1
Topic 10	**Wave phenomena**	**[8]**
10.1	Doppler effect	2
10.2	Beats	2
10.3	Two-source interference of waves	4
Topic 11	**Electromagnetism**	**[9]**
11.1	Electrostatic potential	3
11.2	Electromagnetic induction	4
11.3	Alternating current	2
Topic 12	**Quantum physics and nuclear physics**	**[15]**
12.1	Quantum physics	9
12.2	Nuclear physics	3
12.3	Particle physics	3

Options Standard Level

		Teaching hours
Option A	**Mechanics extension**	**[15]**
A.1	Projectile motion	3
A.2	Gravitation	5
A.3	Orbital motion	2
A.4	Friction	2
A.5	Statics	3
Option B	**Quantum physics and nuclear physics**	**[15]**
B.1	Quantum physics	9
B.2	Nuclear physics	3
B.3	Particle physics	3
Option C	**Energy extension**	**[15]**
C.1	Thermodynamic systems and concepts	1
C.2	Processes	4
C.3	Second law of thermodynamics and entropy	1
C.4	Energy sources and power production	9

Options Standard Level/Higher Level

Standard level students study the core of these options, and higher level students study the whole option (ie the core and the extension material).

		Teaching Hours
Option D	**Biomedical physics**	
	Core (SL + HL)	**[15]**
D.1	Scaling laws—size, form and function	3
D.2	Sound and hearing	5
D.3	Medical imaging	7
	Extension (HL only)	**[7]**
D.4	Biomechanics	3
D.5	Radiation in medicine	4
Option E	**The history and development of physics**	
	Core (SL + HL)	**[15]**
E.1	Astronomy and development of models of the universe	5
E.2	Mechanics	2
E.3	Concepts of heat	2
E.4	Electricity and magnetism	3
E.5	Atomic and nuclear physics	3
	Extension (HL only)	**[7]**
E.6	The quantum concept and atomic models	7

		Teaching Hours
Option F	**Astrophysics**	
	Core (SL + HL)	**[15]**
F.1	Introduction to the universe	2
F.2	Stellar radiation and stellar types	4
F.3	Stellar distances	5
F.4	Cosmology	4
	Extension (HL only)	**[7]**
F.5	Stellar processes and stellar evolution	4
F.6	Galaxies and the expanding universe	3
Option G	**Relativity**	
	Core (SL + HL)	**[15]**
G.1	Introduction	1
G.2	Concepts and postulates of special relativity	2
G.3	Relativistic kinematics	5
G.4	Some consequences of special relativity	4
G.5	Evidence to support special relativity	3
	Extension (HL only)	**[7]**
G.6	Relativistic momentum and energy	2
G.7	General relativity	4
G.8	Evidence to support general relativity	1
Option H	**Optics**	
	Core (SL + HL)	**[15]**
H.1	The nature of light	3
H.2	Reflection at a plane surface	2
H.3	Refraction at a plane interface	3
H.4	Refraction by lenses	3
H.5	Optical instruments	4
	Extension (HL only)	**[7]**
H.6	Diffraction and interference	5
H.7	Thin film interference	2

SYLLABUS DETAILS

Topic 1: Physics and Physical Measurement (11h)

A.S. Obj

1.1 The Realm of Physics (2h)

Range of magnitudes of quantities in our universe

1.1.1 State (express) quantities to the nearest order of magnitude. **1**

1.1.2 State the ranges of magnitude of sizes, masses and times that occur in the universe, from smallest to greatest. **1**

> Sizes—from 10^{-15} m to 10^{+25} m (subnuclear particles to extent of the visible universe).
>
> Masses—from 10^{-30} kg to 10^{+50} kg (electron to mass of the universe).
>
> Times—from 10^{-23} s to 10^{+18} s (passage of light across a nucleus to the age of the universe).

1.1.3 State and compare the order of magnitude of selected (significant) systems in the universe. **2**

> Students should become familiar with the order of magnitudes of significant systems with which they deal, and aim to develop a familiarity with the orders of magnitudes of important masses, lengths, times and other quantities.

1.1.4 State (express) ratios of quantities as differences of orders of magnitude. **1**

> For example, the ratio of the diameter of the hydrogen atom to its nucleus is about 10^5 times, or a difference of five orders of magnitude.

1.2 Measurement and Uncertainties (2h)

The SI system of fundamental and derived units

1.2.1 State the fundamental units in the SI system. **1**

> Students need to know the following: kilogram, meter, second, ampere, mole and kelvin.

1.2.2 Distinguish between, and give examples of, fundamental and derived units. **2**

A.S.		Obj
1.2.3	Convert between different units for quantities. For example, J and kWh, J and eV, years and seconds, and between other systems and SI.	2
1.2.4	State units in the accepted SI format. Use m s^{-2} not m/s/s and m s^{-1} not m/s.	1
1.2.5	State values in scientific notation and in multiples of units with appropriate prefixes. For example, use nanoseconds or gigajoules.	1

Uncertainty and error in experimental measurement

1.2.6	Describe, distinguish between and give examples of random uncertainties and systematic errors.	2
1.2.7	Distinguish between *precision* and *accuracy*. For example, repeated measurements on a voltmeter may have great precision in that they are highly reproducible with small scatter and uncertainty, yet they may be inaccurate (for example if the voltmeter has a zero offset error).	2
1.2.8	Explain how the effects of random uncertainties may be reduced. Students should be aware that systematic errors are not reduced by repeating readings.	3
1.2.9	State random uncertainty as an uncertainty range (±) and represent it graphically as an "error bar".	1
1.2.10	Identify values of quantities and results of calculations to the appropriate number of significant digits. The number of significant digits should reflect the precision of the value or of the input data to a calculation. Only a simple rule is required: for multiplication and division, the number of significant digits in a result should not exceed that of the least precise value upon which it depends.	2

1.3 Mathematical and Graphical Techniques (3h)

Estimation

1.3.1	Estimate approximate values of everyday quantities to one or two significant digits and/or to the nearest order of magnitude. Reasonable estimates for common quantities, eg dimensions of a brick, mass of an apple, duration of a heartbeat or room temperature are expected.	2

A.S.		Obj
1.3.2	State and explain simplifying assumptions in approaching and solving problems. For example, reasonable assumptions that certain quantities may be neglected, others ignored (eg heat losses, internal resistance), or that behaviour is approximately linear.	3
1.3.3	Estimate results of calculations. Examples: $174/118 \approx 180/120 = 3/2 = 1.5$ or $6.3 \times 7.6/4.9 \approx 6 \times 8/5 = 48/5 \approx 50/5 \approx 10$.	2
	Graphs	
1.3.4	Construct graphs from data, choosing suitable scales for the axes. Include or suppress the zero on an axis as appropriate.	3
1.3.5	Draw qualitative graphs to represent dependencies and interpret graph behaviour. Students should be able to give a qualitative physical interpretation of a particular graph, eg as the potential difference increases, the ionization current reaches a maximum.	1
1.3.6	Determine the values of physical quantities from graphs. Include measuring and interpreting the slope (gradient), intercepts and area under a curve, and stating the units for these quantities.	3
1.3.7	Draw best-fit lines to data points on a graph. These can be curves or straight lines as appropriate. Fitting by eye is expected. Mathematical fitting is not required. Students should not join data points with segments.	1
	Graphical analysis and determination of relationships	
1.3.8	Transform equations into generic straight-line form $y = mx + c$ and plot the corresponding graph. This can include plotting various functions of the variables such as reciprocals, powers and roots. Logarithmic functions are not required.	2
1.3.9	Analyse a straight-line graph to determine the equation relating the variables. The parameters of the original function can be obtained from the slope m and intercept c.	3

A.S.		Obj

1.4 Vectors and Scalars (4h)

Note: Although vectors are mentioned here at the beginning of the physics syllabus, this does not necessarily represent the order in which they should be taught. Vectors may be developed within other sections, for example in the context of particular quantities such as force, displacement or velocity.

A.S.		Obj
1.4.1	Distinguish between vector and scalar quantities, and give examples of each. When expressing a vector as a symbol, students should adopt a recognized notation.	**2**
1.4.2	Draw arrows of appropriate length and direction to represent vector quantities.	**1**
1.4.3	State vector quantities either in terms of magnitude and direction or by their components along chosen axes.	**1**
1.4.4	Add and subtract vector quantities by the graphical method. Add and subtract accurately by construction, or approximately, if an estimate is required. Multiplication and division of vectors by scalars is also required.	**1**
1.4.5	Resolve vectors into perpendicular components along chosen axes. For example, resolving parallel and perpendicular to an inclined plane. Choose appropriate axes along which to resolve according to the needs of the physical situation.	**2**
1.4.6	Interpret the physical meaning of vector components where appropriate. For example, interpret vertical and horizontal components of velocity in projectile motion, or force components along and perpendicular to an inclined plane.	**2**
1.4.7	Add two or more vectors by the method of components. First resolve into components, then add the components and recombine them into a resultant vector. Pythagoras' theorem and basic trigonometry are required but not the sine and cosine rules.	**2**
1.4.8	Solve problems involving the vector nature of physical quantities. Problems may involve the vector nature of quantities such as displacement, velocity, acceleration, momentum, force and fields.	**3**

Topic 2: Mechanics (24h)

A.S.		Obj
	2.1 Kinematics (6h)	
	Kinematic concepts	
2.1.1	Define *displacement*, *velocity*, *speed* and *acceleration*. Quantities should be identified as scalar or vector quantities.	1
2.1.2	Define and explain the difference between *instantaneous* and *average* values of speed, velocity and acceleration.	3
2.1.3	Describe an object's motion from more than one frame of reference. Students should be familiar with the term *relative velocity* and should be able to calculate relative velocities in one dimension.	2
	Graphical representation of motion	
2.1.4	Draw and analyse distance–time graphs, displacement–time graphs, velocity–time graphs and acceleration–time graphs. Students should be able to sketch and label these graphs for various situations. They should also be able to write descriptions of the motions represented by such graphs.	3
2.1.5	Analyse and calculate the slopes of displacement–time graphs and velocity–time graphs, and the areas under velocity–time graphs and acceleration–time graphs. Relate these to the relevant kinematic quantity.	3
	Uniformly accelerated motion	
2.1.6	Determine the velocity and acceleration from simple timing situations. Students should be able to interpret data from devices such as a light gate, strobe photograph or ticker timer. Analysis may involve graphing the data, taking measurements and applying kinematics concepts.	3
2.1.7	Derive the equations for uniformly accelerated motion.	3
2.1.8	Describe the vertical motion of an object in a uniform gravitational field.	2
2.1.9	Describe the effects of air resistance on falling objects. Only qualitative descriptions are expected. Students should understand the term terminal velocity.	2
2.1.10	Solve problems involving uniformly accelerated motion.	3

A.S.		Obj
	2.2 Forces and Dynamics (5h)	
	Forces and free-body diagrams	
2.2.1	Describe force as the cause of deformation or velocity change.	2
2.2.2	Identify the forces acting on an object and draw free-body diagrams representing the forces acting. Each force should be labelled by name or given a commonly accepted symbol. Vectors should have lengths approximately proportional to their magnitudes.	2
2.2.3	Resolve forces into components.	3
2.2.4	Determine the resultant force in different situations.	3
2.2.5	Describe the behaviour of a linear spring and solve related problems. Spring combinations will not be assessed.	3
	Newton's first law	
2.2.6	State Newton's first law of motion.	1
2.2.7	Describe examples of Newton's first law.	2
	Equilibrium	
2.2.8	State the condition for translational equilibrium.	1
2.2.9	Solve problems involving translational equilibrium.	3
	Newton's second law	
2.2.10	State Newton's second law of motion. Students should be familiar with the law in both the forms $F = ma$ and $F = \Delta p/\Delta t$.	1
2.2.11	Solve problems involving Newton's second law.	3
	Newton's third law	
2.2.12	State Newton's third law of motion. Students should understand that when two bodies A and B interact, the force that A exerts on B is equal and opposite to the force that B exerts on A.	1
2.2.13	Discuss examples of Newton's third law.	3

A.S.		Obj

2.3 Inertial Mass, Gravitational Mass and Weight (1h)

2.3.1	Define *inertial mass*. Students should describe inertial mass as the ratio of resultant force to acceleration.	1
2.3.2	Compare gravitational mass and inertial mass. Students should understand that although the concepts of gravitational mass and inertial mass are different, they have identical values. A simple argument should be given to show that the equivalence of gravitational mass and inertial mass accounts for objects having the same value for free-fall acceleration.	2
2.3.3	Discuss the concept of *weight*. Students should understand that usage of the term *weight* can be ambiguous, eg weight can mean the gravitational force mg and the reading on a supporting scale; these have different values in non-equilibrium situations.	3
2.3.4	Distinguish between mass and weight.	2

2.4 Momentum (4h)

2.4.1	Define *linear momentum* and *impulse*.	1
2.4.2	State the law of conservation of linear momentum.	1
2.4.3	Derive the law of conservation of momentum for an isolated system consisting of two interacting particles. The law is derived by applying Newton's second law to each particle and Newton's third law to the system.	3
2.4.4	Solve problems involving momentum and impulse. Students should be familiar with elastic and inelastic collisions and explosions.	3

2.5 Work, Energy and Power (6h)

Work

2.5.1	Define *work*. Students should be familiar with situations where the displacement is not in the same direction as the force.	1
2.5.2	Determine the work done by a non-constant force by interpreting a force–displacement graph.	3
2.5.3	Solve problems involving the work done on a body by a force.	3

A.S.		Obj
	Energy and power	
2.5.4	Define *kinetic energy*.	**1**
2.5.5	Describe the concepts of gravitational potential energy and elastic potential energy.	**2**
2.5.6	State the principle of conservation of energy.	**1**
2.5.7	List different forms of energy and describe examples of the transformation of energy from one form into another.	**2**
2.5.8	Define *power*.	**1**
2.5.9	Define and apply the concept of efficiency.	**2**
2.5.10	Solve work, energy and power problems.	**3**

2.6 Uniform Circular Motion (2h)

2.6.1	Draw a vector diagram to show that the acceleration of a particle moving with uniform speed in a circle is directed toward the centre of the circle.	**1**
2.6.2	State the expression for centripetal acceleration.	**1**
2.6.3	Identify the force producing circular motion in various situations. Examples include gravitational force (acting on the moon) and friction (acting sideways on the tyres of a car turning a corner).	**2**
2.6.4	Solve problems for particles moving in circles with uniform speed.	**3**

Topic 3: Thermal Physics (11h)

A.S. Obj

3.1 Thermal Concepts (3h)

Temperature and thermometers

3.1.1 State that temperature is a property that determines the direction of thermal energy transfer between two bodies in thermal contact. **1**

Students should be familiar with the concept of thermal equilibrium.

3.1.2 Explain how a temperature scale is constructed. **3**

3.1.3 State the relation between the Kelvin and Celsius scales of temperature. **1**

$T/\mathrm{K} = t/^{\circ}\mathrm{C} + 273$ is sufficient.

Heat and internal energy

3.1.4 State that temperature is a measure of the average kinetic energy of the molecules of a substance. **1**

3.1.5 State that internal energy is the total potential and kinetic energy of molecules in a substance. **1**

Students should know that the kinetic energy of the molecules arises from their translational/rotational motion and that the potential energy of the molecules arises from the forces between the molecules.

3.1.6 Explain and distinguish between the macroscopic concepts of temperature, internal energy and heat. **3**

Thermal energy transfer

3.1.7 Describe qualitatively, the processes of conduction, convection and radiation. **2**

3.1.8 Describe examples of conduction, convection and radiation. **2**

3.2 Thermal Properties of Matter (5h)

Specific heat capacity

3.2.1 Define and distinguish between *heat capacity* and *specific heat capacity*. **2**

3.2.2 Explain why different substances have different specific heat capacities. **3**

This should be understood in terms of the fact that unit masses of different substances contain different numbers of molecules of different mass.

A.S.		Obj
3.2.3	Describe methods to measure the specific heat capacity of solids and liquids. The electrical method and the method of mixtures are sufficient. The cooling correction is not included in the calculation. Sources of experimental error should be identified and ways to reduce these should be known. Constant flow techniques are not required.	**2**
3.2.4	Solve problems involving specific heat capacities.	**3**
	Phases (states) of matter and latent heat	
3.2.5	Describe the solid, liquid and gaseous states in terms of molecular structure and motion. Only a simple model is required. The speed distribution in gases should be explained qualitatively. Students should be aware how microscopic structure explains bulk behaviour.	**2**
3.2.6	Describe and explain the process of phase changes in terms of molecular behaviour.	**3**
3.2.7	Explain in terms of molecular behaviour why temperature does not change during a phase change.	**3**
3.2.8	Define *specific latent heat*.	**1**
3.2.9	Describe a method for measuring the specific latent heat of fusion and a method for measuring the specific latent heat of vaporization. Adding ice to water in a calorimeter would be suitable for fusion and an electrical method would be suitable for vaporization.	**2**
3.2.10	Solve problems involving specific latent heats. Problems may include all three phases of a substance and specific heat calculations.	**3**
3.2.11	Describe the evaporation process in a liquid in terms of molecular behaviour. Students should be aware that evaporation takes place at all temperatures and results in the cooling of a liquid.	**2**
3.2.12	Identify factors that affect evaporation rate.	**2**

A.S.		Obj

3.3 Ideal Gases (3h)

Gas laws

3.3.1 State the macroscopic gas laws relating pressure, volume and temperature. **1**

Students should be aware that real gases deviate from these laws under certain conditions and that an ideal gas is one that follows the gas laws for all values of p, V and T.

3.3.2 Define the terms *mole* and *molar mass*. **1**

Students should be able to convert between mass and number of moles.

3.3.3 Define the *Avogadro constant*. **1**

3.3.4 State that the equation of state of an ideal gas is $pV = n\mathrm{R}T$. **1**

3.3.5 Describe the concept of the absolute zero and the Kelvin scale. **2**

3.3.6 Solve problems using the equation of state of an ideal gas. **3**

Kinetic model of an ideal gas

3.3.7 Describe the kinetic model of an ideal gas. **2**

Students should be able to describe how the pressure arises from the collisions of the molecules with the walls of the container.

3.3.8 Explain the macroscopic behaviour of an ideal gas in terms of the molecular model. **3**

Only qualitative explanations are required.

Topic 4: Waves (10h)

A.S.		Obj
	4.1 Travelling Waves (3h)	
	Waves	
4.1.1	Describe a wave pulse and a continuous travelling wave. Students should be able to distinguish between the oscillations and the wave motion.	**2**
4.1.2	State that waves transfer energy. Students should understand that there is no net motion of the medium through which the wave travels.	**1**
4.1.3	Describe and give examples of transverse and longitudinal waves. Students should know that sound is a longitudinal wave and that light is a transverse wave.	**2**
4.1.4	Describe waves in two dimensions, including the concepts of wave fronts and rays.	**2**
	Wave characteristics	
4.1.5	Define *displacement*, *amplitude*, *period*, *frequency*, *wavelength* and *wave speed*.	**1**
4.1.6	Describe the terms *crest*, *trough*, *compression* and *rarefaction*.	**2**
4.1.7	Draw and explain displacement–time and displacement–position graphs for transverse and longitudinal waves.	**3**
4.1.8	Derive and apply the relationship between wave speed, wavelength and frequency.	**3**

A.S.		Obj

4.2 Wave Properties (5h)

Note: Although the properties apply to all waves, students should be familiar with the particular cases of sound, light and water.

Reflection, refraction and transmission of waves

A.S.		Obj
4.2.1	Describe the reflection and transmission of one-dimensional waves at a boundary between two media. This should include the sketching of incident, reflected and transmitted waves, and the cases of reflection at free and fixed ends.	2
4.2.2	State Huygens' principle.	1
4.2.3	Apply Huygens' principle to two-dimensional plane waves to show that the angle of incidence is equal to the angle of reflection.	2
4.2.4	Explain refraction using Huygens' principle.	3
4.2.5	Derive, using Huygens' principle, Snell's law for refraction. The concept of refractive index is not required but the ratio of speeds is expected.	3
4.2.6	State and apply Snell's law.	2

Wave diffraction and interference

A.S.		Obj
4.2.7	Explain and discuss qualitatively, using Huygens' principle, the diffraction of waves by apertures and obstacles. The effect of wavelength compared to obstacle size or aperture size should be discussed.	3
4.2.8	Describe examples of diffraction.	2
4.2.9	State the principle of superposition and explain what is meant by constructive and destructive interference.	3
4.2.10	Apply the principle of superposition to find the resultant of two waves. Only one-dimensional situations need to be considered.	2

Doppler effect

A.S.		Obj
4.2.11	Describe the Doppler effect. Only a simple description of the effect for both sound and light is required.	2

A.S.		Obj
	4.3 Standing Waves (2h)	
	Nature and production of standing waves	
4.3.1	Describe the nature of standing waves.	**2**
4.3.2	Explain the formation of standing waves in one dimension.	**3**
4.3.3	Compare standing waves and travelling waves.	**2**
	Boundary conditions and resonance	
4.3.4	Explain the concept of resonance and state the conditions necessary for resonance to occur.	**3**
4.3.5	Describe the fundamental and higher resonant modes in strings and open and closed pipes. Note that fundamental and first harmonic are interchangeable terms.	2
4.3.6	Solve problems involving the fundamental and higher harmonic modes for stretched strings and open and closed pipes. End correction is not required.	**3**

Topic 5: Electricity and Magnetism (15h)

A.S.		Obj
	5.1 Electrostatics (6h)	
	Electric charge	
5.1.1	Describe the process of “electrification” by friction.	2
5.1.2	State that there are two types of electric charge.	1
5.1.3	State and apply the concept of conservation of charge.	2
5.1.4	Describe and explain the properties of conductors and insulators. Students should explain the properties in terms of the freedom of movement of electrons.	3
5.1.5	Explain and describe the process of electrostatic induction.	3
5.1.6	Describe the use of the gold leaf electroscope.	2
	Electric force and electric field	
5.1.7	State Coulomb’s law. Students should be aware of the law in the forms $F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$ and $F = \frac{k q_1 q_2}{r^2}$.	1
5.1.8	Apply Coulomb’s law. The use of vector addition to determine the net force on a charge due to two or more other charges is expected.	2
5.1.9	Define *electric field*. Students should understand the meaning of test charge.	1
5.1.10	Determine the electric field due to one or more point charges.	3
5.1.11	Draw and explain electric field patterns for different charge configurations. Students should be familiar with a point charge, a charged sphere, two point charges and oppositely charged parallel plates. The latter includes edge effect. Students should be aware of the term *radial field*.	3

A.S.		Obj
	Electric potential energy and electric potential difference	
5.1.12	Define the electric potential energy difference between two points in an electric field. Calculations are to be confined to uniform electric fields.	1
5.1.13	Determine the change in potential energy or change in kinetic energy when a charge moves between two points at different potentials.	3
5.1.14	Define the *electronvolt*. Students should be able to relate the electronvolt to the joule.	1
5.1.15	Define *electric potential difference*.	1
5.1.16	Solve problems involving electric potential difference and electric potential energy.	3

5.2 Electric Current and Electric Circuits (6h)

Electric current

5.2.1	Describe a simple model of electrical conduction in a metal. Students should be aware of the term *drift velocity* and of the interactions of conduction electrons with the lattice ions.	2
5.2.2	Define *electric current*. Students should recognize the ampere as a fundamental unit.	1
5.2.3	Define and apply the concept of resistance. Students should be aware that $R = V/I$ is a general definition of resistance. It is not a statement of Ohm's law. Students should be familiar with the term *resistor*.	2
5.2.4	State Ohm's law.	1
5.2.5	Compare ohmic and non-ohmic behaviour. For example, students should be able to draw the I–V characteristics of a filament lamp.	2
5.2.6	Derive and apply expressions for electrical power dissipation in resistors.	3

Electric circuits

5.2.7	Define *electromotive force*.	1
5.2.8	Describe the concept of internal resistance.	2

A.S.		Obj
5.2.9	Derive and apply the equations for equivalent resistances of resistors in series and in parallel.	**3**
5.2.10	Draw circuit diagrams. Students should be able to recognize and use the accepted circuit symbols included in the *Physics Data Booklet*.	**1**
5.2.11	Describe the use of ammeters and voltmeters. Students should be able to describe and draw the correct positioning of ideal ammeters and voltmeters in circuits. Students will not be required to know about shunts and multipliers.	**2**
5.2.12	Solve problems involving series and parallel circuits. Students should appreciate that many circuit problems can be solved by regarding the circuit as a potential divider. Students should be aware that ammeters and voltmeters have their own resistance.	**3**

5.3 Magnetism (3h)

Magnets and magnetic fields

5.3.1	Draw the pattern of magnetic field lines of an isolated bar magnet.	**1**
5.3.2	Draw the magnetic field pattern for the Earth. Students should understand that the Earth's magnetic field is similar to that of a bar magnet with a south magnetic pole near the geographic north pole, and that an isolated suspended magnet will orientate itself along the Earth's magnetic field with its magnetic north pole directed towards the Earth's geographic north pole. They should recognize the compass as one example of a suspended bar magnet.	**1**
5.3.3	Draw and annotate magnetic fields due to currents. These include fields around a straight wire, a flat circular coil and a solenoid. Students should recognize that the magnetic field pattern of a solenoid is similar to that of a bar magnet.	**2**

Magnetic forces

5.3.4	Determine the direction of the force on a current-carrying conductor in a magnetic field. Different rules may be used to determine the force direction. Knowledge of any particular rule is not required.	**3**
5.3.5	Determine the direction of the force on a charge moving in a magnetic field.	**3**

A.S.		Obj
5.3.6	Define the magnitude of the magnetic field strength *B*. This can be defined in terms of the force acting either on a current-carrying conductor or on a moving charge.	1
5.3.7	Solve problems involving the magnetic forces on currents and moving charges. Students should be able to calculate the force for situations where the velocity is not perpendicular to the magnetic field direction.	3
5.3.8	Draw the magnetic field pattern due to two parallel current-carrying wires.	1
5.3.9	Solve problems involving the magnetic forces between two parallel current-carrying wires.	3
5.3.10	State and explain the definition of the ampere. Students should be able to explain how the force between two long parallel currents is the basis of the definition of the ampere.	3
5.3.11	Explain the operation of a simple direct current (dc) motor. Students should understand the components of dc motors, such as the commutator and the brushes.	3

The magnetic field due to currents

A.S.		Obj
5.3.12	Solve problems involving the magnetic field strength around a straight wire.	3
5.3.13	Solve problems involving the magnetic field strength within a solenoid. Students should be aware that *B* depends on the nature of the solenoid core.	3

Topic 6: Atomic and Nuclear Physics (9h)

A.S.		Obj
	6.1 The Atom (2h)	
	Atomic structure	
6.1.1	Describe a model of the atom that features a small nucleus surrounded by electrons.	2
6.1.2	Outline the evidence that supports a nuclear model of the atom. A qualitative explanation of the Geiger–Marsden experiment and its results is all that is required.	2
6.1.3	Outline evidence for the existence of atomic energy levels. Students should be familiar with emission and absorption spectra, but the details of atomic models are not required.	2
	Nuclear structure	
6.1.4	Describe the existence of isotopes as evidence for neutrons.	2
6.1.5	Explain the terms *nuclide, isotope* and *nucleon*.	3
6.1.6	Define *mass number* and *atomic number*.	1
6.1.7	Describe the interactions in the nucleus. Students should be aware that there is a Coulomb interaction between protons and a strong, short-range nuclear interaction between the nucleons.	2
	6.2 Radioactive Decay (3h)	
	Radioactivity	
6.2.1	Describe the phenomenon of natural radioactive decay.	2
6.2.2	Describe alpha, beta and gamma radiation and their properties.	2
6.2.3	Describe the ionizing properties of radiation and its use in the detection of radiation. The Geiger–Muller tube and the ionization chamber are examples of such detection devices. Only a qualitative understanding of the operation of these devices is required.	2

A.S.		Obj
6.2.4	Explain why some nuclei are stable while others are unstable. An explanation in terms of relative numbers of protons and neutrons and the forces involved is all that is required.	3
6.2.5	Determine the atomic and mass numbers of the products of nuclear decay in a transformation or in a series of transformations. Positron decay and the inclusion of the antineutrino in beta minus decay are not required but teachers should not artificially avoid mentioning them.	3

Half-life

6.2.6	State that radioactive decay is a random process and that the average rate of decay for a sample of a radioactive isotope decreases exponentially with time. Exponential decay need not be treated analytically. It is sufficient to know that any quantity that reduces to half its initial value in a constant time decays exponentially and that this law does not depend on the initial amount of the quantity.	1
6.2.7	Define the term *half-life.*	1
6.2.8	Determine the half-life of a nuclide from a decay curve. It is sufficient for students to find a halving-time.	3
6.2.9	Solve radioactive decay problems involving integral numbers of half-lives.	3

6.3 Nuclear Reactions, Fission and Fusion (4h)

Nuclear reactions

6.3.1	Describe and give an example of artificial (induced) transmutation.	2
6.3.2	Construct and complete nuclear reaction equations. For example, ${}^{4}_{2}He+{}^{14}_{7}N={}^{17}_{8}O+{}^{1}_{1}H \qquad {}^{6}_{3}Li + {}^{1}_{0}n = {}^{3}_{1}H + {}^{4}_{2}He$	3
6.3.3	Define the term *unified mass unit*.	1
6.3.4	State and apply Einstein's mass–energy equivalence relationship.	2
6.3.5	Explain the concepts of mass defect and binding energy.	3
6.3.6	Solve problems involving mass defect and binding energies.	3

A.S.		Obj
	Fission and fusion	
6.3.7	Describe the processes of nuclear fission and fusion. Students should be familiar with the concept of a chain reaction.	**2**
6.3.8	Draw and annotate a graph of binding energy per nucleon against atomic number Z, and apply it to predict nuclear energy changes for both the fission and fusion processes.	**2**
6.3.9	State that nuclear fusion is the main source of the Sun's energy.	**1**
6.3.10	Solve problems involving fission and fusion reactions.	**3**

Topic 7: Measurement and Uncertainties (2h)

A.S. Obj

7.1 Graphical Analysis (1h)

Logarithmic functions

7.1.1 Transform equations involving power laws and exponentials into the generic straight line form $y = mx + c$ and plot the corresponding log-log and semi-log graphs from the data. **3**

The use of log-linear and log-log graph paper is not required.

7.1.2 Analyse log-log and semi-log graphs to determine the equation relating two variables. **3**

Students should be able to determine the parameters of the original equation from the slope and the intercept.

7.2 Uncertainties (1h)

Uncertainties in calculated results

7.2.1 State uncertainties as absolute, fractional and percentage uncertainties. **1**

7.2.2 Determine the uncertainties in results calculated from quantities with uncertainties. **3**

A simple approximate method rather than root mean square calculations is sufficient to determine maximum uncertainties. For functions such as addition and subtraction, absolute uncertainties can be added. For multiplication, division and powers, percentage uncertainties can be added. For other functions (eg trigonometrical functions) the mean, highest and lowest possible answers can be calculated to obtain the uncertainty range. If one uncertainty is much larger than others, the approximate uncertainty in the calculated result can be taken as due to that quantity alone.

Uncertainties in graphs

7.2.3 Determine the uncertainties in the slope and intercepts of a straight-line graph. **3**

Students should be able to draw lines of minimum and maximum fit to the data points, plus error bars.

Topic 8: Mechanics (15h)

A.S. **Obj**

8.1 Projectile Motion (3h)

8.1.1 State the independence of the vertical and horizontal components of motion for a projectile in a uniform field. **1**

8.1.2 Describe the trajectory of projectile motion as parabolic in the absence of friction. **2**

Proof of the parabolic nature of the trajectory is not required.

8.1.3 Solve problems on projectile motion. **3**

Problems may involve projectiles launched horizontally or at any angle above or below horizontal. Applying conservation of energy may provide a simpler solution to some problems than using projectile motion kinematics equations.

8.2 Gravitation (5h)

Gravitational force and field

8.2.1 State Newton's law of universal gravitation. **1**

Students should be aware that the masses in the force law are point masses not extended masses, but that the interaction between two spherical masses is the same as if the mass were concentrated at the centres of the spheres.

8.2.2 Define *gravitational field strength*. **1**

Students should recognize the vector nature of gravitational fields.

8.2.3 Derive an expression for the gravitational field as a function of distance from a point mass. **3**

This includes the field outside a spherical mass. See 8.2.1.

8.2.4 Derive an expression for gravitational field at the surface of a planet. **3**

Students should also understand how the gravitational field strength and the acceleration due to gravity at the surface are related.

8.2.5 Solve problems involving gravitational forces and fields. **3**

Vector addition is required to find the gravitational field strength due to more than one mass.

A.S.		Obj
	Gravitational energy and potential	
8.2.6	Define *gravitational potential energy* and *gravitational potential*. Students should understand that the work done in moving a mass between two points in a gravitational field is independent of the path taken and that gravitational potential energy is taken to be zero at infinity.	1
8.2.7	State the expression for gravitational potential due to a point mass.	1
8.2.8	Explain the concept of escape speed.	3
8.2.9	Derive an expression for the escape speed of an object from the surface of a planet.	3
8.2.10	Solve problems involving gravitational potential energy and gravitational potential. These should include problems on escape speed.	3

8.3 Orbital Motion (2h)

Note: Although orbital motion can be circular, elliptical or parabolic, this section only deals with circular orbits. This section is not fundamentally new physics, but an application which synthesizes ideas from gravitation, circular motion, dynamics and energy.

8.3.1	State that gravitation provides the centripetal force for circular orbital motion.	1
8.3.2	State Kepler's third law: the law of periods.	1
8.3.3	Derive Kepler's third law. This derivation is for the case of circular orbits and assumes Newton's law of universal gravitation.	3
8.3.4	Derive expressions for the kinetic, potential and total energy of an orbiting satellite.	3
8.3.5	Draw graphs showing the variation of the kinetic energy, gravitational potential energy and total energy with orbital radius of a satellite.	1
8.3.6	Discuss the concept of weightlessness in both orbital motion and in free fall.	3
8.3.7	Solve problems involving orbital motion.	3

A.S.		Obj
	8.4 Friction (2h)	
8.4.1	Describe the nature and properties of frictional forces. Students should identify the factors affecting friction.	2
8.4.2	Distinguish between static and dynamic (sliding) friction.	2
8.4.3	Define *coefficient of friction*. Both static and dynamic coefficients are required.	1
8.4.4	Solve static and dynamic problems involving friction.	3
	8.5 Statics (3h)	
	Static equilibrium	
8.5.1	Define *torque (moment of a force)*. The vector nature of torque need not be addressed but students should include the sense (eg clockwise or counterclockwise) of a torque.	1
8.5.2	State the conditions for translational and rotational equilibrium.	1
8.5.3	Describe the concept of centre of gravity. Students are not required to calculate the centre of gravity of objects. However, they should be aware that the weight of an object may be taken as concentrated at the centre of gravity for determination of gravitational torques.	2
8.5.4	Solve problems for extended objects in equilibrium.	3

Topic 9: Thermal Physics (6h)

A.S. | Obj

9.1 Thermodynamic Systems and Concepts (1h)

Note: Although there are many thermodynamic systems, in this sub-topic discussion will be restricted to a fixed mass of an ideal gas.

9.1.1 Explain what is meant by *thermodynamic system*. **3**

Students should recognize the distinction between a system and its surroundings.

9.1.2 Describe the concepts *heat*, *work* and *internal energy*. **2**

The descriptions should include the expansion and compression of an ideal gas as an example.

9.1.3 Deduce an expression for the work involved in a volume change of a gas at constant pressure. **3**

9.2 Processes (4h)

The first law of thermodynamics

9.2.1 State the first law of thermodynamics. **1**

9.2.2 State that the first law of thermodynamics is a statement of the principle of energy conservation. **1**

9.2.3 Describe the isochoric (isovolumetric), isobaric, isothermal and adiabatic processes. **2**

In each process the heat transferred, the work done and internal energy change should be addressed. The ideal gas equation of state should be applied to all processes except the adiabatic. Students should realize that a rapid compression or expansion of a gas is approximately adiabatic.

9.2.4 Draw and annotate thermodynamic processes and cycles on p-V diagrams. **2**

9.2.5 Calculate the work done in a thermodynamic cycle from a p-V diagram. **2**

9.2.6 Solve problems involving state changes of a gas. **3**

Heat engines and heat pumps

9.2.7 Outline the concept of the heat engine and the heat pump. **2**

A.S.		Obj
9.2.8	Draw and annotate schematic diagrams of a heat engine and a heat pump. Energy transfer paths should be shown.	**2**
9.2.9	Define the term *thermal efficiency* of a heat engine.	**1**
9.2.10	Draw and annotate the Carnot cycle on a p-V diagram. Students should be aware that the Carnot cycle produces the maximum possible theoretical efficiency of a heat engine operating between two heat reservoirs.	**2**
9.2.11	State Carnot's theorem.	**1**
9.2.12	State an expression for the efficiency of a Carnot engine in terms of the temperatures of the two reservoirs. Discuss the possibility of changing the thermal efficiency by altering the reservoir temperatures.	**1**
9.2.13	Solve problems involving heat engines and heat pumps.	**3**

9.3 Second Law of Thermodynamics and Entropy (1h)

9.3.1	State that heat can be completely converted to work in a single process, but that continuous conversion of heat into work requires a cyclical process and the rejection of some heat.	**1**
9.3.2	State the Kelvin–Planck formulation of the second law of thermodynamics It is sufficient for students to acknowledge the impossibility of constructing a heat engine operating in a cycle that does not transfer energy to a cold reservoir. Teachers might like to show that if this were possible then it would imply that energy can be transferred spontaneously from a cold to a hot reservoir. This leads to the Clausius statement of the second law.	**1**
9.3.3	Analyse situations in terms of whether they are consistent with the first and/or second law.	**3**
9.3.4	State that entropy is a system property that expresses the degree of disorder in the system.	**1**
9.3.5	State the second law in terms of entropy changes. A statement that the overall entropy of the universe is increasing will suffice.	**1**
9.3.6	Discuss examples of natural processes in terms of entropy changes. Students should understand that although local entropy can decrease, any process will increase the total entropy of the system and surroundings.	**3**
9.3.7	Discuss the idea of energy degradation in terms of the second law.	**3**

Topic 10: Wave Phenomena (8h)

A.S.		Obj

10.1 Doppler Effect (2h)

10.1.1	Describe and explain the Doppler effect. Students should recognize that in general the velocities of source and/or detector are specified with respect to the medium. They should know however that light in a vacuum is unique and, in this case, it is the relative velocity of source and detector that is relevant.	3
10.1.2	Construct wavefront diagrams for moving-detector and moving-source situations.	3
10.1.3	Derive the equations for the Doppler effect for sound in the cases of a moving detector and a moving source.	3
10.1.4	Solve problems on the Doppler effect for sound. Problems may include both a moving source and a moving detector but not both simultaneously.	3

10.2 Beats (2h)

10.2.1	Explain the formation of beats. Students should be able to sketch the resultant waveform from the superposition of two component waves.	3
10.2.2	Derive the beat frequency formula.	3
10.2.3	Solve problems involving beats.	3

10.3 Two-source Interference of Waves (4h)

10.3.1	Explain, by means of the principle of superposition, the interference pattern produced by waves from two coherent point sources. Water, light and sound waves should be considered.	3
10.3.2	State the conditions necessary to observe interference between two light sources.	1
10.3.3	Outline Young's double slit experiment for light and draw the intensity distribution of the observed fringe pattern. Restrict this to the situation where the slit width is small compared to the slit separation so that diffraction effects on the pattern are not considered.	2

A.S.		Obj
10.3.4	Derive expressions for the locations of the maxima and minima of the double slit fringe pattern. These include the angular form $\sin \theta = n\lambda/d$ and the form $s = \lambda D/d$ for locations on a screen at distance D, involving the small angle approximation.	**3**
10.3.5	Solve problems involving two-source interference.	**3**

Topic 11: Electromagnetism (9h)

A.S. | Obj

11.1 Electrostatic Potential (3h)

Electric potential due to a point charge

11.1.1 Define *electric potential*. **1**

Students should understand the scalar nature of potential and that the potential at infinity is taken as zero.

11.1.2 Determine the electric potential due to various charge configurations. **3**

This includes single point charge, collections of point charges and the potential outside a charged sphere. Students will not be expected to derive the equation $V = \dfrac{q}{4\pi\varepsilon_0 r}$.

11.1.3 State and apply the formula relating electric field strength to potential gradient. **2**

It is sufficient that students know that $E = -\Delta V/\Delta x$.

11.1.4 Describe the similarities and differences between gravitational fields and electrical fields. **2**

Equipotentials

11.1.5 Describe and sketch patterns of equipotential surfaces. **2**

This should include patterns due to isolated point charges, charged conducting spheres, two point charges and parallel conducting plates.

11.1.6 Explain the relation of equipotential surfaces to electric field lines. **3**

11.2 Electromagnetic Induction (4h)

Induced electromotive force (e.m.f.)

11.2.1 Describe the production of an induced e.m.f. by relative motion between a conductor and a magnetic field (motionally induced e.m.f.). **2**

11.2.2 Derive the formula for the e.m.f. induced in a straight conductor moving in a magnetic field. **3**

11.2.3 Define *magnetic flux* and *flux linkage*. **1**

11.2.4 Describe the production of an induced e.m.f. that is produced by a time-changing magnetic flux. **2**

A.S.		Obj
11.2.5	State Faraday's law.	1
11.2.6	Explain how a motionally induced e.m.f. can be equated to a rate of change of magnetic flux. Students should be able to show that the induced e.m.f. , Blv, is equal to $\frac{\Delta\phi}{\Delta t}$.	3
11.2.7	State Lenz's law.	1
11.2.8	Solve electromagnetic induction problems.	3

11.3 Alternating Current (2h)

11.3.1	Describe the e.m.f. induced in a coil rotating within a uniform magnetic field. Students should understand, without deriving, that the induced e.m.f. is sinusoidal if the rotation is uniform.	2
11.3.2	Explain the operation of a basic alternating current (ac) generator.	3
11.3.3	Define the concepts of root mean square voltage and root mean square current.	1
11.3.4	Solve ac circuit problems for ohmic resistors.	3
11.3.5	Describe the components and characteristics of an ideal transformer and explain its operation. A qualitative explanation is sufficient.	3
11.3.6	Explain the use of high voltage step-up and step-down transformers in the transmission of electric power.	3
11.3.7	Solve problems on the operation of ideal transformers and power transmission.	3

Topic 12: Quantum Physics and Nuclear Physics (15h)

A.S.		Obj
	12.1 Quantum Physics (9h)	
	The quantum nature of radiation	
12.1.1	Describe the photoelectric effect and Einstein's explanation of this effect. Students should be familiar with the concept of the photon and should be able to explain why the wave model of light is unable to explain the photoelectric effect.	2
12.1.2	Outline an experiment to test the Einstein model. Millikan's experiment involving the application of a stopping potential would be a suitable example.	2
12.1.3	Solve problems involving the photoelectric effect.	3
	The wave nature of matter	
12.1.4	Describe de Broglie's hypothesis and the concept of matter waves. Students should also be aware of wave–particle duality (the dual nature of both radiation and matter).	2
12.1.5	Outline an experiment to test the de Broglie hypothesis.	2
12.1.6	Solve problems involving matter waves. For example, students should be able to calculate the wavelength of moving electrons.	3
	Atomic spectra and atomic energy states	
12.1.7	Outline how atomic spectra can be observed.	2
12.1.8	Explain how atomic spectra provide evidence for the quantization of energy in atoms. An explanation in terms of energy differences between allowed electron energy states is sufficient.	3
12.1.9	Outline the Bohr model of the hydrogen atom. No mathematical details are required. Refer to the fact that the model enabled the discrete wavelengths of the hydrogen spectrum to be predicted.	2
12.1.10	State the limitations of the Bohr model.	1

A.S.		Obj
12.1.11	Outline the Schrödinger model of the hydrogen atom. The model assumes that electrons in the atom can be described by wave functions. These have to fit boundary conditions in three dimensions in the atom, giving rise to both radial and angular allowed modes with discrete energy states (analogous to the discrete allowed frequencies of standing waves). The electron has an undefined position, but the square of the amplitude of the wave function gives the probability of finding it at a point.	2
12.1.12	Calculate spectral wavelengths from energy level differences and vice versa.	2

X-rays

12.1.13	Outline the experimental set up for the production of X-rays.	2
12.1.14	Draw and annotate a typical X-ray spectrum. Students should be able to identify the continuous and characteristic features of the spectrum and the minimum wavelength limit.	2
12.1.15	Explain the origins of the features of a typical X-ray spectrum.	3

12.2 Nuclear Physics (3h)

The nucleus

12.2.1	Explain how the radii of nuclei can be determined by charged particle scattering experiments. Use of energy conservation for determining closest-approach distances for Coulomb scattering experiments is sufficient.	3
12.2.2	Describe how the masses of nuclei can be determined using a mass spectrometer. Students should be able to draw a schematic diagram of the mass spectrometer but the experimental details are not required. Students should appreciate that nuclear mass values provided evidence for the existence of isotopes.	2
12.2.3	Describe one piece of evidence for the existence of nuclear energy levels. For example, alpha particles produced by the decay of a nuclide have discrete energies; gamma ray spectra are discrete. Students should appreciate that the nucleus, like the atom, is a quantum system with allowed states and discrete energy levels.	2

A.S.		Obj
	Radioactive decay	
12.2.4	Describe both β+ and β– decay, including the existence of the neutrino and the antineutrino. Students should know that β energy spectra are continuous and that the neutrino was postulated to account for the missing energy and momentum.	2
12.2.5	State the radioactive decay law as an exponential function and define the *decay constant.*	1
12.2.6	Derive the relationship between the decay constant and half-life.	3
12.2.7	Solve problems using the radioactive decay law.	3
12.2.8	Outline methods for measuring the half-life of an isotope. Students should know the principles of measurement for both long and short half-lives.	2

12.3 Particle Physics (3h)

Note: This section is intended to be a brief factual introduction to particle physics.

12.3.1	Outline the concept of antiparticles and give examples.	2
12.3.2	Outline the concepts of particle production and annihilation and apply the conservation laws to these processes. Students should know that particles can be produced in high-energy interactions in particle accelerators. Details of accelerators are not required. Students should appreciate that these processes are instances of the conversion of energy to rest mass and vice versa (in accordance with Einstein's mass–energy relation), and are subject to various conservation laws: mass–energy, momentum, electric charge, lepton number and baryon number.	2
12.3.3	List and outline the four fundamental interactions. Students should also be aware that the electromagnetic force and weak nuclear force are instances of a single electroweak force with two types of exchange particles.	2
12.3.4	List the three classes of fundamental particle. It is sufficient to know that the classes are leptons, quarks and exchange bosons (force mediators), and that there are six types of quarks and leptons, plus their antiparticles, grouped in three generations. Students should know that isolated quarks have not been detected.	1

A.S.		Obj
12.3.5	State that there are three classes of observed particle. It is sufficient to know that the classes are leptons, hadrons and exchange bosons. Hadrons are divided into mesons and baryons.	1
12.3.6	Outline the structure of nucleons in terms of quarks. Students should be able to relate nucleon properties to composition, eg describe protons as “up, up, down”.	2
12.3.7	Outline the concept of an interaction as mediated by exchange of particles. Students should be able to associate the four interactions with their respective exchange particles and should also be aware of the colour force between quarks and the associated gluons.	2

Options Outline

Options Standard Level

A Mechanics extension

B Quantum physics and nuclear physics

C Energy extension

Options Standard Level/Higher Level

D Biomedical physics

E The history and development of physics

F Astrophysics

G Relativity

H Optics

Standard level candidates are required to study any **two** options from A–H.
The duration of each option is 15 hours.

Higher level candidates are required to study any **two** options from D–H.
The duration of each option is 22 hours.

Option A: Mechanics Extension (15h)

Note: This option is identical to topic 8.

A.S. — Obj

A.1 Projectile Motion (3h)

A.1.1 State the independence of the vertical and horizontal components for motion of a projectile in a uniform field. **1**

A.1.2 Describe the trajectory of projectile motion as parabolic in the absence of friction. **2**

Proof of the parabolic nature of the trajectory is not required.

A.1.3 Solve problems on projectile motion. **3**

Problems may involve projectiles launched horizontally or at any angle above or below horizontal. Applying conservation of energy may provide a simpler solution to some problems than using projectile motion kinematics equations.

A.2 Gravitation (5h)

Gravitational force and field

A.2.1 State Newton's law of universal gravitation. **1**

Students should be aware that the masses in the force law are point masses not extended masses, but that the interaction between two spherical masses is the same as if the mass were concentrated at the centres of the spheres.

A.2.2 Define *gravitational field strength.* **1**

Students should recognize the vector nature of gravitational fields.

A.2.3 Derive an expression for the gravitational field as a function of distance from a point mass. **3**

This includes the field outside a spherical mass. See A.2.1.

A.2.4 Derive an expression for the gravitational field at the surface of a planet. **3**

Students should also understand how the gravitational field strength and the acceleration due to gravity at the surface are related.

A.2.5 Solve problems involving gravitational forces and fields. **3**

Vector addition may be required to find the gravitational field strength due to more than one mass.

A.S.		Obj
	Gravitational energy and potential	
A.2.6	Define *gravitational potential energy* and *gravitational potential*. Students should understand that the work done in moving a mass between two points in a gravitational field is independent of the path taken and that gravitational potential energy is taken to be zero at infinity.	1
A.2.7	State the expression for gravitational potential due to a point mass.	1
A.2.8	Explain the concept of escape speed.	3
A.2.9	Derive an expression for the escape speed of an object from the surface of a planet.	3
A.2.10	Solve problems involving gravitational potential energy and gravitational potential. These should include problems on escape speed.	3

A.3 Orbital Motion (2h)

Note: Although orbital motion can be circular, elliptical or parabolic, this section only deals with circular orbits. This section is not fundamentally new physics, but an application which synthesizes ideas from gravitation, circular motion, dynamics and energy.

A.3.1	State that gravitation provides the centripetal force for circular orbital motion.	1
A.3.2	State Kepler's third law: the law of periods.	1
A.3.3	Derive Kepler's third law. This derivation is for the case of circular orbits and assumes Newton's law of universal gravitation.	3
A.3.4	Derive expressions for the kinetic, potential and total energy of an orbiting satellite.	3
A.3.5	Draw graphs showing the variation of the kinetic energy, gravitational potential energy and total energy with orbital radius of a satellite.	1
A.3.6	Discuss the concept of weightlessness in orbital motion and in free fall.	3
A.3.7	Solve problems involving orbital motion.	3

A.S.		Obj

A.4 Friction (2h)

A.S.		Obj
A.4.1	Describe the nature and properties of frictional forces. Students should identify the factors affecting friction.	**2**
A.4.2	Distinguish between static and dynamic (sliding) friction.	**2**
A.4.3	Define *coefficient of friction*. Both static and dynamic coefficients are required.	**1**
A.4.4	Solve static and dynamic problems involving friction.	**3**

A.5 Statics (3h)

A.S.		Obj
A.5.1	Define *torque (moment of a force)*. The vector nature of torque need not be addressed but students should include the sense (eg clockwise or counterclockwise) of a torque.	**1**
A.5.2	State the conditions for translational and rotational equilibrium.	**1**
A.5.3	Describe the concept of centre of gravity. Students are not required to calculate the centre of gravity of objects. However, they should be aware that the weight of an object may be taken as concentrated at the centre of gravity for determination of gravitational torques.	**2**
A.5.4	Solve problems involving extended objects in equilibrium.	**3**

Option B: Quantum Physics and Nuclear Physics (15h)

Note: This option is identical to topic 12.

A.S.		Obj
	B.1 Quantum Physics (9h)	
	The quantum nature of radiation	
B.1.1	Describe the photoelectric effect and Einstein's explanation of this effect. Students should be familiar with the concept of the photon and should be able to explain why the wave model of light is unable to explain the photoelectric effect.	2
B.1.2	Outline an experiment to test the Einstein model. Millikan's experiment involving the application of a stopping potential would be a suitable example.	2
B.1.3	Solve problems involving the photoelectric effect.	3
	The wave nature of matter	
B.1.4	Describe de Broglie's hypothesis and the concept of matter waves. Students should also be aware of wave–particle duality (the dual nature of both radiation and matter).	2
B.1.5	Outline an experiment to test the de Broglie hypothesis.	2
B.1.6	Solve problems involving matter waves. For example, students should be able to calculate the wavelength of moving electrons.	3
	Atomic spectra and atomic energy states	
B.1.7	Outline how atomic spectra can be observed.	2
B.1.8	Explain how atomic line spectra provide evidence for the quantization of energy in atoms. An explanation in terms of energy differences between allowed electron energy states is sufficient.	3
B.1.9	Outline the Bohr model of the hydrogen atom. No mathematical details are required. Refer to the fact that the model enabled the discrete wavelengths of the hydrogen spectrum to be predicted.	2
B.1.10	State the limitations of the Bohr model.	1

A.S.		Obj
B.1.11	Outline the Schrödinger model of the hydrogen atom. The model assumes that electrons in the atom can be described by wave functions. These have to fit boundary conditions in three dimensions in the atom, giving rise to both radial and angular allowed modes with discrete energy states (analogous to the discrete allowed frequencies of standing waves). The electron has an undefined position, but the square of the amplitude of the wave function gives the probability of finding it at a point.	2
B.1.12	Calculate spectral wavelengths from energy level differences and vice versa.	2

X-rays

B.1.13	Outline the experimental set up for the production of X-rays.	2
B.1.14	Draw and annotate a typical X-ray spectrum. Students should be able to identify the continuous and characteristic features of the spectrum and the minimum wavelength limit.	2
B.1.15	Explain the origins of the features of a typical X-ray spectrum.	3

B.2 Nuclear Physics (3h)

The nucleus

B.2.1	Explain how the radii of nuclei can be determined by charged particle scattering experiments. Use of energy conservation for determining closest-approach distances for Coulomb scattering experiments is sufficient.	3
B.2.2	Describe how the masses of nuclei can be determined using a mass spectrometer. Students should be able to draw a schematic diagram of the mass spectrometer but the experimental details are not required. Students should appreciate that nuclear mass values provided evidence for the existence of isotopes.	2
B.2.3	Describe one piece of evidence for the existence of nuclear energy levels. For example, alpha particles produced by the decay of a nuclide have discrete energies; gamma ray spectra are discrete. Students should appreciate that the nucleus, like the atom, is a quantum system with allowed states and discrete energy levels.	2

A.S.		Obj
	Radioactive decay	
B.2.4	Describe both β+ and β– decay, including the existence of the neutrino and the antineutrino. Students should know that β energy spectra are continuous and that the neutrino was postulated to account for the missing energy and momentum.	2
B.2.5	State the radioactive decay law and define the *decay constant*.	1
B.2.6	Derive the relationship between the decay constant and half-life.	3
B.2.7	Solve problems using the radioactive decay law.	3
B.2.8	Outline methods for measuring the half-life of an isotope. Students should know the principles of measurement for both long and short half-lives.	2

B.3 Particle Physics (3h)

Note: This section is intended to be a brief factual introduction to particle physics.

B.3.1	Outline the concept of antiparticles and give examples.	2
B.3.2	Outline the concepts of particle production and annihilation and apply the conservation laws to these processes. Students should know that particles can be produced in high-energy interactions in particle accelerators. Details of accelerators are not required. Students should appreciate that these processes are instances of the conversion of energy to rest mass and vice versa (in accordance with Einstein's mass–energy relation), and are subject to various conservation laws: mass–energy, momentum, electric charge, lepton number and baryon number.	2
B.3.3	List and outline the four fundamental interactions. Students should also be aware that the electromagnetic force and weak nuclear force are instances of a single electroweak force, with two types of exchange particles.	2
B.3.4	List the three classes of fundamental particle. It is sufficient to know that the classes are leptons, quarks and exchange bosons (force mediators), and that there are six types of quarks and leptons (plus their antiparticles) grouped in three generations. Students should know that isolated quarks have not been detected.	1

A.S.		Obj
B.3.5	State that there are three classes of observed particle. It is sufficient to know that the classes are leptons, hadrons and exchange bosons. Hadrons are divided into mesons and baryons.	1
B.3.6	Outline the structure of nucleons in terms of quarks. Students should be able to relate nucleon properties to composition, eg describe protons as “up, up, down”.	2
B.3.7	Outline the concept of an interaction as mediated by exchange of particles. Students should be able to associate the four interactions with their respective exchange particles and should also be aware of the colour force between quarks and the associated gluons.	2

Option C: Energy Extension (15h)

Note: The first three sub-topics of this option, C.1, C.2 and C.3, are identical to topic 9.

This option includes a study of thermodynamic concepts and introduces the first and second laws of thermodynamics. The concept of entropy is only qualitatively discussed. Energy sources, both renewable and non-renewable, are explored. Examples of some such sources are discussed in more detail and their relative advantages and disadvantages are considered.

A.S. Obj

C.1 Thermodynamic Systems and Concepts (1h)

Note: Although there are many thermodynamic systems, in this sub-topic discussion will be restricted to a fixed mass of an ideal gas.

C.1.1 Explain what is meant by *thermodynamic system*. **3**

Students should recognize the distinction between a system and its surroundings.

C.1.2 Describe the concepts *heat*, *work* and *internal energy*. **2**

The descriptions should include the expansion and compression of an ideal gas as an example.

C.1.3 Deduce an expression for the work involved in a volume change of a gas at constant pressure. **3**

C.2 Processes (4h)

The first law of thermodynamics

C.2.1 State the first law of thermodynamics. **1**

C.2.2 State that the first law of thermodynamics is a statement of the principle of energy conservation. **1**

C.2.3 Describe the isochoric (isovolumetric), isobaric, isothermal and adiabatic processes. **2**

In each process the heat transferred, the work done and internal energy change should be addressed. The ideal gas equation of state should be applied to all processes except the adiabatic. Students should realize that a rapid compression or expansion of a gas is approximately adiabatic.

C.2.4 Draw and annotate thermodynamic processes and cycles on p-V diagrams. **2**

A.S.		Obj
C.2.5	Calculate the work done in a thermodynamic cycle from a p-V diagram.	2
C.2.6	Solve problems involving state changes of a gas.	3

Heat engines and heat pumps

A.S.		Obj
C.2.7	Outline the concept of the heat engine and the heat pump.	2
C.2.8	Draw and annotate schematic diagrams of a heat engine and a heat pump. Energy transfer paths should be shown.	2
C.2.9	Define the term *thermal efficiency* of a heat engine.	1
C.2.10	Draw and annotate the Carnot cycle on a p-V diagram. Students should be aware that the Carnot cycle produces the maximum possible theoretical efficiency of a heat engine operating between two heat reservoirs.	2
C.2.11	State Carnot's theorem.	1
C.2.12	State an expression for the efficiency of a Carnot engine in terms of the temperatures of the two reservoirs. Discuss the possibility of changing the thermal efficiency by altering the reservoir temperatures.	1
C.2.13	Solve problems involving heat engines and heat pumps.	3

C.3 Second Law of Thermodynamics and Entropy (1h)

A.S.		Obj
C.3.1	State that heat can be completely converted to work in a single process, but that continuous conversion of heat into work requires a cyclical process and the rejection of some heat.	1
C.3.2	State the Kelvin–Planck formulation of the second law of thermodynamics. It is sufficient for students to acknowledge the impossibility of constructing a heat engine operating in a cycle that does not transfer energy to a cold reservoir. Teachers might like to show that if this were possible then it would imply that energy can be transferred spontaneously from a cold to a hot reservoir. This leads to the Clausius statement of the second law.	1
C.3.3	Analyse situations in terms of whether they are consistent with the first and/or second law.	3
C.3.4	State that entropy is a system property that expresses the degree of disorder in the system.	1

A.S.		Obj
C.3.5	State the second law in terms of entropy changes. A statement that the overall entropy of the universe is increasing will suffice.	1
C.3.6	Discuss examples of natural processes in terms of entropy changes. Students should understand that although local entropy can decrease, any process will increase the total entropy of the system and surroundings.	3
C.3.7	Discuss the idea of energy degradation in terms of the second law.	3

C.4 Energy sources and power production (9h)

Energy sources and power generation

C.4.1	Outline and distinguish between renewable and non-renewable energy sources. Students should be able to give examples of both types of sources.	2
C.4.2	Outline the principal mechanisms involved in the production of electrical power. Students should essentially know that electrical energy can be produced by rotating coils in a magnetic field. The rotational energy is usually supplied by steam turbines. In C.4.3–C.4.18 the students look in more detail at energy sources that can be used to provide the rotational mechanical energy.	2

Nuclear power stations

C.4.3	Describe how the neutrons produced in a fission reaction can be used to initiate further fission reactions (chain reaction). Students should know that low energy neutrons promote nuclear fission. They should also know about critical mass.	2
C.4.4	Describe the main energy transformations that take place in a nuclear power station.	2
C.4.5	Discuss the role of the moderator and control rods in the production of controlled fission in a fission reactor.	3
C.4.6	Discuss the role of the heat exchanger in a fission reactor.	3

Fossil fuel power

C.4.7	Describe the origin of fossil fuels.	2
C.4.8	Discuss the main energy transformations that take place in a fossil fuel power station.	3
C.4.9	Discuss the advantages and disadvantages of producing electrical energy using nuclear fission and producing electrical energy by burning fossil fuels.	3

A.S.		Obj
	Hydroelectric power	
C.4.10	Describe the main energy transformations that take place in a hydroelectric installation.	**2**
C.4.11	Discuss the advantages and disadvantages of hydroelectric power.	**3**
	Solar power	
C.4.12	Describe the energy transformations that take place in a photovoltaic cell and active solar heater. No construction details or details of operation are required.	**2**
C.4.13	Discuss the advantages and disadvantages of solar devices.	**3**
C.4.14	Define the *solar constant*. Account for seasonal and regional variations.	**1**
C.4.15	Solve problems involving the intensity of solar radiation at a specific location for a specific application. Calculations of solar panel area are required for a specified hot water supply.	**3**
	Wind power	
C.4.16	Outline the basic features of a wind generator. A standard horizontal axis machine is sufficient.	**2**
C.4.17	Determine the power that could be delivered by a wind generator if the wind kinetic energy could be completely converted into mechanical kinetic energy, and explain why this is impossible. Identify the dependence of power on the generator frontal blade's effective area and on the cube of wind speed.	**3**
C.4.18	Discuss the advantages and disadvantages of using wind energy on a large-scale basis.	**3**

Option D: Biomedical Physics (15h)

A.S.		Obj
	D.1 Scaling Laws—Size, Form and Function (3h)	
	Scaling	
D.1.1	State and explain how area and volume scale with the linear dimensions of an object.	3
D.1.2	Identify physical properties directly proportional to area or volume, and state how these properties scale with linear dimensions. For example, mass and weight are proportional to volume, heat loss rate is proportional to surface area, the forces which can be exerted by muscles and sustained by bones are proportional to cross-sectional area.	2
D.1.3	Solve scaling problems involving linear dimensions, area and volume, and the physical quantities directly proportional to these.	3
D.1.4	Distinguish between absolute physical quantities (eg surface area) and relative physical quantities (eg surface area per unit body mass).	2
D.1.5	Determine how relative physical quantities scale with the linear dimensions of an object. Examples could include bone stress (force per unit area), heat loss rate per unit mass, and oxygen absorption rate per unit mass.	3
D.1.6	Solve problems involving the scaling of relative physical quantities.	3
	Size, form and function	
D.1.7	Describe examples of relative physical quantities that vary with the size of creatures of similar form.	2
D.1.8	Explain why creatures scaled up or down in size might not be viable. The application of scaling and simple physical principles are all that is required.	3
D.1.9	Explain why and in what respects the form and function of creatures of different size must differ. For example, explain why legs do not scale proportionately to body size, so that a small antelope (like a gazelle) has relatively slender legs in relation to its size, while a large antelope (like an eland) has disproportionately thicker legs.	3
D.1.10	Explain how and why, when scale changes, some aspects of the physical world may be emphasized while others may become less significant. The molecular forces on a liquid surface may be more significant than gravity for insects, while the opposite is true for larger creatures.	3

A.S.		Obj
D.1.11	Solve problems involving differences in shape and form for creatures of varying sizes. For example, determine the relative thickness of leg bones (in relation to length) for a pig and a rhinoceros, assuming the bone stress is to be the same for both.	3

D.2 Sound and Hearing (5h)

Sound intensity and the dB scale

D.2.1	Define *sound intensity* and state its dependence on the square of the wave amplitude.	1
D.2.2	Define *bel*, *decibel scale* of loudness and *sound intensity level*.	1
D.2.3	Solve problems involving the dB scale.	3

The ear and the mechanism of hearing

D.2.4	Describe the function and operation of the different parts of the ear. This includes the outer, middle and inner ear and the mechanisms of sound transmission.	2
D.2.5	Explain how the middle ear transforms sound pressure variations in air into larger pressure variations in the cochlear fluid. This can be dealt with in terms of the different areas of the ear drum and oval window, together with a small lever action of the ossicles. Although the concept of "impedance matching" is not formally required, students should appreciate that without a mechanism for pressure transformation between media of different densities (air and fluid) most sound would be reflected, rather than transmitted into the cochlear fluid.	3
D.2.6	Explain the terms *pitch* and *loudness*.	3
D.2.7	State the range of frequencies audible to the human ear.	1
D.2.8	Define the threshold of hearing and describe the human perception of loudness at different frequencies. Students should be able to interpret the intensity–frequency diagram.	2
D.2.9	Outline how the cochlea distinguishes between the different frequencies that might be present in a sound wave.	2

A.S.		Obj
	Hearing tests	
D.2.10	Describe various hearing tests, and explain how they can be used to diagnose the type and extent of hearing loss. Knowledge of simple tuning fork tests, and how audiograms are performed for both air and bone conduction, is sufficient.	3
D.2.11	Interpret audiograms of various types showing both bone and air conduction curves.	3
	Hearing defects and correction	
D.2.12	Distinguish between conductive and sensory hearing losses and describe possible origins.	2
D.2.13	Explain how selective frequency losses can lead to loss of speech discrimination.	3
D.2.14	Outline how hearing aids work and explain their characteristics and limitations. Students should be aware of both analogue and digital aids and the basic idea of cochlear implants, but no details of how these operate are required.	3

D.3 Medical Imaging (7 h)

Note: Students should be able to discuss the advantages and disadvantages of various imaging techniques for particular purposes .

A.S.		Obj
	X-ray imaging	
D.3.1	Describe what is meant by X-ray quality.	2
D.3.2	Outline the different attenuation mechanisms of X-rays by various materials, including body tissues. Students need only know about simple scattering and the photoelectric effect in tissues and bone.	2
D.3.3	Define the terms *attenuation coefficient* and *half-value thickness.*	1
D.3.4	Describe X-ray detection, recording and display techniques. Students should know about photographic film, enhancement, electronic detection and display.	2
D.3.5	Explain standard X-ray imaging techniques used in medicine. Students should know about the barium meal technique and moving-source or film technique.	3

A.S.		Obj
D.3.6	Outline the basis of computed tomography (CT) in X-ray imaging.	**2**
D.3.7	Solve problems involving the use of X-ray imaging.	**3**
	Ultrasonic imaging	
D.3.8	Describe the characteristics of ultrasound.	**2**
D.3.9	Explain the SONAR principle used in medical ultrasonic diagnosis.	**3**
D.3.10	Outline and distinguish between A-scans and B-scans.	**2**
D.3.11	Identify the factors that affect the choice of diagnostic frequency used.	**2**
	Other imaging techniques	
D.3.12	Outline the basic principles of nuclear magnetic resonance. Students need only give a simple qualitative description of the principle.	**2**
D.3.13	Discuss the use of radioactive tracers in medical diagnosis and in the study of body function.	**3**
D.3.14	Outline the use of positron emission tomography (PET).	**2**

Option D: Extension Material (HL only) (7h)

A.S.		Obj
	D.4 Biomechanics (3h)	
	Skeleton, muscle and movement	
D.4.1	Define the concept of *centre of gravity*. Students should be able to estimate qualitatively the approximate locations of the centres of gravity of various body parts.	1
D.4.2	Solve problems involving the forces in muscles and joints of the body. Students should be able to apply the statics principles of rotational and translational equilibrium.	3
D.4.3	Explain how large forces, much larger than the weight of objects that they support, can arise in the joints, muscles and tendons of the body. Students should be able to give examples such as the elbow with the forearm, the ankle and the back. Precautions against injury should also be discussed, eg why lifting with a bent back is to be discouraged.	3
D.4.4	Apply the concepts of *mechanical advantage* and *velocity ratio* (or *movement ratio*) to lever systems in the body. The so called “classes” of lever are not required, but students should appreciate that most limb structures in the body act at a mechanical disadvantage while displaying a corresponding movement advantage.	2
	Energy conversion and expenditure	
D.4.5	Define metabolic rate and basal metabolic rate.	1
D.4.6	Describe the physical mechanisms by which temperature regulation in the body is achieved. Students should be familiar with the contributions made by conduction, convection, radiation, evaporation and expiration.	2
D.4.7	Determine energy expenditures for various physical activities, and energy available from various types of food. Students will be provided with appropriate data on the average power of various activities and on the energy content of food.	3
D.4.8	Solve problems involving energy, work done, power and efficiency, given appropriate data.	3

A.S.		Obj
	D.5 Radiation in Medicine (4h)	
	Biological effects of radiation, dosimetry and radiation safety	
D.5.1	Outline the biological effects of ionizing radiation. A simple explanation in terms of interaction of radiation with molecules and body cells, and hence on body tissues and processes, is all that is required.	**2**
D.5.2	Define the terms *exposure, absorbed dose (energy absorbed per unit mass), quality factor (relative biological effectiveness)* and *dose equivalent* as used in radiation dosimetry.	**1**
D.5.3	Discuss the precautions required in situations involving radiation and the types of protection that may be used. Students should consider shielding, distance and time-of-exposure factors.	**3**
D.5.4	Solve problems involving radiation dosimetry.	**3**
	Radiation sources in diagnosis and therapy	
D.5.5	Distinguish between physical half-life, biological half-life and effective half-life.	**2**
D.5.6	Calculate the effective half-life from the physical half-life and the biological half-life.	**2**
D.5.7	Outline the basis of radiation therapy for cancer. This should include the mechanisms and the differential effects on normal and malignant cells, as well as a description of the types of sources available.	**2**
D.5.8	Solve problems involving the choice of radioisotope suitable for a particular diagnostic or therapeutic application.	**3**

Option E: The History and Development of Physics (15h)

A.S.		Obj

E.1 Astronomy and Development of Models of the Universe (5h)

Astronomical observations

A.S.		Obj
E.1.1	Describe the observed motion of the stars during one night. Nightly arcs or circles of stars, centred around the "celestial pole" is sufficient detail.	2
E.1.2	Describe the observed motion of the sun in the sky each day, and how this varies over the year, at different latitudes.	2
E.1.3	Describe how the observed motions of the planets vary with time with respect to the stars. Students should be familiar with the term *retrograde motion*.	2
E.1.4	Describe the observed motion of the moon during a lunar month.	2

Development of models of the universe

Note: The structure and rationale of each model should be discussed, as well as its successes and limitations. Ideological perspectives and assumptions behind the models should also be included.

A.S.		Obj
E.1.5	Describe the Aristotelian/Ptolemaic model of the universe and explain how it accounted for the motions of the stars, sun, moon and planets. Students should be able to illustrate the model by constructing appropriate diagrams to explain the various observed motions and the relations between them.	3
E.1.6	Describe the Aristarchian/Copernican model of the universe and explain how it accounted for the motions of the stars, sun, moon and planets. Students should be able to illustrate the model by constructing appropriate diagrams to explain the various observed motions and the relations between them.	3
E.1.7	Discuss the advantages of, and objections to, the heliocentric model. Students should be aware of the conflict between Galileo and the Church.	3

A.S.		Obj
E.1.8	Discuss Kepler's model and his development of the three laws of planetary motion. Students should appreciate the importance of Brahe's accurate data to Kepler, prior to which the previous models gave apparently satisfactory explanations.	3

Newton's synthesis

A.S.		Obj
E.1.9	Explain why Newton's law of gravitation is called a *universal law*. It is sufficient for students to know that Newton's insight was in connecting the local earthbound phenomenon of falling objects with the force required to keep bodies like the moon in orbit about the earth.	3
E.1.10	Describe and discuss the contributions of Newton to the derivation and explanation of Kepler's laws.	3

E.2 Mechanics (2h)

Development of concepts of motion, force and mass

A.S.		Obj
E.2.1	Describe and discuss the Aristotelian views of motion and force. Students should be familiar with the Aristotelian concept of "natural" motion in various circumstances.	3
E.2.2	Describe, discuss and apply the experimental methods used by Galileo to study motion. Students should appreciate that Galileo's experimental approach was the birth of the scientific method. They should also be able to discuss Galileo's use of mathematics in understanding accelerated motion.	3
E.2.3	Compare Newtonian and Aristotelian theories of motion, force and mass.	2
E.2.4	Discuss the concept of mechanical determinism in the universe. See also E.6.10 for HL students.	3

E.3 Concepts of Heat (2h)

A.S.		Obj
E.3.1	Describe and evaluate the phlogiston/caloric theory of heat.	3
E.3.2	Describe and discuss the contributions of Rumford and Joule to the demise of the caloric theory.	3
E.3.3	Describe Joule's experiment to measure the mechanical equivalent of heat, interpret the results and solve related problems.	3

A.S.		Obj

E.4 Electricity and Magnetism (3h)

Discovery of natural electrification and magnetism

A.S.		Obj
E.4.1	Describe the early discoveries and investigations of electrification and electric effects. Students should be familiar with the properties of amber etc, electrification by friction and by induction, attraction and repulsion, conductors and insulators.	2
E.4.2	Describe the early discoveries and applications of natural magnetism. This includes lodestone, magnets, the compass, navigation and the Earth's magnetic field.	2

The concepts of electric charge, electric force and electric field

A.S.		Obj
E.4.3	Discuss the development of explanatory models for electrification and electric effects, leading to the modern concept of charge. This should include the two fluid model of Du Fay, the single fluid model of Franklin and the modern atomic model of matter and concept of charge. Outline the successes and shortcomings of each model in accounting for the phenomena.	3
E.4.4	Compare the methods of Franklin/Priestley and Coulomb in establishing the inverse square nature of the electrostatic force. Students should be able to discuss the nature of indirect and direct methods.	2
E.4.5	Outline Coulomb's experiments that established the inverse square distance relation and the proportionality of force to charge magnitude.	2

Magnetic effects of electric currents and electric effects of magnetic fields

A.S.		Obj
E.4.6	Describe and discuss the discoveries and investigations of Oersted and Ampere.	3
E.4.7	Discuss Faraday's search for, and eventual discovery of, electromagnetic induction.	3

A.S.		Obj

E.5 Atomic and Nuclear Physics (3h)

The electron

E.5.1	Outline and discuss the discovery and investigation of cathode rays, hypotheses of their nature, and the discovery of the electron. Students should be aware of the work of Lenard, Crookes and Hertz etc, as well as evidence and arguments for the wave and particle views of the nature of cathode rays.	3
E.5.2	Outline Thomson's experiment to measure the charge-to-mass ratio of the electron.	2

The atom and the nucleus

E.5.3	Compare Thomson's plum pudding model of the atom with Rutherford's nuclear model of the atom.	2
E.5.4	Describe and discuss Chadwick's discovery of the neutron.	3

Option E: Extension Material (HL only) (7h)

A.S.		Obj
	E.6 The Quantum Concept and Atomic Models (7h)	
	Atomic spectra and the Bohr model of the atom	
E.6.1	Describe the atomic spectrum of hydrogen, the search for explanations and the discovery of the (empirical) Rydberg formula for spectral series. Students should be aware of the hydrogen atom spectral series and Rydberg formula.	2
E.6.2	State the Bohr postulates as applied to the hydrogen atom. This extends assessment statements 12.1.9 and 12.1.10.	1
E.6.3	Derive the energy levels of the hydrogen atom. Students should be able to show that $E_n = -\frac{13.6}{n^2}$.	3
E.6.4	Derive the Rydberg formula from energy level differences.	3
E.6.5	Discuss the successes and limitations of the Bohr model.	3
E.6.6	Solve problems on the Bohr model and spectra. Problems may include hydrogen-like situations such as singly ionized helium.	3
	The de Broglie hypothesis and the Schrödinger model of the atom	
E.6.7	Outline de Broglie’s development of the concept of matter waves.	2
E.6.8	Outline how the Schrödinger model of the atom leads to quantized energy states and quantization of emitted radiation. The model assumes that electrons in the atom can be described by wave functions. These have to fit boundary conditions in three dimensions in the atom, giving rise to both radial and angular allowed modes with discrete energy states (analogous to the discrete allowed frequencies of standing waves). The electron has an undefined position, but the square of the amplitude of the wave function gives the probability of finding it at a point.	2
E.6.9	Compare and contrast the Bohr and Schrödinger models of the atom. Students should be able to comment on the assumptions, applicability, limitations, successes, etc of these models.	2
	The Heisenberg uncertainty principle and the loss of determinism	
E.6.10	Outline the Heisenberg uncertainty principle with regard to position–momentum and time–energy, and discuss its implications on determinism. This complements the discussion on mechanical determinism in E.2.4.	3

Option F: Astrophysics (15h)

A.S.		Obj

F.1 Introduction to the Universe (2h)

The solar system and beyond

A.S.		Obj
F.1.1	Outline the general structure of the solar system. Students should know that the planets orbit the Sun in ellipses and moons orbit planets. (Details of Kepler's laws are not required.) Students should also know the names of the planets, their approximate comparative sizes and comparative distances from the Sun, the nature of the comets and the nature and position of the asteroid belt.	2
F.1.2	Describe the bodies comprising the universe. This includes collections of bodies such as galaxies and interstellar matter. A glossary overview is sufficient.	2
F.1.3	Distinguish between a stellar cluster and a constellation.	2
F.1.4	Define a *light year*.	1
F.1.5	Compare the relative distances between stars and between galaxies, in terms of order of magnitude.	2
F.1.6	Describe the apparent motion of the stars/constellations over a period of a night and over a period of a year, and explain these observations in terms of the rotation and revolution of the Earth. This is the basic background for stellar parallax. Other observations, for example seasons and the motion of planets, are not expected.	3

F.2 Stellar Radiation and Stellar Types (4h)

Energy source

A.S.		Obj
F.2.1	State that fusion is the main energy source of stars. Students should know that the basic process is one in which hydrogen is converted into helium. They do not need to know about the fusion of elements with higher atomic numbers.	1
F.2.2	State that in a stable star (for example our Sun) there is an equilibrium between radiation pressure and gravitational pressure.	1

Luminosity

A.S.		Obj
F.2.3	Define the luminosity of a star.	1
F.2.4	Define apparent brightness and state how it is measured.	1

A.S.		Obj
	Wien's law and The Stefan–Boltzmann law	
F.2.5	Outline the nature of black-body radiation. Students should know that black-body radiation is the radiation emitted by a "perfect" emitter.	2
F.2.6	Draw and annotate a graph of the spectra of black bodies at different temperatures.	2
F.2.7	State Wien's (displacement) law and apply it to explain the colours of different stars.	2
F.2.8	State the Stefan–Boltzmann law and apply it to compare the luminosities of different stars.	2
	Stellar spectra	
F.2.9	Explain how atomic spectra can be used to deduce chemical and physical data for stars. Students need only refer to the chemical composition of the outer layers of a star from its absorption spectrum and surface temperature from Wien's law.	3
F.2.10	Describe the overall classification system of spectral classes. Students need only refer to the principal spectral classes (OBAFGKM).	2
	Types of star	
F.2.11	Describe the different types of stars. Students need only refer to single and binary stars, Cepheids, red giants and white dwarfs. Different types of Cepheids are not required.	2
F.2.12	Describe the characteristics of visual, spectroscopic and eclipsing binary stars.	2
	The Hertzsprung–Russell diagram	
F.2.13	Identify the general regions of star types on a Hertzsprung–Russell diagram. Main sequence, red giant, white dwarf and Cepheid stars should be shown, with scales of luminosity (or absolute magnitude), spectral class and/or surface temperature indicated. Students are not required to state explicitly the log nature of the scales, but they should be aware that the scale is not linear.	2

A.S.		Obj
	F.3 Stellar Distances (5h)	
	Parallax method	
F.3.1	Define the *parsec*.	1
F.3.2	Describe the method of determining the distance to a star using stellar parallax.	2
F.3.3	Explain why the method of stellar parallax is limited to measuring stellar distances less than about 100 parsecs.	3
F.3.4	Determine the distance to a star using stellar parallax.	3
	Absolute and apparent magnitudes	
F.3.5	Describe the apparent magnitude scale. Students should know that apparent magnitude depends on luminosity and the distance to the star. They should also understand that a magnitude 1 star is 100 times brighter than a magnitude 6 star.	2
F.3.6	Describe the concept of absolute magnitude and determine absolute magnitudes.	3
F.3.7	Solve problems involving ratios of apparent brightness and of apparent magnitudes.	3
	Spectroscopic parallax	
F.3.8	State that the luminosity of a star can be estimated from its spectrum.	1
F.3.9	Explain how the stellar distance can be determined by using the apparent brightness and luminosity.	3
F.3.10	State that the method of spectroscopic parallax is limited to measuring stellar distances less than about 10Mpc. Students should know that the greater the distance to an individual star, the greater the absolute error in luminosity.	1
F.3.11	Solve problems involving stellar distances, apparent brightness and luminosity.	3

A.S.		Obj
	Cepheid variables	
F.3.12	Outline the nature of a Cepheid variable. Students should know that a Cepheid variable is a star in which the outer layers undergo a periodic compression and contraction which produces a periodic variation in its luminosity.	2
F.3.13	State the relationship between period and average absolute magnitude for Cepheids. The different classes of Cepheids need not be known.	1
F.3.14	Explain that Cepheids can be used as “standard candles”. It is sufficient for students to know that if a Cepheid can be located in a particular galaxy then the distance to the galaxy can be determined.	3
F.3.15	Determine the distance to a Cepheid using the luminosity–period graph.	3

F.4 Cosmology (4h)

Olbers’ paradox

F.4.1	State that Newton assumed an infinite, uniform and static universe.	1
F.4.2	Explain Olbers’ paradox. Students should be able to show quantitatively, using the inverse square law of luminosity, that Newton’s model of the universe leads to the idea that the sky should never be dark.	3
F.4.3	Discuss solutions to Olbers’ paradox.	3

The Big Bang model

F.4.4	State that the Doppler red shift of light from galaxies indicates that the universe is expanding.	1
F.4.5	Describe both space and time as originating with the Big Bang. Students should know that the universe is not expanding into a void.	2
F.4.6	Describe the discovery of the background microwave radiation by Penzias and Wilson.	2
F.4.7	Explain how a uniform background radiation in the microwave region is consistent with the Big Bang model. A simple explanation in terms of the universe “cooling down” is all that is required.	3

A.S.		Obj
	The development of the universe	
F.4.8	Distinguish between the terms *open*, *flat* and *closed* when used to describe the universe.	2
F.4.9	Define the term *critical density*.	3
F.4.10	Discuss how critical density is related to the open, flat and closed models of the universe.	
F.4.11	Outline current attempts to determine the critical density of the universe. Dark matter, MACHOs and WIMPs could be referred to, or any other developments as they appear. This section is intended to demonstrate the ongoing type of research.	2

Option F: Extension Material (HL only) (7h)

A.S.		Obj

F.5 Stellar Processes and Stellar Evolution (4h)

Nucleosynthesis

A.S.		Obj
F.5.1	Outline the possible fusion processes in main sequence stars. Details of the chains do not need to be recalled.	2
F.5.2	Describe the conditions that initiate fusion in a star.	2
F.5.3	Outline the changes that take place in nucleosynthesis if a star leaves the main sequence and becomes a red giant. Students only need to know an outline of the processes of helium fusion and silicon fusion to form iron.	2

Evolutionary paths of stars and stellar processes

A.S.		Obj
F.5.4	State that the initial mass of a star determines its lifetime and its final fate.	1
F.5.5	Describe the Chandrasekhar limit.	2
F.5.6	Explain how the Chandrasekhar limit is used to predict the fate of stars of different mass.	3
F.5.7	Compare the fate of a red giant and a red supergiant. Students should know that: • a red giant forms a planetary nebula and then becomes a white dwarf which ultimately becomes invisible • a red supergiant experiences a supernova and becomes a neutron star or collapses to a black hole.	2
F.5.8	Draw evolutionary paths of stars on an HR diagram.	1
F.5.9	Outline the characteristics of pulsars and quasars.	2

F.6 Galaxies and the Expanding Universe (3h)

Types of galaxy

A.S.		Obj
F.6.1	Describe the structure of the Milky Way galaxy. Students should know that it is a spiral shape with a central bulge and a halo, and that our solar system is located in the disc about two thirds of the way from the Milky Way's centre.	2

A.S.		Obj
F.6.2	List types of galaxies. The terms spiral, elliptical and irregular are sufficient, no subdivisions are necessary.	1
	Galactic motion	
F.6.3	Describe the distribution of galaxies in the universe. Students should understand the terms *galactic cluster* and *galactic supercluster*.	2
F.6.4	Explain the red shift of light from distant galaxies. Students should realize that the red shift is due to the expansion of the universe.	3
F.6.5	Determine the recession speed of galaxies using the simplified red shift equation.	3
	Hubble's law	
F.6.6	State Hubble's law.	1
F.6.7	Discuss the limitations of Hubble's law.	3
F.6.8	Explain how the Hubble constant can be determined.	3
F.6.9	Explain how the Hubble constant can be used to determine the age of the universe. Students need only consider a constant rate of expansion.	3
F.6.10	Solve problems involving Hubble's law.	3
F.6.11	Discuss the stages in the development of the universe following the Big Bang, from the so-called inflationary epoch to the formation of galactic clusters. Mention should be made of the inflationary epoch; the production of excess matter over antimatter; the formation of light nuclei; the uniting of electrons and nuclei into atoms; the formation of stars, galaxies and galactic clusters. Detailed accounts of each process are not necessary.	3

Option G: Relativity (15h)

A.S. | Obj

G.1 Introduction (1h)

Frames of reference

Note: This links to core section 2.2. While it does not imply any further knowledge, it helps develop an understanding of the relative motion of two observers.

G.1.1 Explain what is meant by a frame of reference. **3**

G.1.2 Describe what is meant by a Galilean transformation. **2**

G.1.3 Calculate relative velocities using the Galilean transformation equations. **2**

Electromagnetic theory and the speed of light

G.1.4 State that Maxwell's theory of electromagnetic radiation predicted a speed of electromagnetic waves in a vacuum that is independent of the velocity of the source. **1**

Students should be familiar with the concept of oscillating electric and magnetic fields and that the speed of these fields is dependent only on the electric and magnetic constants of the medium through which they travel. The speed is therefore independent of the source. Students do not need any other details of Maxwell's four equations.

G.1.5 State that the Galilean transformation equations fail if applied to a moving source of light. **1**

Students should know that Maxwell's prediction implies that the speed of light in a vacuum has the same value for all observers.

G.2 Concepts and Postulates of Special Relativity (2h)

G.2.1 Explain what is meant by an inertial frame of reference. **3**

G.2.2 State the two postulates of the special theory of relativity. **1**

G.2.3 Discuss the concept of simultaneity. **3**

Students should be able to describe a situation where two events that are simultaneous in one frame of reference are not simultaneous in another.

A.S.		Obj

G.3 Relativistic Kinematics (5h)

Time dilation

G.3.1 Explain the concept of a *light clock*. **3**

Only a very simple explanation is required here. For example, the time taken for a beam of light to bounce between two perfect, parallel mirrors can be used to measure time.

G.3.2 Derive the time dilation formula. **3**

Students should be able to construct a simple proof of the time dilation formula based on the concept of the "light clock" and the postulates of relativity. Students should also understand that for two observers in two different inertial reference frames, all measurements are symmetrical.

G.3.3 Draw and annotate a graph of how the Lorentz factor varies with relative velocity. **2**

Students do not need to remember values, but they should be aware that at low velocities (less than 0.5c) the Lorentz factor is very close to 1 and that it approaches infinity at very high velocities.

G.3.4 Define the term *proper time*. **1**

G.3.5 Solve problems using the time dilation formula. **3**

Length contraction

G.3.6 Describe the phenomenon of length contraction. **2**

Students will not be examined on a proof of the length contraction formula.

G.3.7 Define the term *proper length*. **1**

G.3.8 Solve problems involving length contraction. **3**

G.4 Some Consequences of Special Relativity (4h)

The twin paradox

G.4.1 Describe how the concept of time dilation leads to the "twin paradox". **2**

Different observers' versions of the time taken for a journey at speeds close to light speed could be compared. Students should be aware that, since one of the twins makes an outward and return journey, this is no longer a symmetric situation for the twins. (See G.3.2.)

A.S.		Obj
	Velocity addition	
G.4.2	Solve one-dimensional problems involving the relativistic addition of velocities. The derivation of the velocity addition formula is not required. Students should realize that Galilean and relativistic velocity addition give the same answer at low relative velocities and that relativistic velocity addition does not give a relative velocity greater than the speed of light.	3
	Relativistic mass increase	
G.4.3	Define the term *rest mass*.	1
G.4.4	Solve problems involving relativistic mass increase. The derivation of the mass increase formula will not be examined. Students should be able to calculate the total mass of a moving object and to apply this value in a subsequent calculation of, for example, an electron accelerated through a potential difference.	3
G.4.5	Explain in terms of the relativistic mass equation why no mass can ever attain or exceed the speed of light in a vacuum.	3
	Mass-energy	
G.4.6	State that the equivalence of mass and energy is predicted by special relativity.	1
G.4.7	Distinguish between rest mass energy and total energy.	2

G.5 Evidence to Support Special Relativity (3h)

	Muon experiments	
G.5.1	Discuss muon decay as experimental evidence for time dilation and length contraction.	3
	The Michelson-Morley experiment	
G.5.2	Outline the set-up of the Michelson–Morley experiment. Students should be able to outline the principles behind the Michelson interferometer using a simple sketch of the apparatus.	2
G.5.3	Outline the result of the Michelson–Morley experiment and its implication. The constancy of the speed of light and the fact that there is no absolute reference frame is the accepted explanation.	2

Option G: Extension Material (HL only) (7 h)

A.S.		Obj

G.6 Relativistic Momentum and Energy (2h)

Note: Derivation of the relativistic momentum and energy formulas will not be examined.

G.6.1	Solve problems involving objects moving at relativistic speeds using Einstein's mass–energy equation.	3
G.6.2	Solve problems involving relativistic momentum and energy. Students should be able to calculate, for example, the kinetic energy, total energy, speed and momentum of an electron accelerated through a given potential difference. Students should be familiar with the units of $MeVc^{-2}$ for mass and $MeVc^{-1}$ for momentum. Other multiples could also be considered (eg $GeVc^{-2}$ for mass).	3

G.7 General Relativity (4h)

Note: This section is intended as an introduction to the ideas of general relativity and is non-mathematical in its approach .

The equivalence principle

G.7.1	Explain the difference between the terms *gravitational mass* and *inertial mass.*	3
G.7.2	Describe and discuss Einstein's principle of equivalence. Students should be familiar with Einstein's closed elevator "thought experiment".	3
G.7.3	Deduce that the principle of equivalence predicts bending of light rays in a gravitational field.	3

Spacetime

G.7.4	Describe the concept of spacetime.	2
G.7.5	State that moving objects take the shortest path between two points in spacetime.	1
G.7.6	Explain gravitational attraction in terms of the warping of spacetime by matter. The model representing the curving of spacetime in terms of the bending of a "sheet" of spacetime is sufficient.	3

A.S.		Obj
	Gravitational red shift	
G.7.7	Describe the concept of gravitational red shift. Students should be aware that this gravitational red shift is a prediction of the general theory of relativity.	2
G.7.8	Solve problems involving frequency shifts between different points in a uniform gravitational field. Only the simplified formula is required.	3
	Black holes	
G.7.9	Describe black holes. Students should know that black holes are a region of spacetime with extreme curvatures due to the presence of a mass.	2
G.7.10	Define the term *Schwarzchild radius*.	1
G.7.11	Apply the equation for calculating the Schwarzchild radius.	2

G.8 Evidence to Support General Relativity (1h)

G.8.1	Outline the experimental evidence for the bending of star light rays by the Sun. An outline of the principles used in, for example, Arthur Eddington's measurements of the 1919 eclipse is sufficient.	2
G.8.2	Explain the effect of "gravitational lensing".	3
	Evidence for gravitational red shift	
G.8.3	Outline an experiment that provides evidence for gravitational red shift. The Pound–Rebka experiment (or a suitable alternative such as the shift in frequency of an atomic clock) is sufficient.	2

Option H: Optics (15h)

A.S.		Obj

H.1 The Nature of Light (3h)

Speed of light

H.1.1 Outline the electromagnetic nature of light. **2**

It is sufficient for students to know that an oscillating electric charge produces sinusoidally varying electric and magnetic fields and that the energy of the oscillating charge is propagated by means of the varying fields. Students should know that electromagnetic waves are transverse waves and can travel in a vacuum.

H.1.2 Describe the different regions of the electromagnetic spectrum. **2**

Students should know the order of magnitude of the frequencies for the different regions, and should also be able to identify a possible source of the radiation in each region.

H.1.3 Outline an experiment that measures the speed of light in a vacuum. **2**

No specific experiment is required, but Michelson's method involving a rotating mirror would be appropriate. Experimental details are not required. Students should be aware that the speed of light in vacuum is now a defined value in terms of which the metre is defined.

Dispersion

H.1.4 Describe the dispersion of white light by a prism. **2**

Students should know that different colours disperse in order of decreasing frequencies and that the colours can combine to produce white light.

H.1.5 Explain the dispersion of white light by a prism in terms of the frequency dependence of refractive index. **3**

No quantitative discussion is required but students should know that the refractive index for glass is smaller for red light than it is for blue light.

Lasers

H.1.6 Identify laser light as a source of *monochromatic*, *coherent* light. **2**

Students should be able to explain monochromatic and coherent.

H.1.7 Outline a laser application from technology, industry or medicine. **2**

Possible examples include:

- technology (bar-code scanners, laser discs)
- industry (surveying, welding and machining metals, drilling tiny holes in metals)
- medicine (destroying tissue in small areas, attaching the retina, corneal correction, cauterizing lymph vessels and capillaries).

A.S.		Obj

H.2 Reflection at a Plane Surface (2h)

Nature of reflection

H.2.1	Distinguish between reflection at a mirror and diffuse reflection.	2
H.2.2	Define the terms *normal*, *incident ray*, *reflected ray*. Students should know that the ray is a line that is perpendicular to the wave fronts. They should recognize geometric optics as a study in which the wave nature of light can be ignored.	1
H.2.3	State the law of reflection.	1

Formation of an image by reflection

H.2.4	Construct a ray diagram to determine the formation of an image by reflection at a plane surface.	3
H.2.5	Explain the difference between a *real* and a *virtual* image.	3
H.2.6	Describe the nature of the image formed by reflection.	2

H.3 Refraction at a Plane Interface (3h)

Snell's law and refractive index

H.3.1	Define *refractive index*.	1
H.3.2	Solve problems involving Snell's law and refractive index.	3

Image formation

H.3.3	Describe the nature of the image formed by refraction at a plane surface.	2
H.3.4	Explain why when part of a stick is immersed in water it appears to be bent.	3
H.3.5	Explain why the apparent depth of a body immersed in a liquid is not its actual depth.	3
H.3.6	Derive the formula connecting real depth, apparent depth and refractive index.	3
H.3.7	Solve problems involving refraction at a plane interface.	3

A.S.		Obj
	Critical angle	
H.3.8	State that, in general, light will be partially transmitted and partially reflected at a boundary between two media.	1
H.3.9	Describe the phenomenon of total internal reflection. Students should understand the terms *critical ray* and *critical angle*.	2
H.3.10	Derive a relationship between the critical angle and the refractive indices of the media.	3
H.3.11	Solve problems involving total internal reflection.	3
H.3.12	Explain the view as seen by an underwater observer when looking at the water–air interface.	3
H.3.13	Describe the action of prismatic reflectors. For example, periscopes or binoculars.	2
H.3.14	Discuss how a light ray is transmitted along the length of an optical fibre.	3
H.3.15	Outline the uses of optical fibres. It is sufficient that students know how optical fibres are used in the transmission of data and in medicine (endoscopes).	2

H.4 Refraction by Lenses (3h)

A.S.		Obj
	Types of lenses	
H.4.1	Explain qualitatively, in terms of refraction, the converging and diverging action of lenses.	3
H.4.2	Identify whether a lens is converging or diverging.	2
	Image formation	
H.4.3	Define the terms *principal axis*, *focal point*, *focal length*, *linear magnification*.	1
H.4.4	Construct ray diagrams to locate images formed by lenses. Students should appreciate that any other rays incident on the lens from the object will also be focused, and that the image will be formed even if some of the rays are blocked off.	3
H.4.5	Determine the nature of images formed by different types of lenses with different object-to-lens separations.	3

A.S. **Obj**

H.4.6 Solve problems for a single lens and a combination of lenses using the thin lens equation. **3**

> Problems can be solved either by scale drawing or calculation. Students do not need to know the lensmaker's formula.

H.5 Optical Instruments (4h)

Note: Only single- and two -lens instruments will be considered .

The simple magnifying glass

H.5.1 Define the terms *near point* and *far point* for the unaided eye. **1**

> The near point is also known as the "least distance of distinct vision". For the normal eye, the far point can be taken to be infinity and the near point is conventionally taken as 25 cm. (The optical principles inside the eye are not required.)

H.5.2 Define *angular magnification*. **1**

H.5.3 Derive an expression for the angular magnification of a simple magnifying glass when the image is formed at the near point and at infinity. **3**

The compound microscope and astronomical telescope

H.5.4 Construct a ray diagram to determine the position of the final image formed by a compound microscope used in normal adjustment. **3**

> Students should be familiar with the terms *objective lens* and *eyepiece lens*.

H.5.5 Construct a ray diagram to explain how the image is formed by an astronomical telescope. **3**

> Only the case for image at infinity is required.

H.5.6 Derive the equation relating angular magnification and focal lengths of the lenses in an astronomical telescope. **3**

H.5.7 Solve problems involving the compound microscope and the astronomical telescope. **3**

> Problems can be solved either by scale ray diagrams or by calculation.

Aberrations

H.5.8 Describe the meaning of spherical aberration and chromatic aberration. **2**

H.5.9 Describe a method to reduce or eliminate the effect of spherical aberration. **2**

H.5.10 Describe a method to reduce the effect of chromatic aberration. **2**

Option H: Extension Material (HL only) (7h)

A.S.		Obj

H.6 Diffraction and Interference (5h)

Note: All diffraction in this section is taken to be Fraunhofer diffraction, ie involving plane wave fronts.

Diffraction

A.S.		Obj
H.6.1	Draw the diffraction fringe patterns produced by a single edge, a narrow slit and a circular aperture.	1
H.6.2	Explain diffraction patterns qualitatively.	3
H.6.3	Draw the relative intensity versus angle plot for the diffraction of light at a single slit.	1
H.6.4	Derive the condition for the position of the minima of the diffraction pattern. Students should be aware of the small angle approximation for the condition $\theta = \frac{\lambda}{b}$ and should also be able to calculate the full width of the central maximum in terms of the distance of the slit from the screen.	3
H.6.5	Explain the effect that diffraction has on the intensity distribution of the fringes produced by double slit interference. Students should be able to sketch the intensity distribution for finite slit widths and calculate the positions of the interference and diffraction minima.	3

Resolution

A.S.		Obj
H.6.6	Draw a relative intensity versus angle plot for the diffraction produced by light from two sources that passes through a slit, for situations where the diffraction patterns are well resolved, just resolved and not resolved.	1
H.6.7	State the Rayleigh criterion for two sources to be just resolved.	1
H.6.8	Solve problems involving the resolution of two sources diffracted by a slit and by a circular aperture. The derivation of $\theta = 1.22\frac{\lambda}{b}$ is not required.	3

A.S.		Obj
	Multiple slit diffraction	
H.6.9	Explain the effect on the double slit intensity distribution of adding further slits at the same slit separation. Students should be able to explain why the principal maxima maintain the same separation but become much sharper.	3
H.6.10	Derive the diffraction grating formula.	3
H.6.11	Outline how the diffraction grating is used to investigate spectra and measure wavelength. Students should also be able to explain what happens when white light is incident on a diffraction grating.	2
H.6.12	Solve problems involving the diffraction grating. Knowledge of the spectrometer is not required.	3

H.7 Thin Film Interference (2h)

Parallel films

H.7.1	State the conditions for light to undergo either a phase change of π, or no phase change, on reflection from an interface.	1
H.7.2	Describe how a source of light gives rise to an interference pattern when the light is reflected by both surfaces of a parallel film.	2
H.7.3	Derive the conditions for constructive and destructive interference.	3
H.7.4	Solve problems involving parallel films.	3
H.7.5	Explain the formation of coloured fringes when white light is reflected from thin films, such as oil films and bubbles.	3

Wedge films

H.7.6	Explain the production of interference fringes by a thin air wedge.	3
H.7.7	Describe how wedge fringes can be used to measure very small separations.	2

MATHEMATICAL REQUIREMENTS

All physics students need to be familiar with a range of mathematical techniques. The abilities described here are not pre-requisites for undertaking a Diploma Programme physics course, but they do represent the skills expected of examination candidates by the end of such a course. (The requirements written in **bold** apply only to **higher level** students.)

Arithmetic and Computation

- Make calculations involving addition, subtraction, multiplication and division.
- Recognize and use expressions in decimal and standard form (scientific) notation.
- Use calculators to evaluate **exponentials**; reciprocals; roots; logarithms to base 10; **logarithms to base e**; powers; arithmetic means; degrees; **radians**; natural sine, cosine and tangent functions and their inverse.
- Express fractions as percentages and vice versa.

Algebra

- Change the subject of an equation by manipulation of the terms including integer and fractional indices and square roots.
- Solve simple algebraic equations, and **simultaneous linear equations involving two variables**.
- Substitute numerical values into algebraic equations.
- Comprehend the meanings of (and use) the symbols /, <, >, ≥, ≤, $\boldsymbol{x}$, **≈**, $|\boldsymbol{x}|$, a, $\triangle\boldsymbol{x}$.

Geometry and Trigonometry

- Calculate areas of right-angled and isosceles triangles, circumferences and areas of circles, volumes of rectangular blocks, cylinders and spheres, and surface areas of rectangular blocks, cylinders and spheres. Relevant formulas need not be recalled.
- Use Pythagoras' theorem, similarity of triangles and recall that the angles of a triangle add up to 180^0 (and of a rectangle, 360^0).
- Understand the relationship between degrees and radians, and translate from one to the other.
- Recall the small angle approximations.