Diploma Programme

Physics guide

First assessment 2025

International Baccalaureate®
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The International Baccalaureate Organization (known as the IB) offers four high-quality and challenging educational programmes for a worldwide community of schools, aiming to create a better, more peaceful world. This publication is one of a range of materials produced to support these programmes.

IB mission statement

The International Baccalaureate aims to develop inquiring, knowledgeable and caring young people who help to create a better and more peaceful world through intercultural understanding and respect.

To this end the organization works with schools, governments and international organizations to develop challenging programmes of international education and rigorous assessment.

These programmes encourage students across the world to become active, compassionate and lifelong learners who understand that other people, with their differences, can also be right.

IB learner profile

The aim of all IB programmes is to develop internationally minded people who, recognizing their common humanity and shared guardianship of the planet, help to create a better and more peaceful world.

As IB learners we strive to be:

INQUIRERS
We nurture our curiosity, developing skills for inquiry and research. We know how to learn independently and with others. We learn with enthusiasm and sustain our love of learning throughout life.

KNOWLEDGEABLE
We develop and use conceptual understanding, exploring knowledge across a range of disciplines. We engage with issues and ideas that have local and global significance.

THINKERS
We use critical and creative thinking skills to analyse and take responsible action on complex problems. We exercise initiative in making reasoned, ethical decisions.

COMMUNICATORS
We express ourselves confidently and creatively in more than one language and in many ways. We collaborate effectively, listening carefully to the perspectives of other individuals and groups.

PRINCIPLED
We act with integrity and honesty, with a strong sense of fairness and justice, and with respect for the dignity and rights of people everywhere. We take responsibility for our actions and their consequences.

OPEN-MINDED
We critically appreciate our own cultures and personal histories, as well as the values and traditions of others. We seek and evaluate a range of points of view, and we are willing to grow from the experience.

CARING
We show empathy, compassion and respect. We have a commitment to service, and we act to make a positive difference in the lives of others and in the world around us.

RISK-TAKERS
We approach uncertainty with forethought and determination; we work independently and cooperatively to explore new ideas and innovative strategies. We are resourceful and resilient in the face of challenges and change.

BALANCED
We understand the importance of balancing different aspects of our lives—intellectual, physical, and emotional—to achieve well-being for ourselves and others. We recognize our interdependence with other people and with the world in which we live.

REFLECTIVE
We thoughtfully consider the world and our own ideas and experience. We work to understand our strengths and weaknesses in order to support our learning and personal development.

The IB learner profile represents 10 attributes valued by IB World Schools. We believe these attributes, and others like them, can help individuals and groups become responsible members of local, national and global communities.

Contents

Purpose of this document

This publication is intended to guide the planning, teaching and assessment of physics in schools. Subject teachers are the primary audience, although it is expected that teachers will use the guide to inform students and parents about the subject.

This guide can be found on the subject page of the Programme Resource Centre at resources.ibo.org, a password-protected International Baccalaureate (IB) website designed to support IB teachers. It can also be purchased from the IB store at store.ibo.org.

Additional resources

Additional publications such as specimen papers and markschemes, teacher support material (TSM), subject reports and grade descriptors can also be found on the Programme Resource Centre. Past examination papers as well as markschemes can be purchased from the IB store.

Teachers are encouraged to check the Programme Resource Centre for additional resources created or used by other teachers. Teachers can provide details of useful resources, for example: websites, books, videos, journals or teaching ideas.

Acknowledgement

The IB wishes to thank the educators and associated schools for generously contributing time and resources to the production of this guide.

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The Diploma Programme

The Diploma Programme (DP) is a rigorous pre-university course of study designed for students in the 16 to 19 age range. It is a broad-based two-year course that aims to encourage students to be knowledgeable and inquiring, but also caring and compassionate. There is a strong emphasis on encouraging students to develop intercultural understanding, open-mindedness, and the attitudes necessary for them to respect and evaluate a range of points of view.

The Diploma Programme model

The course is presented as six academic areas enclosing a central core (see figure 1). It encourages the concurrent study of a broad range of academic areas. Students study two modern languages (or a modern language and a classical language), a humanities or social science subject, an experimental science, mathematics and one of the creative arts. It is this comprehensive range of subjects that makes the DP a demanding course of study designed to prepare students effectively for university entrance. In each of the academic areas students have flexibility in making their choices, which means they can choose subjects that particularly interest them and that they may wish to study further at university.

Figure 1

Diploma Programme model

Choosing the right combination

Students are required to choose one subject from each of the six academic areas, although they can, instead of an arts subject, choose two subjects from another area. Normally, three subjects (and not more than four) are taken at higher level (HL), and the others are taken at standard level (SL). The IB recommends 240 teaching hours for HL subjects and 150 hours for SL. Subjects at HL are studied in greater depth and breadth than at SL.

At both levels, many skills are developed, especially those of critical thinking and analysis. At the end of the course, students' abilities are measured by means of external assessment. Many subjects contain some element of coursework assessed by teachers.

The core of the Diploma Programme model

All DP students participate in the three course elements that make up the core of the model.

Theory of knowledge (TOK) is a course that is fundamentally about critical thinking and inquiry into the process of knowing rather than about learning a specific body of knowledge. The TOK course examines the nature of knowledge and how we know what we claim to know. It does this by encouraging students to analyse knowledge claims and explore questions about the construction of knowledge. The task of TOK is to emphasize connections between areas of shared knowledge and link them to personal knowledge in such a way that an individual becomes more aware of their own perspectives and how they might differ from others.

In TOK, students explore the means of producing knowledge within the core theme of "knowledge and the knower" as well as within various optional themes (knowledge and technology, knowledge and politics, knowledge and language, knowledge and religion, and knowledge and indigenous societies) and areas of knowledge (the arts, natural sciences, human sciences, history and mathematics). The course also encourages students to make comparisons between different areas of knowledge and reflect on how knowledge is arrived at in the various disciplines, what the disciplines have in common, and the differences between them.

Creativity, activity, service (CAS) is at the heart of the DP. The emphasis in CAS is on helping students to develop their own identities, in accordance with the ethical principles embodied in the IB mission statement and the IB learner profile. It involves students in a range of activities alongside their academic studies throughout the DP. The three strands of CAS are creativity (arts and other experiences that involve creative thinking), activity (physical exertion contributing to a healthy lifestyle) and service (an unpaid and voluntary exchange that has a learning benefit for the student). Possibly, more than any other component in the DP, CAS contributes to the IB's mission to create a better and more peaceful world through intercultural understanding and respect.

The extended essay (EE), including the world studies extended essay, offers the opportunity for IB students to investigate a topic of special interest, in the form of a 4,000-word piece of independent research. The area of research undertaken is chosen from one of the students' six DP subjects, or in the case of the interdisciplinary world studies essay, two subjects, and acquaints them with the independent research and writing skills expected at university. This leads to a major piece of formally presented, structured writing, in which ideas and findings are communicated in a reasoned and coherent manner, appropriate to the subject or subjects chosen. It is intended to promote high-level research and writing skills, intellectual discovery and creativity. An authentic learning experience, it provides students with an opportunity to engage in personal research on a topic of choice, under the guidance of a supervisor.

Approaches to teaching and approaches to learning

Approaches to teaching and approaches to learning (ATL) across the DP refers to deliberate strategies, skills and attitudes that permeate the teaching and learning environment. These approaches and tools, intrinsically linked with the learner profile attributes, enhance student learning and assist student preparation for the DP assessment and beyond. The aims of approaches to teaching and learning in the DP are to:

- empower teachers as teachers of learners as well as teachers of content
- empower teachers to create clearer strategies for facilitating learning experiences in which students are more meaningfully engaged in structured inquiry and greater critical and creative thinking
- promote both the aims of individual subjects (making them more than course aspirations) and linking previously isolated knowledge (concurrency of learning)
- encourage students to develop an explicit variety of skills that will equip them to continue to be actively engaged in learning after they leave school, and to help them not only obtain university admission through better grades but also prepare for success during tertiary education and beyond
- enhance further the coherence and relevance of the students' DP experience
- allow schools to identify the distinctive nature of an IB DP education, with its blend of idealism and practicality.

The five ATL (developing thinking skills, social skills, communication skills, self-management skills and research skills) along with the six approaches to teaching (teaching that is inquiry-based, conceptually focused, contextualized, collaborative, differentiated and informed by assessment) encompass the key values and principles that underpin IB pedagogy.

The IB mission statement and the IB learner profile

The DP aims to develop in students the knowledge, skills and attitudes they will need to fulfil the aims of the IB, as expressed in the organization's mission statement and the learner profile. Teaching and learning in the DP represent the reality in daily practice of the organization's educational philosophy.

Academic integrity

Academic integrity in the DP is a set of values and behaviours informed by the attributes of the learner profile. In teaching, learning and assessment, academic integrity serves to promote personal integrity, engender respect for the integrity of others and their work, and ensure that all students have an equal opportunity to demonstrate the knowledge and skills they acquire during their studies.

All coursework—including work submitted for assessment—is to be authentic, based on the student's individual and original ideas with the ideas and work of others fully acknowledged. Assessment tasks that require teachers to provide guidance to students or that require students to work collaboratively must be completed in full compliance with the detailed guidelines provided by the IB for the relevant subjects.

For further information on academic integrity in the IB and the DP, please consult the IB publications *Academic integrity policy*, *Effective citing and referencing*, *Diploma Programme: From principles into practice* and the general regulations in *Diploma Programme Assessment procedures* (updated annually). Specific information regarding academic integrity as it pertains to external and internal assessment components of this DP subject can be found in this guide.

Acknowledging the ideas or work of another person

Coordinators and teachers are reminded that candidates must acknowledge all sources used in work submitted for assessment. The following is intended as a clarification of this requirement.

DP candidates submit work for assessment in a variety of media that may include audiovisual material, text, graphs, images and/or data published in print or electronic sources. If a candidate uses the work or ideas of another person, the candidate must acknowledge the source using a standard style of referencing in a consistent manner. A candidate's failure to acknowledge a source will be investigated by the IB as a potential breach of regulations that may result in a penalty imposed by the IB final award committee.

The IB does not prescribe which style(s) of referencing or in-text citation should be used by candidates; this is left to the discretion of appropriate faculty/staff in the candidate's school. The wide range of subjects, response languages and the diversity of referencing styles make it impractical and restrictive to insist on particular styles. In practice, certain styles may prove most commonly used, but schools are free to choose a style that is appropriate for the subject concerned and the language in which candidates' work is written. Regardless of the reference style adopted by the school for a given subject, it is expected that the minimum information given includes: name of author, date of publication, title of source, and page numbers as applicable.

Candidates are expected to use a standard style and use it consistently so that credit is given to all sources used, including sources that have been paraphrased or summarized. When writing text candidates must clearly distinguish between their words and those of others by the use of quotation marks (or other method, such as indentation) followed by an appropriate citation that denotes an entry in the bibliography. If an electronic source is cited, the date of access must be indicated. Candidates are not expected to show faultless expertise in referencing, but are expected to demonstrate that all sources have been acknowledged. Candidates must be advised that audiovisual material, text, graphs, images and/or data published in print or in electronic sources that is not their own must also attribute the source. Again, an appropriate style of referencing/citation must be used.

Learning diversity and learning support requirements

Schools must ensure that equal access arrangements and reasonable adjustments are provided to candidates with learning support requirements that are in line with the IB documents *Access and inclusion policy* and *Learning diversity and inclusion in IB programmes: Removing barriers to learning.*

The publications *Meeting student learning diversity in the classroom* and *The IB guide to inclusive education: a resource for whole school development* are available to support schools in the ongoing process of increasing access and engagement by removing barriers to learning.

Programme standards and practices

The programme standards and practices are a set of principles for schools to ensure quality and fidelity in the implementation of IB programmes. Teaching and learning are important markers of quality and effective practice in schools; thus the expectations teachers and learners share across all IB programmes can be found in the programme standards and practices.

The programme standards and practices provide a framework to help teachers understand their rights and responsibilities in IB World Schools as they develop learning environments and experiences for their students. The IB recognizes that in order for effective teaching to take place, teachers must be supported in their understanding, well-being, environment and resources. Teachers use the core tenets of IB philosophy and pedagogy (approaches to teaching, ATL, the learner profile and international-mindedness) to design learning experiences that prepare learners to fulfil the aims and objectives outlined in this guide.

To learn more about teachers' rights and responsibilities, please see the IB publication *Programme standards and practices* on the Programme Resource Centre.

Nature of science

What is nature of science?

Nature of science (NOS) is an overarching theme in the biology, chemistry and physics courses that seeks to explore conceptual understandings related to the purpose, features and impact of scientific knowledge.

What do we want to know in science?

Nobel laureate and influential popularizer of science, Richard Feynman, once described the process of science using the analogy of watching an unknown board game being played "... and you don't know the rules of the game, but you're allowed to look at the board from time to time. And from these observations, you try to figure out what the rules are of the game, [and] the rules of the pieces moving" (Feynman et al., 1963).

What is the scientific endeavour?

Classifying such observations and underlying patterns in the natural world is the essence of what scientists do, underpinned by the assumption that the universe exists as an external reality accessible to the human experience. The varied and often non-linear processes used in scientific methodologies have several key features in common to maximize the validity and reliability of knowledge produced. The development of falsifiable hypotheses, a requirement for replicable data, and the utilization of peer-review may be among the most essential of these and help differentiate a scientific process from a pseudoscientific one. The communal and collaborative nature of this approach further strengthens the objectivity of science by ensuring the inclusion of diverse perspectives and shared responsibility for its outcomes.

What type of knowledge do we produce?

Formal scientific knowledge may encompass several categories including representative models, explanatory theories and descriptive laws. As the focus of each discipline of natural science differs, so too does the balance of their contributions to each category. What remains constant, however, is the acknowledgement of assumptions, exceptions and limitations of scientific knowledge to provide realistic parameters to our understanding of the natural world. Claims of certainty are treated with caution given the presence of paradigmatic shifts throughout the history of science.

What is the impact of scientific knowledge?

As well as the pursuit of knowledge for its own sake, it is useful to consider the interplay of science with other areas of society. Although advances in technology traditionally fuelled great leaps in scientific understanding, in recent times it may be more common to see science as a driver of technological development. In addition, the implications of science within environmental, political, social, cultural and economic domains can also be profound. These connections illustrate the importance of local, national and international scientific bodies that engage with the public understanding of science and heighten the responsibility of scientists to adhere to principles of academic integrity in their research.

Table 1

Aspects of nature of science

Aspects	How are scientific knowledge claims generated, tested, communicated, evaluated and used? What issues arise from these actions?
Observations	Scientists act as observers, looking at Earth and all other parts of the universe, to obtain data about natural phenomena. Observations can be made directly using human senses, or with the aid of instruments such as electronic sensors. Unexpected or unplanned observations can open up new research fields.
Patterns and trends	Scientists analyse their observations, looking for patterns or trends, and try to draw general conclusions by inductive reasoning. They also look for discrepancies. Scientists classify objects through pattern recognition. A trend may take the form of a positive or negative correlation between variables. Correlations may be based on a causal relationship, but correlation does not prove causation.
Hypotheses	Scientists make provisional explanations for the patterns that they have observed in natural phenomena. These hypotheses can be tested, with further observations or experiments, to obtain support for a hypothesis or show that it is false.
Experiments	Scientists design and perform experiments to obtain data, which can be used to test hypotheses. The quality of experimental evidence depends on careful control of variables and on the quantity of data generated. Progress in science often follows technological developments that allow new experimental techniques. Creativity and imagination play a role in experimental design, interpretation and conclusion.
Measurement	Quantitative measurements are more objective than qualitative observations, but all measurements are limited in precision and accuracy. Measurements are repeated to strengthen the reliability of data. Random errors in measurement due to unknown or unpredictable differences lead to imprecision and uncertainty, whereas systematic errors lead to inaccuracy.
Models	Scientists construct models as artificial representations of natural phenomena. They are useful when direct observation or experimentation is difficult. Models are simplifications of complex systems and can be physical representations, abstract diagrams, mathematical equations or algorithms. All models have limitations that need to be considered in their application.
Evidence	Scientists adopt a sceptical attitude to claims and evaluate them using evidence. Some claims cannot be tested using verifiable evidence, so cannot be falsified. They are therefore not scientific. Scientific knowledge must be supported by evidence.
Theories	Scientists develop general explanations that are widely applicable, based on observed patterns or tested hypotheses. Predictions can be generated from these theories by deductive reasoning. If these predictions are tested, they may corroborate a theory or show that it is false and should be rejected. Paradigm shifts take place when a new theory replaces an old one. The term “law” is sometimes used for statements that allow predictions to be made about natural phenomena without explaining them.
Falsification	Scientists can use evidence to falsify a claim formulated as a hypothesis, theory or model, but they cannot prove with certainty that such a claim is true. There is therefore inherent uncertainty in all scientific knowledge. Nonetheless, many theories in science are corroborated by strong evidence and allow for prediction and explanation. Scientists must remain open-minded with respect to new evidence.

Aspects	How are scientific knowledge claims generated, tested, communicated, evaluated and used? What issues arise from these actions?
Science as a shared endeavour	Scientists communicate and collaborate throughout the world. Agreed conventions and common terminology facilitate unambiguous communication. Peer review is essential to verify the research methods of knowledge claims prior to their publication in journals.
Global impact of science	Scientists have an obligation to assess the risks associated with their work and must aim to do no harm. Developments in science may have ethical, environmental, political, social, cultural and economic consequences that must be considered during decision-making. The pursuit of science may have unintended consequences. Research proposals are often filtered through ethics boards. Scientists have a responsibility to communicate their findings to the public with honesty and clarity.

How is NOS different from TOK?

In contrast to the specificity of understanding of science, the TOK course encourages students to think critically about the concepts that underpin knowledge production. For example, peer review is used as a tool to support objectivity in scientific research. Through the study of TOK, students question the limitations of the peer review process and extend their thinking to an assessment of objectivity in other areas of knowledge.

Nature of physics

What is physics?

To study physics is to attempt to understand the nature of the universe itself. It is the search for answers from how the universe exploded into life in the Big Bang to what the nature of time is itself. Some of the greatest discoveries in history have been made by physicists and these discoveries have revolutionized our world—and physicists are continuing to change the way we think today.

Physics encompasses everything that we do as human beings. The very meaning of the word is “the study of nature”. Indeed, when the discipline was first defined, it was about observing the Milky Way, the entire known universe at the time, while wondering about the existence of the atom. As with the universe, physics knowledge is constantly expanding. The existence of black holes, gravitational forces so strong that even light is unable to escape, was first theorized in the 18th century. In 2019, an image of a black hole was captured for the first time.

However, physics is not just about staring into the vastness of space or scrutinizing the tiniest particles that make up the fabric of the universe. The fact is that discoveries in physics are the root of ideas that revolutionize the technology used in our daily lives. It is an everyday, grounded science encompassing advances in communication, medical technology and renewable energy.

It is above all a creative discipline. Physics requires solid knowledge of basic principles and a willingness to put them to the test in new ways. It requires curiosity and an appetite to explore what might be.

> Creativity is essential to particle physics, cosmology, and to mathematics, and to other fields of science, just as it is to its more widely acknowledged beneficiaries—the arts and humanities.
>
> Lisa Randall

> Look up at the stars and not down at your feet … Be curious.
>
> Stephen Hawking

What do physicists do?

To put it succinctly, physicists seek to expand knowledge. They work to test hypotheses and explain observations. They use the results to build evidence, which ultimately leads to discoveries. These are scrutinized by the scientific community and, if accepted, become knowledge. This progression is a process of continuous succession of inquiry questions which when answered, raise new ones, leading to further inquiry, further explorations, further discoveries and the deepening of knowledge. This collective work by the scientific community is one of the features of “doing” physics.

The process of doing physics never ends. Even the soundest findings are subject to rigorous questions and further scientific exploration. Physicists constantly test and re-evaluate accepted truths. Knowledge is constantly scrutinized and rechecked, and therefore, confirmed or rejected by fresh insights. It is in this manner that objective experiments are subjectively experienced by scientists who repeat them to confirm the value of what is transmitted, constituting the essence of the scientific experience.

> Facts are not science—as the dictionary is not literature.
>
> Martin H. Fischer

> …it is worthwhile rechecking by new direct experience, and not necessarily trusting the … experience from the past.
>
> Richard Feynman

How do physicists do physics?

This question is the subject of heated debate in the world of education. Some argue that the "doing" of physics is a set of fixed steps to construct scientific methods around arguments. Beyond the debate, the way scientists work and construct knowledge is, in the words of John Dewey more than a hundred years ago, "the only method of thinking that has proved fruitful in any subject".

There is an even simpler summary of how physicists do physics: "Write down the problem, think hard, write down the answer" (Richard Feynman). This—considered alongside Albert Einstein's famous pronouncement that "Imagination is more important than knowledge"—is an excellent overview of the general features of a physicist's work. In summary, they collect evidence to reach partial conclusions that eventually might be accepted as laws or explanatory theories.

However, physicists also create models. These could be mathematical equations, analogies or physical representations. They take different formats, some more abstract than others, but they all aim at the same objective—to mediate and enable understanding.

In laboratories all over the world, physicists are working on exploring the boundaries of long-established disciplines like mechanics and electromagnetism. Meanwhile, physicists explore new frontiers of understanding as varied as the existence of gravitational waves, the path to artificial intelligence, sustainable energy sources on earth and the expansion of travel into space. There are almost no limits to the areas where physics is relevant today.

> Equipped with his five senses, man explores the universe around him and calls the adventure Science.
>
> Edwin Powell Hubble

> Physics is really nothing more than a search for ultimate simplicity, but so far all we have is a kind of elegant messiness.
>
> Bill Bryson

Distinction between SL and HL

Students at SL and HL share the following.

- An understanding of science through a stimulating experimental programme
- The nature of science as an overarching theme
- The study of a concept-based syllabus
- One piece of internally assessed work, the scientific investigation
- The collaborative sciences project

The SL course provides students with a fundamental understanding of physics and experience of the associated skills. The HL course requires students to increase their knowledge and understanding of the subject, and so provides a solid foundation for further study at university level.

The SL course has a recommended 150 teaching hours, compared to 240 hours for the HL course. This difference is reflected in the additional content studied by HL students. Some of the HL content is conceptually more demanding and explored in greater depth. The distinction between SL and HL is therefore one of both breadth and depth. The increased breadth and depth at HL result in increased networked knowledge, requiring the student to make more connections between diverse areas of the syllabus.

Physics and the core

Physics and theory of knowledge

The TOK course plays a special role in the DP by providing opportunities for students to reflect on the nature, scope and limitations of knowledge and the process of knowing through an exploration of knowledge questions.

The areas of knowledge (AOK) are specific branches of knowledge, each of which can be seen to have a distinct nature and sometimes use different methods of gaining knowledge. In TOK, students explore five compulsory AOK: history, the human sciences, the natural sciences, mathematics and the arts.

There are several different ways in which aspects of the physics course can be connected to the exploration of knowledge. During the teaching and learning of the physics course, teachers and students evaluate knowledge claims by exploring questions concerning their validity, reliability, credibility and certainty, as well as individual and cultural perspectives on them.

Exploration of the relationship between knowledge and TOK concepts can help students to deepen their understanding and make connections between disciplines. For example, while discussing the depletion of energy sources and the constant need for new energy resources to meet energy demands, students can explore the concepts of responsibility, power and justification.

Many aspects of the physics course lend themselves to the exploration of knowledge questions. Some examples are provided in the following table.

Table 2

Examples of knowledge questions

Learning opportunities	Knowledge question
Expressing laws as formulas	Can all knowledge be expressed in words or symbols?
Time dilation	What is the role of imagination and intuition in the creation of hypotheses in the natural sciences?
Analysis of light from distant galaxies using spectroscopy	How do the tools that we use shape the knowledge that we produce?
Classification of star types	To what extent do the classification systems we use in the pursuit of knowledge affect the conclusions that we reach?
The shift from the world of classical physics to the quantum world	How can it be that scientific knowledge changes over time? What role do paradigm shifts play in the progression of scientific knowledge?

For more information, please refer to the *Theory of knowledge guide* and the *Theory of knowledge teacher support material.*

Physics and the extended essay

Students who choose to write an EE in physics undertake independent research as part of an in-depth study of a focused topic. The topic for study may be generated from the physics course or may relate to a subject area beyond the syllabus content. This detailed study will help develop research, thinking, self-management and communication skills, which will support students' learning in the physics course, and in further studies.

Examples of areas for research topics

- Fluid dynamics: time it takes to empty a water can via a small opening at the bottom of the can.
- Sound waves: analysis of harmonics of a note played with a musical instrument using fast Fourier Transform or the waveforms of the same musical note played on different musical instruments.
- Induced emf: maximum emf induced in a small rectangular coil fixed into position between the poles of a horseshoe magnet sitting at the centre of a rotating turntable.

Students and supervisors must ensure that an EE does not duplicate other work submitted for the diploma.

For more information, please refer to the *Extended essay guide* and the *Extended essay teacher support material*.

Physics and creativity, activity, service

The CAS component of the DP core provides many opportunities for students to link science concepts and topics to practical experiences. Teachers can highlight how knowledge and understanding developed through the course might inform meaningful experiences. Outside the classroom, CAS experiences might also ignite students' passion for addressing topics inside the physics classroom.

Some examples of relevant CAS experiences are as follows.

- Organizing a science club for students in lower years
- Implementing environmental initiatives within the school or local community, such as recycling, composting and roof gardens
- Organizing or participating in a social media outreach or advocacy campaign, for example, on an environmental or health concern

CAS experiences can be a single event or may be an extended series of events. It is important that CAS experiences be distinct from and not submitted as part of a physics assessment.

For more information, please refer to the *Creativity, activity, service guide* and the *Creativity, activity, service teacher support material.*

Physics and international-mindedness

Science has been, and continues to be, a truly international endeavour. From the beginnings of seismology in China, through material science in Mesopotamia to astronomy in the Islamic Golden Age, the search for an objective understanding of the natural world transcends the limitations imposed by national boundaries. The scientific process, requiring curiosity, insight and an open-minded approach, benefits from the widest possible participation across genders and cultures through inclusivity and diversity.

Given the global nature of many scientific issues, international organizations often have a focus on the engagement of science with the public domain. The World Health Organization and the Intergovernmental Panel on Climate Change are two well-known examples that model a responsibility to inform nations of scientific progress on an equitable basis. Underlying this responsibility is the interest of promoting a peaceful and sustainable future.

Advancements in technology, along with the cost of modern research facilities, continues to reinforce the role of international collaborative work. The project between the Joint Institute of Nuclear Research in Russia and the Lawrence Livermore National Laboratory in the USA to provide evidence for the existence of element 118, oganesson, is a good example of international collaboration.

The importance of collaboration in contemporary science is reflected by the large number of international organizations tasked with collating and sharing data with the scientific community. Access to shared knowledge through websites and databases must be integrated into classroom teaching as it plays an important role in validating experimental work.

In addition to integrating technology and collaborative work, the collaborative sciences project provides an excellent opportunity for students to engage with global issues.

Physics and the IB learner profile

Each box provides an example of how each learner profile attribute could be modelled by learners and teachers.

Example attribute
• Learners who best embody the attribute with reference to science. • Directing teachers with possible routes to develop the attribute in the classroom. • Practical ways in which learners demonstrate the attribute in the process of "doing" science.

Attributes of the IB learner profile

Inquirer
• Inquirers are curious, they actively use research skills, work independently and show enthusiasm about the world around them. • Teachers facilitate skill development and promote inquiry; they provide students with opportunities to ask questions, search for answers, and experiment. • Learners use their inquiry skills to extend their scientific knowledge and engage with research.

Knowledgeable
• Learners explore concepts, ideas and issues related to science in order to broaden and deepen their understanding of factual and procedural knowledge. • Access to a variety of resources and opportunities provides learner agency to develop scientific knowledge and understanding. • Learners apply their knowledge to unfamiliar contexts and make connections between concepts and facts to illustrate their understanding of science.

Thinker
• Learners are eager to solve complex problems and reflect on their thinking strategies. • Teachers provide opportunities for learners to critically analyse their approaches and methods and deepen their understanding of science, allowing them to be creative in finding solutions to problems. • Learners practise reasoning and critical thinking by testing assumptions, formulating hypotheses, interpreting data and drawing conclusions from the evidence provided.

Communicator
• Learners collaborate effectively with others and use a variety of modes of communication to express their ideas and opinions. • Teachers facilitate group work, encourage open discussions and the use of the scientific language to provide models for successful communication. • Learners demonstrate effective communication skills as part of collaborative activities through listening to others and sharing ideas.

Principled
• Learners take responsibility for their work, promote shared values and act in an ethical manner. • Teachers can provide opportunities to model principled behaviour including acknowledging the work of others and citing sources. The collaborative sciences project provides opportunities for learners to take a principled stance. • Learners appreciate the importance of integrity in data collection and consider all data, even that which does not match their original hypothesis.

Open-minded
• Open-minded learners accept that different perspectives, models or hypotheses exist, and these can be used to enhance scientific understanding. • Teachers can provide models that were at the time supported by data or observations, but through reasoning, deduction or falsification may be rejected or refined.

Open-minded
• Learners need to be prepared to have their perspectives and ideas challenged through the study of science.

Caring
• Learners act to protect the environment and to improve the lives of others. • Teachers can draw attention to how daily choices have consequences by challenging learners to adopt sustainable practice and providing support to help fellow learners. Reference should be made to the *Sciences experimentation guidelines*. • Learners can connect curriculum content to global challenges such as healthcare, energy supply or food production. The collaborative sciences project provides an opportunity for learners to support each other to enable their group to achieve their goal successfully.

Risk-taker
• Risk-takers seek new opportunities to develop their learning and explore new approaches to solve problems. They actively thrive on challenges. • Teachers can provide support and guidance for learners, encouraging them to explore new techniques or methods of learning. This might include scaffolds for the use of language, the design of experiments and the analysis of data. As learners grow in confidence, these supports can be phased out giving them more freedom to choose their own approach. • Learners should be prepared for the next set of experimental data to falsify their ideas as uncertainty is a feature of science. They understand that this is a step forward in their understanding.

Balanced
• Balanced learners look holistically at all aspects of their development and ensure that various tasks are given appropriate attention without focusing on one to the detriment of others. • Teachers should encourage learners to consider a balanced perspective on scientific issues without bias. • Learners need to organize their own time effectively, giving themselves sufficient time to complete all parts of their learning without negatively impacting on the emotional and social aspects of their lives.

Reflective
• Reflective learners consider why and how they achieve success, and also how they could change their approach when learning is difficult. • Teachers provide opportunities for learners to continually review strategies, methods, techniques and approaches to problem-solving in order to improve their conceptual understandings in science. Assessment criteria or checklists can help learners to consider the quality of their work in a guided way. • Learners develop skills and concepts throughout the course, networking their knowledge by continually reflecting on their understanding.

Approaches to the teaching and learning of physics

The approaches to learning framework

What are approaches to learning skills and why do we teach them?

The approaches to learning (ATL) framework seeks to develop in students affective, cognitive and metacognitive skills that will support their learning processes during and beyond their IB experience. The development of ATL skills is closely connected with the IB learner profile attributes and therefore helps to advance the IB mission. The ATL skills are an integral part of IB learning and teaching that should be developed across the whole programme—it is not expected that a single course should ever address all of them.

How are they organized?

The ATL framework for IB programmes consists of five general skill categories: thinking skills, communication skills, social skills, research skills and self-management skills. Each of these categories covers a broad range, as shown by the examples presented in the table below. The ATL skill categories are closely linked and interrelated and therefore individual skills may be relevant to more than one category.

How do we teach them?

ATL skills can be learned and taught, improved with practice and developed incrementally. The table below illustrates, through a number of examples, how the physics course can support ATL skill development. The examples shown in the table are not exhaustive. Teachers are encouraged to adapt them for use in their school context and collaboratively identify further examples of ATL skill development.

Further information on the ATL framework and strategies for the development of the ATL skills can be found in the *Physics teacher support material* and the *Diploma Programme Approaches to teaching and learning website*.

Table 3

ATL skills and development

Skill category	Examples of ATL skill development in the classroom
Thinking skills	• Being curious about the natural world • Asking questions and framing hypotheses based upon sensible scientific rationale • Designing procedures and models • Reflecting on the credibility of results • Providing a reasoned argument to support conclusions • Evaluating and defending ethical positions • Combining different ideas in order to create new understandings • Applying key ideas and facts in new contexts • Engaging with, and designing, linking questions • Experimenting with new strategies for learning • Reflecting at all stages of the assessment and learning cycle
Communication skills	• Practising active listening skills

Skill category	Examples of ATL skill development in the classroom
	• Evaluating extended writing in terms of relevance and structure • Applying interpretive techniques to different forms of media • Reflecting on the needs of the audience when creating engaging presentations • Clearly communicating complex ideas in response to open-ended questions • Using digital media for communicating information • Using terminology, symbols and communication conventions consistently and correctly • Presenting data appropriately • Delivering constructive criticism appropriately
Social skills	• Working collaboratively to achieve a common goal • Assigning and accepting specific roles during group activities • Appreciating the diverse talents and needs of others • Resolving conflicts during collaborative work • Actively seeking and considering the perspective of others • Reflecting on the impact of personal behaviour or comments on others • Constructively assessing the contribution of peers
Research skills	• Evaluating information sources for accuracy, bias, credibility and relevance • Explicitly discussing the importance of academic integrity and full acknowledgement of the ideas of others • Using a single, standard method of referencing and citation • Comparing, contrasting and validating information • Using search engines and libraries effectively
Self-management skills	• Breaking down major tasks into a sequence of stages • Being punctual and meeting deadlines • Taking risks and regarding setbacks as opportunities for growth • Avoiding unnecessary distractions • Drafting, revising and improving academic work • Setting learning goals and adjusting them in response to experience • Seeking and acting on feedback

Experimental programme

Integral to the student experience of a physics course is the learning that takes place through scientific inquiry within the classroom, laboratory or in the field. Experimentation through a variety of forms can be used to introduce a topic, address a phenomenon or allow students to consider and examine authentic questions and curiosities.

A school's experimental programme should allow students to experience the full breadth and depth of the course, develop scientific skills and demonstrate safe, competent and methodical use of a range of tools, techniques and equipment. Students should therefore be encouraged to develop investigations to support their learning through open-ended inquiry with a focus on laboratory and fieldwork experiments, databases, simulations and modelling.

Conceptual learning

Concept-based teaching and learning is encouraged across the continuum of IB programmes.

Concepts are mental representations of categories. They are constructed, modified and activated by the learner through learning experiences. Concepts do not exist in isolation but are interrelated. Conceptual understanding is always a work in progress—it is continually being developed and refined.

Conceptual understanding is therefore an outcome of a non-linear, ongoing process of evolving understandings, adapting previous understandings, and identifying and dispelling misconceptions. It consists of making connections between prior and new knowledge to construct and build an awareness of this network of knowledge.

Concepts vary in their level of abstraction and universality.

- They can be organizing ideas that are applicable in many contexts and have relevance both within and across subject areas.
- They can provide a deep understanding of specific knowledge fields (or fields of knowledge) and help to organize knowledge further, as well as reveal connections between different areas of the subject.

For example, consider the following sequence of three concepts.

Change	>	Energy	>	Thermal radiation

Thermal radiation is a component in the understanding of energy, which in turn helps to develop an understanding of change in physics.

Outcomes of a concept-based approach

Fostering critical thinking, the outcome of a concept-based approach is that students are able to:

- identify examples of a concept
- organize, reflect on, modify and expand their network of knowledge
- apply concepts to existing and future knowledge
- apply their conceptual understanding as a scientific thinking tool for predicting outcomes, justifying conclusions and evaluating knowledge claims.

Structure of the syllabus and conceptual understanding

The structure of this physics syllabus is intended to promote concept-based learning and teaching that can be connected through three concepts: energy, particles and forces. These three concepts appear throughout the physics syllabus in each of the themes.

There are five organizing themes in the physics syllabus.

A. Space, time and motion

B. The particulate nature of matter

C. Wave behaviour

D. Fields

E. Nuclear and quantum physics

The themes have been chosen to represent the main areas of physics relevant for this level of study and do not suggest a teaching order.

Each of these themes is subdivided into topics. “Space, time and motion” includes the topics of kinematics and rigid body mechanics, “Fields” includes the topics of gravitational fields and induction, “Nuclear and quantum physics” includes the topics of radioactive decay and fission. Each of the topics comprises guiding questions, recommended teaching hours for each level, a list of understandings that students should know, guidance and linking questions.

The topics can be connected through three concepts: energy, particles and forces. Each topic is headed by guiding questions to give a sense of what is covered. The purpose of these guiding questions is to promote inquiry: they are therefore not straightforward and best answered once the associated understandings have been acquired. Teachers and students are encouraged to create their own guiding questions based on the content of units of study.

Linking questions strengthen students' understanding by making connections. Linking questions are intended to promote the skills in the study of physics and highlight links between different topics. The questions encourage students to look at a topic from a range of different perspectives, originating in another part of the course. Linking questions are designed to facilitate these connections and their ideal outcome is to promote a highly networked understanding of physics. For example, when considering the processes within a nuclear fission plant, students can make the connections from the structure of the nucleus via the release of kinetic energy in the form of neutrons, all the way through to the generation of electricity. By looking at this process through the concept of energy, transformation and conservation laws are also highlighted, which further connect to other areas of physics. The linking questions found in the guide are not exhaustive. Students and teachers may well encounter other connections between understandings and concepts in the syllabus, leading to additional linking questions.

Teaching physics in context

The study of physics enables constructive engagement with topical scientific issues. By contextualizing physics concepts, scientific knowledge claims can be evaluated more effectively, and informed choices on such issues as human health and the environment can be made. Physics research has brought innovation and benefit to many fields and continues to be at the heart of seeking effective solutions to many global challenges. It is therefore important to explore applications of physics in our world while teaching the course to elicit interest, understanding and curiosity.

Teaching the content of the course in relation to specific contexts supports the pedagogical principle of teaching in local and global contexts as part of the approaches to teaching framework and offers a number of advantages. First, it helps students relate their learning to genuine applications of physics, highlighting the relevance to global issues as well as the significance in students' own contexts. Second, it develops an appreciation for the interaction between scientific solutions and their implications, be it ethical, environmental or economic. Third, it helps to illustrate some of the NOS aspects underpinning the course.

The *Physics teacher support material* highlights possible areas that could be visited throughout the course and that may provide context for some topics to stimulate the application of ideas and problem-solving skills. Consideration of these and related areas may help provide ideas for the scientific investigation, the collaborative sciences project, TOK exhibition, CAS, or an EE in physics or world studies.

Engaging with sensitive topics

Students and teachers are encouraged to engage with exciting, stimulating and personally relevant topics and issues that may be, at times, sensitive or personally challenging. Teachers should be aware of this and provide guidance on how to engage with such topics in a responsible manner. Consideration should be given to the personal, political and spiritual values of others.

Prior learning

Past experience shows that students will be able to study physics at SL successfully with no background in, or previous knowledge of, science. Their approach to learning, characterized by the IB learner profile attributes, will be significant here.

However, for most students considering the study of physics at HL, while there is no intention to restrict access, some previous exposure to formal science education would be necessary. Specific topic details are not specified but students who have undertaken the IB Middle Years Programme (MYP) or studied an equivalent national science qualification or a school-based science course would be well prepared for an HL subject.

Links to the Middle Years Programme

The MYP sciences courses seek to promote skills and attitudes needed to apply scientific knowledge in theoretical, experimental and authentic contexts. A strong foundation is established for DP sciences in which learners will capitalize on—and continue advancing—their skills and attitudes to develop knowledge and understanding commensurate with pre-university level science.

The MYP offers a framework for learning and teaching while maintaining flexibility with curriculum content. The content in MYP sciences courses can therefore vary greatly from one school to another. Content in DP sciences courses is more prescribed, and this is one of the main differences teachers will notice when comparing the two programmes.

A connected, conceptual curriculum where learning is inquiry-based and contextualized is the pedagogical principle that underpins both programmes and indeed the entire IB continuum (International Baccalaureate, 2019).

Conceptual learning focuses on organizing ideas and their interconnections. A conceptual approach is encouraged in IB programmes because it promotes deep learning and facilitates the construction of further knowledge. Conceptual understanding aids the application of knowledge in unfamiliar and novel contexts. This skill is reflected in the aims and assessment objectives of both programmes.

Broad concepts frame MYP learning and teaching with the purpose of unifying ideas across subject areas. Discipline-specific related concepts are intended to provide disciplinary depth (International Baccalaureate, 2014). Key and related concepts are not required in the DP, although some teachers may find that they wish to continue developing a curriculum around them. In DP sciences, overarching concepts are manifested in the course roadmaps and the NOS. DP sciences seek to highlight the interconnectedness of the course understandings. The intention is to promote conceptual understanding and further the construction of learners' knowledge networks.

Both MYP and DP teaching involve inquiry-based approaches, which foster a high degree of student engagement, collaboration and interaction. The inquiry, design, experimental, analysis, evaluation and communication skills encouraged by criteria B and C will serve students well as they prepare to undertake the scientific investigation for the internal assessment (IA). In addition, MYP students will gain familiarity with criterion-related assessment and the use of assessment criteria, which will further support their understanding of the DP sciences IA criteria.

IB programmes encourage the exploration of scientific principles in connection to local and global contexts. Doing so helps students ground abstract concepts in more concrete local and global real-world situations as well as cultivating international-mindedness (see the "Approaches to teaching" section in *Diploma Programme Approaches to teaching and learning website*). Teachers should therefore weave opportunities for contextualization into the curriculum. MYP sciences criterion D analyses the real-world application of science. In the DP, sciences teachers are encouraged to frequently anchor their teaching in real-world applications that are invoked throughout the course of the programme.

In addition to equipping students with scientific knowledge and skills, the MYP and DP sciences courses share similar guiding principles that seek to develop in students the learner profile attributes.

Links to the Career-related Programme

In the Career-related Programme (CP), students study at least two DP subjects, a core consisting of four components and a career-related study, which is determined by the local context and aligned with student needs. The CP has been designed to add value to the students' career-related studies. This provides the context for the choice of DP courses. The physics course can assist CP students planning careers in a variety of professional fields where, for example, a sound understanding of science and mathematical skills are important. This includes technological and manufacturing industries, and engineering. While physics helps students understand the underlying science in the contemporary world, it also encourages the development of strong problem-solving, critical thinking and ethical approaches that will assist students in the global workplace.

Collaborative sciences project

The collaborative sciences project is an interdisciplinary sciences project, providing a worthwhile challenge to DP and CP students, addressing real-world problems that can be explored through the sciences. The nature of the challenge should allow students to integrate factual, procedural and conceptual knowledge developed through the study of their disciplines.

Through the identification and research of complex issues, students can develop an understanding of how interrelated systems, mechanisms and processes impact a problem. Students will then apply their collective understanding to develop solution-focused strategies that address the issue. With a critical lens they will evaluate and reflect on the inherent complexity of solving real-world problems.

Students will develop an understanding of the extent of global interconnectedness between regional, national, and local communities, which will empower them to become active and engaged citizens of the world. While addressing local and global issues, students will appreciate that the issues of today exist across national boundaries and can only be solved through collective action and international cooperation.

The collaborative sciences project supports the development of students' ATL skills, including teambuilding, negotiation and leadership. It facilitates an appreciation of the environment, and the social and ethical implications of science and technology.

Full details of the requirements are in the *Collaborative sciences project guide*.

Aims

The course enables students, through the overarching theme of the NOS, to:

1. develop conceptual understanding that allows connections to be made between different areas of the subject, and to other DP sciences subjects
2. acquire and apply a body of knowledge, methods, tools and techniques that characterize science
3. develop the ability to analyse, evaluate and synthesize scientific information and claims
4. develop the ability to approach unfamiliar situations with creativity and resilience
5. design and model solutions to local and global problems in a scientific context
6. develop an appreciation of the possibilities and limitations of science
7. develop technology skills in a scientific context
8. develop the ability to communicate and collaborate effectively
9. develop awareness of the ethical, environmental, economic, cultural and social impact of science.

Assessment objectives

The assessment objectives for physics reflect those parts of the aims that will be formally assessed either internally or externally. It is the intention of this course that students are able to fulfil the following assessment objectives.

1. Demonstrate knowledge of:
    a. terminology, facts and concepts
    b. skills, techniques and methodologies.
2. Understand and apply knowledge of:
    a. terminology and concepts
    b. skills, techniques and methodologies.
3. Analyse, evaluate, and synthesize:
    a. experimental procedures
    b. primary and secondary data
    c. trends, patterns and predictions.
4. Demonstrate the application of skills necessary to carry out insightful and ethical investigations.

Assessment objectives in practice

Assessments align with the course's aims, objectives and conceptual approach; the NOS and subject-specific skills are also assessed. This allows students to demonstrate learning effectively through varied tasks that are reliably and accurately marked or moderated by subject-area educators and experts.

Assessment objective	Which component addresses this assessment objective?	How is the assessment objective addressed?
AO1 Demonstrate knowledge	Paper 1 Paper 2 Scientific investigation	Students respond to a range of multiple-choice, short-answer questions and extended-response questions. Students investigate and answer a research question that is their own.
AO2 Understand and apply knowledge	Paper 1 Paper 2 Scientific investigation	Students respond to a range of multiple-choice, short-answer, data-based and extended-response questions. Students investigate and answer a research question that is their own.
AO3 Analyse, evaluate, and synthesize	Paper 1 Paper 2 Scientific investigation	Students respond to a range of multiple-choice, short-answer, data-based and extended-response questions. Students investigate and answer a research question that is their own.
AO4 Demonstrate the application of skills necessary to carry out insightful and ethical investigations	Scientific investigation	Students investigate and answer a research question that is their own.

Component	Approximate weighting of assessment objectives (%)	
	AO1 + AO2	AO3
Paper 1	50	50
Paper 2	50	50
Internal assessment	Covers AO1, AO2, AO3 and AO4	

Syllabus outline

Syllabus component	Teaching hours	
	SL	HL
Syllabus content	**110**	**180**
A. Space, time and motion	27	42
B. The particulate nature of matter	24	32
C. Wave behaviour	17	29
D. Fields	19	38
E. Nuclear and quantum physics	23	39
Experimental programme	**40**	**60**
Practical work	20	40
Collaborative sciences project	10	10
Scientific investigation	10	10
Total teaching hours	**150**	**240**

The recommended teaching time is 150 hours to complete SL courses and 240 hours to complete HL courses as stated in the general regulations (in *Diploma Programme Assessment procedures*).

Syllabus roadmap

The aim of the syllabus is to integrate concepts, topic content and the nature of science through inquiry. Students and teachers are encouraged to personalize their approach to the syllabus according to their circumstances and interests.

Skills in the study of physics should be integrated into the teaching of the syllabus content.

Table 4

Physics syllabus content overview

A. Space, time and motion	B. The particulate nature of matter	C. Wave behaviour	D. Fields	E. Nuclear and quantum physics
A.1 Kinematics • A.2 Forces and momentum • A.3 Work, energy and power • A.4 Rigid body mechanics ••• A.5 Galilean and special relativity •••	B.1 Thermal energy transfers • B.2 Greenhouse effect • B.3 Gas laws • B.4 Thermodynamics ••• B.5 Current and circuits •	C.1 Simple harmonic motion •• C.2 Wave model • C.3 Wave phenomena •• C.4 Standing waves and resonance • C.5 Doppler effect ••	D.1 Gravitational fields •• D.2 Electric and magnetic fields •• D.3 Motion in electromagnetic fields • D.4 Induction •••	E.1 Structure of the atom •• E.2 Quantum physics ••• E.3 Radioactive decay •• E.4 Fission • E.5 Fusion and stars •

• Topics with content that should be taught to all students

•• Topics with content that should be taught to all students plus additional HL content

••• Topics with content that should only be taught to HL students

Syllabus format

This is the overarching theme.

This is the name of the topic.

Guiding questions frame the topic—by studying the topic students will be able to answer the question(s) with increasing depth.

Understandings list specific areas to be taught.

Standard level and higher level: 3 hours

3 hours total teaching is recommended, whether for standard level (SL) or higher level (HL).

Additional higher level is content for that level only.

Guidance provides clarifications and limitations to the topic.

Linking questions link one topic to another in physics or, when indicated by "(NOS)", the nature of science. They signpost related content and problem-solving beyond immediate content. Teachers and students are encouraged to create their own linking questions.

C. Wave behaviour

C.1 Simple harmonic motion

Guiding questions

What makes the harmonic oscillator model applicable to a wide range of physical phenomena?

Understandings

Standard level and higher level: 3 hours

Students should understand:

- conditions that lead to simple harmonic motion

Additional higher level: 4 hours

Students should understand:

- that a particle undergoing simple harmonic motion can be described using phase angle

Guidance

The significance of the minus sign in the defining equation for simple harmonic motion should be understood.

Linking questions

How can greenhouse gases be modelled as simple harmonic oscillators?

What physical explanation leads to the enhanced greenhouse effect? (NOS)

Skills in the study of physics

The skills and techniques students must experience through the course are encompassed within the tools. These support the application and development of the inquiry process in the delivery of the physics course.

Tools

- **Tool 1:** Experimental techniques
- **Tool 2**: Technology
- **Tool 3:** Mathematics

Inquiry process

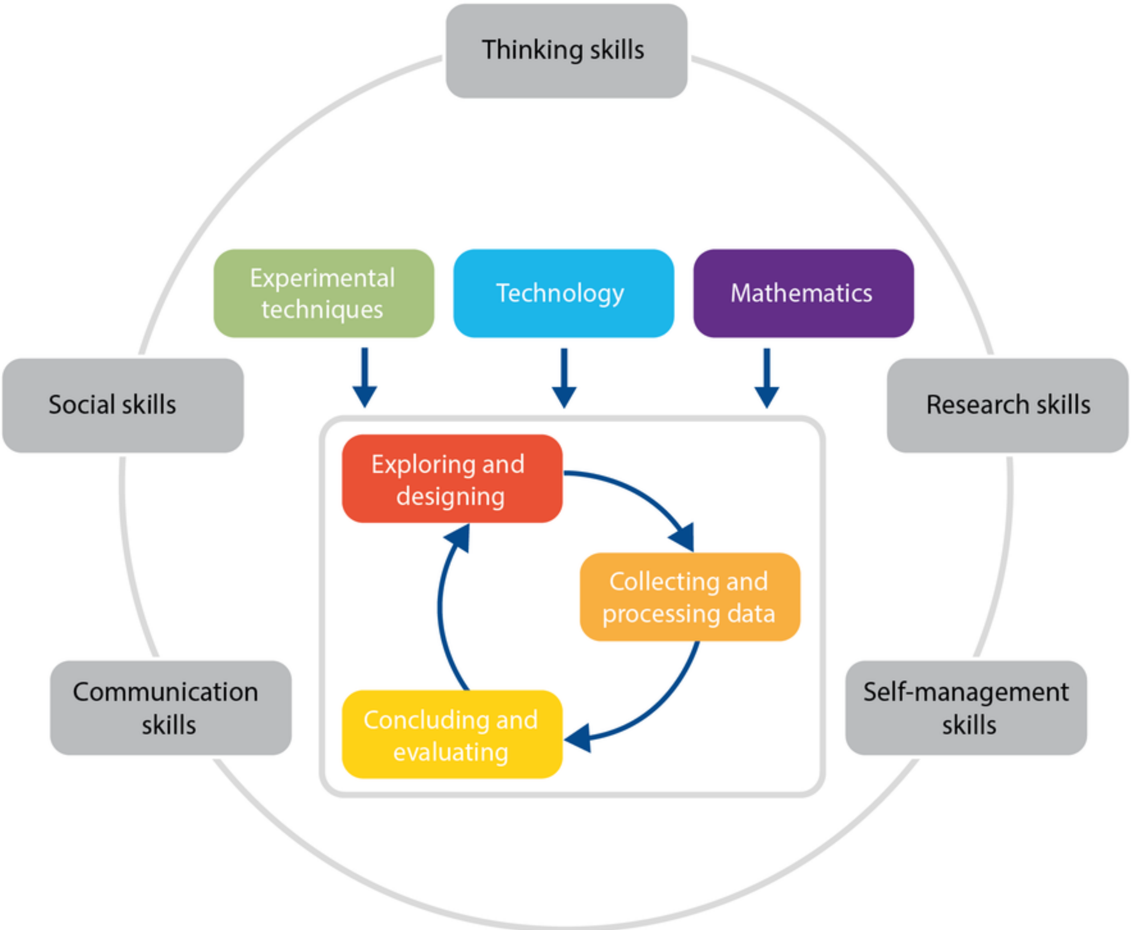
- **Inquiry 1:** Exploring and designing
- **Inquiry 2:** Collecting and processing data
- **Inquiry 3:** Concluding and evaluating

Teachers are encouraged to provide opportunities for students to encounter and practise the skills throughout the programme. Rather than being taught as stand-alone topics, they should be integrated into the teaching of the syllabus when they are relevant to the syllabus topics being covered. The skills in the study of physics can be assessed through internal and external assessment.

The approaches to learning provide the framework for the development of these skills.

Figure 2

Skills for physics



Tools

Tool 1: Experimental techniques

Skill	Description
Addressing safety of self, others and the environment	Recognize and address relevant safety, ethical or environmental issues in an investigation.
Measuring variables	Understand how to accurately measure the following to an appropriate level of precision. • Mass • Time • Length • Volume • Temperature • Force • Electric current • Electric potential difference

Skill	Description
	• Angle • Sound and light intensity

Tool 2: Technology

Skill	Description
Applying technology to collect data	• Use sensors. • Identify and extract data from databases. • Generate data from models and simulations. • Carry out image analysis and video analysis of motion.
Applying technology to process data	• Use spreadsheets to manipulate data. • Represent data in a graphical form. • Use computer modelling.

Tool 3: Mathematics

Skill	Description
Applying general mathematics	• Use basic arithmetic and algebraic calculations to solve problems. • Calculate areas and volumes for simple shapes. • Carry out calculations involving decimals, fractions, percentages, ratios, reciprocals, exponents and trigonometric ratios. • Carry out calculations involving logarithmic and exponential functions. • Determine rates of change. • Calculate mean and range. • Use and interpret scientific notation (for example, 3.5×10^6). • Select and manipulate equations. • Derive relationships algebraically. • Use approximation and estimation. • Appreciate when some effects can be neglected and why this is useful. • Compare and quote ratios, values and approximations to the nearest order of magnitude. • Distinguish between continuous and discrete variables. • Understand direct and inverse proportionality, as well as positive and negative relationships or correlations between variables. • Determine the effect of changes to variables on other variables in a relationship. • Calculate and interpret percentage change and percentage difference. • Calculate and interpret percentage error and percentage uncertainty. • Construct and use scale diagrams. • Identify a quantity as a scalar or vector.

Skill	Description
	• Draw and label vectors including magnitude, point of application and direction. • Draw and interpret free-body diagrams showing forces at point of application or centre of mass as required. • Add and subtract vectors in the same plane (limited to three vectors). • Multiply vectors by a scalar. • Resolve vectors (limited to two perpendicular components).
Using units, symbols and numerical values	• Apply and use International System of Units (SI) prefixes and units. • Identify and use symbols stated in the guide and the data booklet. • Work with fundamental units. • Use of units (for example, eV, eVc^{-2}, ly, pc, h, day, year) whenever appropriate. • Express derived units in terms of SI units. • Check an expression using dimensional analysis of units (the formal process of dimensional analysis will not be assessed). • Express quantities and uncertainties to an appropriate number of significant figures or decimal places.
Processing uncertainties	• Understand the significance of uncertainties in raw and processed data. • Record uncertainties in measurements as a range (±) to an appropriate level of precision. • Propagate uncertainties in processed data in calculations involving addition, subtraction, multiplication, division and raising to a power. • Express measurement and processed uncertainties—absolute, fractional (relative) and percentage—to an appropriate number of significant figures or level of precision.
Graphing	• Sketch graphs, with labelled but unscaled axes, to qualitatively describe trends. • Construct and interpret tables, charts and graphs for raw and processed data including bar charts, pie charts, histograms, scatter graphs and line and curve graphs. • Construct and interpret graphs using logarithmic scales. • Plot linear and non-linear graphs showing the relationship between two variables with appropriate scales and axes. • Draw lines or curves of best fit. • Draw and interpret uncertainty bars. • Extrapolate and interpolate graphs. • Linearize graphs (only where appropriate). • On a best-fit linear graph, construct lines of maximum and minimum gradients with relative accuracy (by eye) considering all uncertainty bars. • Determining the uncertainty in gradients and intercepts.

Skill	Description
	• Interpret features of graphs including gradient, changes in gradient, intercepts, maxima and minima, and areas under the graph.

Inquiry process

Inquiry 1: Exploring and designing

Skill	Description
Exploring	• Demonstrate independent thinking, initiative and insight. • Consult a variety of sources. • Select sufficient and relevant sources of information. • Formulate research questions and hypotheses. • State and explain predictions using scientific understanding.
Designing	• Demonstrate creativity in the designing, implementation and presentation of the investigation. • Develop investigations that involve hands-on laboratory experiments, databases, simulations and modelling. • Identify and justify the choice of dependent, independent and control variables. • Justify the range and quantity of measurements. • Design and explain a valid methodology. • Pilot methodologies.
Controlling variables	Appreciate when and how to: • calibrate measuring apparatus, including sensors • maintain constant environmental conditions of systems • insulate against heat loss or gain • reduce friction • reduce electrical resistance • take background radiation into account.

Inquiry 2: Collecting and processing data

Skill	Description
Collecting data	• Identify and record relevant qualitative observations. • Collect and record sufficient relevant quantitative data. • Identify and address issues that arise during data collection.
Processing data	• Carry out relevant and accurate data processing.
Interpreting results	• Interpret qualitative and quantitative data. • Interpret diagrams, graphs and charts. • Identify, describe and explain patterns, trends and relationships. • Identify and justify the removal or inclusion of outliers in data (no mathematical processing is required).

Skill	Description
	• Assess accuracy, precision, reliability and validity.

Inquiry 3: Concluding and evaluating

Skill	Description
Concluding	• Interpret processed data and analysis to draw and justify conclusions. • Compare the outcomes of an investigation to the accepted scientific context. • Relate the outcomes of an investigation to the stated research question or hypothesis. • Discuss the impact of uncertainties on the conclusions.
Evaluating	• Evaluate hypotheses. • Identify and discuss sources and impacts of random and systematic errors. • Evaluate the implications of methodological weaknesses, limitations and assumptions on conclusions. • Explain realistic and relevant improvements to an investigation.

Data booklet

The IB publishes a *Physics data booklet* which contains electrical symbols, mathematical equations, constants, and physics equations relevant to the course. Students must have access to a copy for the duration of the course so that they can become familiar with its contents. Direct reference is made to relevant equations in the understandings sections of the guide. This helps to maintain the emphasis on interpretation and application rather than memorization of symbols, constants and equations. A clean copy of the *Physics data booklet* must also be made available to candidates for all examination papers at both SL and HL.

Syllabus content

A. Space, time and motion

A.1 Kinematics

Guiding questions

How can the motion of a body be described quantitatively and qualitatively?

How can the position of a body in space and time be predicted?

How can the analysis of motion in one and two dimensions be used to solve real-life problems?

Understandings

Standard level and higher level: 9 hours

Students should understand:

- that the motion of bodies through space and time can be described and analysed in terms of position, velocity, and acceleration
- velocity is the rate of change of position, and acceleration is the rate of change of velocity
- the change in position is the displacement
- the difference between distance and displacement
- the difference between instantaneous and average values of velocity, speed and acceleration, and how to determine them
- the equations of motion for solving problems with uniformly accelerated motion as given by

  $$s = \frac{u + v}{2}t$$

  $$v = u + at$$

  $$s = ut + \frac{1}{2}at^2$$

  $$v^2 = u^2 + 2as$$
- motion with uniform and non-uniform acceleration
- the behaviour of projectiles in the absence of fluid resistance, and the application of the equations of motion resolved into vertical and horizontal components
- the qualitative effect of fluid resistance on projectiles, including time of flight, trajectory, velocity, acceleration, range and terminal speed.

Additional higher level

There is no additional higher level content in A.1

Guidance

A quantitative approach to projectile motion will be limited to situations where fluid resistance is absent or can be neglected.

The trajectory of projectile motion is parabolic in the absence of fluid resistance, but the equation of the trajectory is not required.

Familiarity with projectiles launched horizontally, at angles above, and at angles below the horizontal is required.

Projectile motion will only involve problems using a constant value of g close to the surface of the Earth.

Fluid resistance refers to the effects of gases and liquids on the motion of a body.

Linking questions

How does the motion of a mass in a gravitational field compare to the motion of a charged particle in an electric field?

How are the equations for rotational motion related to those for linear motion?

When can certain types of problems on projectile motion be solved by applying conservation of energy instead of kinematic equations?

How effectively do the equations of motion model Newton's laws of dynamics?

How does a gravitational force allow for orbital motion?

How does the motion of an object change within a gravitational field?

How does graphical analysis allow for the determination of other physical quantities? (NOS)

A.2 Forces and momentum

Guiding questions

How can forces acting on a system be represented both visually and algebraically?

How can Newton's laws be modelled mathematically?

How can knowledge of forces and momentum be used to predict the behaviour of interacting bodies?

Understandings

Standard level and higher level: 10 hours

Students should understand:

- Newton's three laws of motion
- forces as interactions between bodies
- that forces acting on a body can be represented in a free-body diagram
- that free-body diagrams can be analysed to find the resultant force on a system
- the nature and use of the following contact forces
    - normal force F_N is the component of the contact force acting perpendicular to the surface that counteracts the body
    - surface frictional force F_f acting in a direction parallel to the plane of contact between a body and a surface, on a stationary body as given by $F_f \leq \mu_s F_N$ or a body in motion as given by $F_f = \mu_d F_N$ where μ_s and μ_d are the coefficients of static and dynamic friction respectively
    - tension
    - elastic restoring force F_H following Hooke's law as given by $F_H = -kx$ where k is the spring constant
    - viscous drag force F_d acting on a small sphere opposing its motion through a fluid as given by $F_d = 6\pi\eta rv$ where η is the fluid viscosity, r is the radius of the sphere and v is the velocity of the sphere through the fluid
    - buoyancy F_b acting on a body due to the displacement of the fluid as given by $F_b = \rho V g$ where V is the volume of fluid displaced
- the nature and use of the following field forces
    - gravitational force F_g is the weight of the body and calculated is given by $F_g = mg$
    - electric force F_e
    - magnetic force F_m

- that linear momentum as given by $p = mv$ remains constant unless the system is acted upon by a resultant external force
- that a resultant external force applied to a system constitutes an impulse J as given by $J = F\Delta t$ where F is the average resultant force and Δt is the time of contact
- that the applied external impulse equals the change in momentum of the system
- that Newton's second law in the form $F = ma$ assumes mass is constant whereas $F = \frac{\Delta p}{\Delta t}$ allows for situations where mass is changing
- the elastic and inelastic collisions of two bodies
- explosions
- energy considerations in elastic collisions, inelastic collisions, and explosions
- that bodies moving along a circular trajectory at a constant speed experience an acceleration that is directed radially towards the centre of the circle—known as a centripetal acceleration as given by $a = \frac{v^2}{r} = \omega^2 r = \frac{4\pi^2 r}{T^2}$
- that circular motion is caused by a centripetal force acting perpendicular to the velocity
- that a centripetal force causes the body to change direction even if its magnitude of velocity may remain constant
- that the motion along a circular trajectory can be described in terms of the angular velocity ω which is related to the linear speed v by the equation as given by $v = \frac{2\pi r}{T} = \omega r$.

Additional higher level

There is no additional higher level content in A.2.

Guidance

Sketches and interpretations of free-body diagrams and a determination of the resultant force are for one- and two-dimensional situations only.

Forces should be labelled using commonly accepted names or symbols.

Newton's first law will be applied to problems involving translational equilibrium.

Examples of Newton's third law will include the identification of force pairs in various situations.

The use of simultaneous equations involving conservation of momentum and energy in collisions is not required.

A quantitative approach to collisions and explosions is for one-dimensional situations for standard level students and for two-dimensional situations for higher level students.

Situations should involve both uniform and non-uniform circular motion in both horizontal and vertical planes.

Analysis of forces on bodies in non-uniform circular motion in a vertical plane at points other than the top or bottom is not required.

Quantitative treatment of problems involving banked surfaces is not required.

Linking questions

How do collisions between charge carriers and the atomic cores of a conductor result in thermal energy transfer?

How can knowledge of electrical and magnetic forces allow the prediction of changes to the motion of charged particles?

How does the application of a restoring force acting on a particle result in simple harmonic motion?

How are concepts of equilibrium and conservation applied to understand matter and motion from the smallest atom to the whole universe?

Why is no work done on a body moving along a circular trajectory?

In which way is conservation of momentum relevant to the workings of a nuclear power station?

If experimental measurements contain uncertainties, how can laws be developed based on experimental evidence? (NOS)

What assumptions about the forces between molecules of gas allow for ideal gas behaviour? (NOS)

A.3 Work, energy and power

Guiding questions

How are concepts of work, energy and power used to predict changes within a system?

How can a consideration of energetics be used as a method to solve problems in kinematics?

How can transfer of energy be used to do work?

Understandings

Standard level and higher level: 8 hours

Students should understand:

- the principle of the conservation of energy
- that work done by a force is equivalent to a transfer of energy
- that energy transfers can be represented on a Sankey diagram
- that work W done on a body by a constant force depends on the component of the force along the line of displacement as given by $W = Fs\cos\theta$
- that work done by the resultant force on a system is equal to the change in the energy of the system
- that mechanical energy is the sum of kinetic energy, gravitational potential energy and elastic potential energy
- that in the absence of frictional, resistive forces, the total mechanical energy of a system is conserved
- that if mechanical energy is conserved, work is the amount of energy transformed between different forms of mechanical energy in a system, such as:
    - the kinetic energy of translational motion as given by $E_k = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
    - the gravitational potential energy, when close to the surface of the Earth as given by $\Delta E_p = mg\Delta h$
    - the elastic potential energy as given by $E_H = \frac{1}{2}k(\Delta x)^2$
- that power developed P is the rate of work done, or the rate of energy transfer, as given by $P = \frac{\Delta W}{\Delta t} = Fv$
- efficiency η in terms of energy transfer or power as given by $\eta = \frac{E_{output}}{E_{input}} = \frac{P_{output}}{P_{input}}$
- energy density of the fuel sources.

Additional higher level

There is no additional higher level content in A.3.

Guidance

The change in the total mechanical energy of a system should be interpreted in terms of the work done on the system by any non-conservative force.

Linking questions

Which other quantities in physics involve rates of change?

How is the equilibrium state of a system, such as the Earth's atmosphere or a star, determined?

How do travelling waves allow for a transfer of energy without a resultant displacement of matter?

Why is the equation for the change in gravitational potential energy only relevant close to the surface of the Earth, and what happens when moving further away from the surface?

Where do the laws of conservation apply in other areas of physics? (NOS)

A.4 Rigid body mechanics

Guiding questions

How can the understanding of linear motion be applied to rotational motion?

How is the understanding of the torques acting on a system used to predict changes in rotational motion?

How does the distribution of mass within a body affect its rotational motion?

Understandings

Standard level and higher level

There is no standard level content in A.4.

Additional higher level: 7 hours

Students should understand:

- the torque τ of a force about an axis as given by $\tau = Fr\sin\theta$
- that bodies in rotational equilibrium have a resultant torque of zero
- that an unbalanced torque applied to an extended, rigid body will cause angular acceleration
- that the rotation of a body can be described in terms of angular displacement, angular velocity and angular acceleration
- that equations of motion for uniform angular acceleration can be used to predict the body's angular position θ, angular displacement $\Delta\theta$, angular speed ω and angular acceleration α, as given by

  $$\Delta\theta = \frac{\omega_f + \omega_i}{2}t$$

  $$\omega_f = \omega_i + \alpha t$$

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

  $$\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$$

- that the moment of inertia I depends on the distribution of mass of an extended body about an axis of rotation
- the moment of inertia for a system of point masses as given by $I = \Sigma mr^2$
- Newton's second law for rotation as given by $\tau = I\alpha$ where τ is the average torque
- that an extended body rotating with an angular speed has an angular momentum L as given by $L = I\omega$
- that angular momentum remains constant unless the body is acted upon by a resultant torque
- that the action of a resultant torque constitutes an angular impulse ΔL as given by $\Delta L = \tau\Delta t = \Delta(I\omega)$
- the kinetic energy of rotational motion as given by $E_k = \frac{1}{2}I\omega^2 = \frac{L^2}{2I}$.

Guidance

The vector nature of torque and angular momentum need not be addressed, but the sense (clockwise or counter-clockwise) of a torque should be included.

A calculation of the centre of mass of bodies is not required; there should be an understanding that when considering linear motion, the mass of an extended body may be taken as concentrated at the centre of mass.

The equation for the moment of inertia of a specific mass distribution will be provided when necessary.

Simultaneous rotational and translational motion will be restricted to rolling without slipping.

Angular speed will be used rather than angular velocity as a formal vector treatment.

The term angular velocity will be used although a formal vector treatment is not required.

Situations should involve change of moment of inertia in extended bodies and coupled pairs of bodies.

Linking questions

How does rotation apply to the motion of charged particles or satellites in orbit?

How does conservation of angular momentum lead to the determination of the Bohr radius?

How does a torque lead to simple harmonic motion?

How are the laws of conservation and equations of motion in the context of rotational motion analogous to those governing linear motion?

How can rotation lead to the generation of an electric current?

A.5 Galilean and special relativity

Guiding questions

How do observers in different reference frames describe events in terms of space and time?

How does special relativity change our understanding of motion compared to Galilean relativity?

How are space–time diagrams used to represent relativistic motion?

Understandings

Standard level and higher level

There is no standard level content in A.5.

Additional higher level: 8 hours

Students should understand:

- reference frames
- that Newton's laws of motion are the same in all inertial reference frames and this is known as Galilean relativity
- that in Galilean relativity the position x' and time t' of an event are given by $x' = x - vt$ and $t' = t$
- that Galilean transformation equations lead to the velocity addition equation as given by $u' = u - v$
- the two postulates of special relativity
- that the postulates of special relativity lead to the Lorentz transformation equations for the coordinates of an event in two inertial reference frames as given by

  $x' = \gamma(x - vt)$

  $t' = \gamma\left(t - \frac{vx}{c^2}\right)$

  where $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
- that Lorentz transformation equations lead to the relativistic velocity addition equation as given by

  $u' = \frac{u - v}{1 - \frac{uv}{c^2}}$

- that the space–time interval Δs between two events is an invariant quantity as given by $(\Delta s)^2 = (c\Delta t)^2 - (\Delta x)^2$
- proper time interval and proper length
- time dilation as given by $\Delta t = \gamma \Delta t_0$
- length contraction as given by $L = \frac{L_0}{\gamma}$
- the relativity of simultaneity
- space–time diagrams
- that the angle between the world line of a moving particle and the time axis on a space–time diagram is related to the particle's speed as given by $\tan\theta = \frac{v}{c}$
- that muon decay experiments provide experimental evidence for time dilation and length contraction.

Guidance

An inertial reference frame is non-accelerating.

The derivation of the Lorentz transformation equations and the relativistic velocity addition equations are not required.

The derivation of the time dilation and length contraction equations is not required.

The time axis on space–time diagrams will be labelled ct.

The discussion of world lines of moving particles will be limited to constant velocity.

Time dilation, length contraction and simultaneity can be visualized using space–time diagrams.

The scales on the time axes ct and ct' and on the space axes x and x' of two inertial reference frames moving relative to one another are not the same and are defined by lines of constant space–time interval.

Linking questions

How are equations of linear motion adapted in relativistic contexts?

Why is the equation for the Doppler effect for light so different from that for sound?

Special relativity places a limit on the speed of light. What other limits exist in physics? (NOS)

B. The particulate nature of matter

B.1 Thermal energy transfers

Guiding questions

How do macroscopic observations provide a model of the microscopic properties of a substance?

How is energy transferred within and between systems?

How can observations of one physical quantity be used to determine the other properties of a system?

Understandings

Standard level and higher level: 6 hours

Students should understand:

- molecular theory in solids, liquids and gases
- density ρ as given by $\rho = \frac{m}{V}$
- that Kelvin and Celsius scales are used to express temperature
- that the change in temperature of a system is the same when expressed with the Kelvin or Celsius scales

- that Kelvin temperature is a measure of the average kinetic energy of particles as given by $\overline{E_k} = \frac{3}{2}k_B T$
- that the internal energy of a system is the total intermolecular potential energy arising from the forces between the molecules plus the total random kinetic energy of the molecules arising from their random motion
- that temperature difference determines the direction of the resultant thermal energy transfer between bodies
- that a phase change represents a change in particle behaviour arising from a change in energy at constant temperature
- quantitative analysis of thermal energy transfers Q with the use of specific heat capacity c and specific latent heat of fusion and vaporization of substances L as given by $Q = mc\Delta T$ and $Q = mL$
- that conduction, convection and thermal radiation are the primary mechanisms for thermal energy transfer
- conduction in terms of the difference in the kinetic energy of particles
- quantitative analysis of rate of thermal energy transfer by conduction in terms of the type of material and cross-sectional area of the material and the temperature gradient as given by $\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta x}$
- qualitative description of thermal energy transferred by convection due to fluid density differences
- quantitative analysis of energy transferred by radiation as a result of the emission of electromagnetic waves from the surface of a body, which in the case of a black body can be modelled by the Stefan-Boltzmann law as given by $L = \sigma A T^4$ where L is the luminosity, A is the surface area and T is the absolute temperature of the body
- the concept of apparent brightness b
- luminosity L of a body as given by $b = \frac{L}{4\pi d^2}$
- the emission spectrum of a black body and the determination of the temperature of the body using Wien's displacement law as given by $\lambda_{max} T = 2.9 \times 10^{-3}\,\mathrm{mK}$ where λ_{max} is the peak wavelength emitted.

Additional higher level

There is no additional higher level content in B.1.

Guidance

An elementary explanation of the physical differences between solids, liquids and gases in terms of the molecular model is required.

The conversion of Kelvin and Celsius scales is required.

The terms melting, freezing, boiling, condensing and evaporation should be familiar.

The luminosity of a star can be expressed in watts or in terms of the luminosity of the Sun $L_\odot$.

Linking questions

How is the understanding of systems applied to other areas of physics?

How can the phase change of water be used in the process of electricity generation?

What applications does the Stefan-Boltzmann law have in astrophysics and in the use of solar energy?

How can observations of one physical quantity allow for the determination of another? (NOS)

What role does the molecular model play in understanding other areas of physics? (NOS)

Where do inverse square law relationships appear in other areas of physics? (NOS)

How has international collaboration helped to develop the understanding of the nature of matter? (NOS)

B.2 Greenhouse effect

Guiding questions

How does the greenhouse effect help to maintain life on Earth and how does human activity enhance this effect?

How is the atmosphere as a system modelled to quantify the Earth–atmosphere energy balance?

Understandings

Standard level and higher level: 6 hours

Students should understand:

- the conservation of energy
- emissivity as the ratio of the power radiated per unit area by a surface compared to that of an ideal black surface at the same temperature as given by $\text{emissivity} = \frac{\text{power radiated per unit area}}{\sigma T^4}$
- albedo as a measure of the average energy reflected off a macroscopic system as given by $\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$
- that Earth's albedo varies daily and is dependent on cloud formations and latitude
- the solar constant S
- that the incoming radiative power is dependent on the projected surface of a planet along the direction of the path of the rays, resulting in a mean value of the incoming intensity being $\frac{S}{4}$
- that methane CH_4, water vapour H_2O, carbon dioxide CO_2, and nitrous oxide N_2O, are the main greenhouse gases and each of these has origins that are both natural and created by human activity
- the absorption of infrared radiation by the main greenhouse gases in terms of the molecular energy levels and the subsequent emission of radiation in all directions
- that the greenhouse effect can be explained in terms of both a resonance model and molecular energy levels
- that the augmentation of the greenhouse effect due to human activities is known as the enhanced greenhouse effect.

Additional higher level

There is no additional higher level content in B.2.

Guidance

Problems will include the estimation of equilibrium temperature of a body using energy balance between incoming and outgoing radiation intensity, including albedo, emissivity, and solar or other constants.

Energy balance problems will include energy exchanged between the surface and the atmosphere of a body.

The burning of fossil fuels is a primary cause of the enhanced greenhouse effect.

Linking questions

What relevance do simple harmonic motion and resonance have to climate change?

How do different methods of electricity production affect the energy balance of the atmosphere?

How are developments in science and technology affected by climate change?

What limitations are there in using a resonance model to explain the greenhouse effect?

B.3 Gas laws

Guiding questions

How are the macroscopic characteristics of a gas related to the behaviour of individual molecules?

What assumptions and observations lead to universal gas laws?

How can models be used to help explain observed phenomena?

Understandings

Standard level and higher level: 6 hours

Students should understand:

- pressure as given by $P = \frac{F}{A}$ where F is the force exerted perpendicular to the surface
- the amount of substance n as given by $n = \frac{N}{N_A}$ where N is the number of molecules and N_A is the Avogadro constant
- that ideal gases are described in terms of the kinetic theory and constitute a modelled system used to approximate the behaviour of real gases
- that the ideal gas law equation can be derived from the empirical gas laws for constant pressure, constant volume and constant temperature as given by $\frac{PV}{T} = \text{constant}$
- the equations governing the behaviour of ideal gases as given by $PV = Nk_BT$ and $PV = nRT$
- that the change in momentum of particles due to collisions with a given surface gives rise to pressure in gases and, from that analysis, pressure is related to the average translational speed of molecules as given by $P = \frac{1}{3}\rho v^2$
- the relationship between the internal energy U of an ideal monatomic gas and the number of molecules or amount of substance as given by $U = \frac{3}{2}Nk_BT$ or $U = \frac{3}{2}RnT$
- the temperature, pressure and density conditions under which an ideal gas is a good approximation of a real gas.

Additional higher level

There is no additional higher level content in B.3.

Guidance

The assumption of the kinetic model is of an ideal gas.

The differences between an ideal gas and a real gas should be understood.

Gas laws are limited to constant volume, constant temperature, constant pressure and the ideal gas law.

Changes of state of an ideal gas can be represented on pressure–volume diagrams.

A qualitative explanation of the macroscopic properties of an ideal gas in terms of molecular behaviour is required.

Linking questions

How does the concept of force and momentum link mechanics and thermodynamics?

How does a consideration of the kinetic energy of molecules relate to the development of the gas laws?

How can gas particles of high kinetic energy be used to perform work?

What other simplified models are relied upon to communicate the understanding of complex phenomena? (NOS)

B.4 Thermodynamics

Guiding questions

How can energy transfers and energy storage within a system be analysed?

How can the future evolution of a system be determined?

In what way is entropy fundamental to the evolution of the universe?

Understandings

Standard level and higher level

There is no standard level content in B.4.

Additional higher level: 8 hours

Students should understand:

- that the first law of thermodynamics as given by $Q = \Delta U + W$ results from the application of conservation of energy to a closed system and relates the internal energy of a system to the transfer of energy as heat and as work
- that the work done by or on a closed system as given by $W = P\Delta V$ when its boundaries are changed can be described in terms of pressure and changes of volume of the system
- that the change in internal energy as given by $\Delta U = \frac{3}{2}Nk_{\mathrm{B}}\Delta T = \frac{3}{2}nR\Delta T$ of a system is related to the change of its temperature
- that entropy S is a thermodynamic quantity that relates to the degree of disorder of the particles in a system
- that entropy can be determined in terms of macroscopic quantities such as thermal energy and temperature as given by $\Delta S = \frac{\Delta Q}{T}$ and also in terms of the properties of individual particles of the system as given by $S = k_{\mathrm{B}} \ln \Omega$ where k_{B} is the Boltzmann constant and Ω is the number of possible microstates of the system
- that the second law of thermodynamics refers to the change in entropy of an isolated system and sets constraints on possible physical processes and on the overall evolution of the system
- that processes in real isolated systems are almost always irreversible and consequently the entropy of a real isolated system always increases
- that the entropy of a non-isolated system can decrease locally, but this is compensated by an equal or greater increase of the entropy of the surroundings
- that isovolumetric, isobaric, isothermal and adiabatic processes are obtained by keeping one variable fixed
- that adiabatic processes in monatomic ideal gases can be modelled by the equation as given by $PV^{\frac{5}{3}} = \text{constant}$
- that cyclic gas processes are used to run heat engines
- that a heat engine can respond to different cycles and is characterized by its efficiency as given by $\eta = \frac{\text{useful work}}{\text{input energy}}$
- that the Carnot cycle sets a limit for the efficiency of a heat engine at the temperatures of its heat reservoirs as given by $\eta_{\mathrm{Carnot}} = 1 - \frac{T_{\mathrm{c}}}{T_{\mathrm{h}}}$.

Guidance

A closed system is understood to be one in which no mass can be transferred in or out, but energy can be transferred in both directions as heat or as work.

An isolated system is understood to be one in which neither mass nor energy can be transferred in or out.

Problems will use the Clausius' sign convention where Q is the resultant thermal energy supplied to the system and W is the resultant work done by the system.

The second law of thermodynamics should be described in Clausius form and Kelvin form, as well as in terms of entropy change in reversible and irreversible processes occurring in isolated systems.

Work done on a system is taken to be negative.

Work done by a system is taken to be positive.

In quantitative problems, systems will be limited to monatomic ideal gases, including situations where pressure is not constant.

The microstates of a system are equally probable and can be described in a simple combinatorial model (for example, based on coins).

Linking questions

What are the consequences of the second law of thermodynamics to the universe as a whole?

Why is there an upper limit on the efficiency of any energy source or engine?

How are efficiency considerations important in motors and generators?

What paradigm shifts enabling change to human society, such as harnessing the power of steam, can be attributed to advancements in physics understanding? (NOS)

B.5 Current and circuits

Guiding questions

How do charged particles flow through materials?

How are the electrical properties of materials quantified?

What are the consequences of resistance in conductors?

Understandings

Standard level and higher level: 6 hours

Students should understand:

- that cells provide a source of emf
- chemical cells and solar cells as the energy source in circuits
- that circuit diagrams represent the arrangement of components in a circuit
- direct current (dc) I as a flow of charge carriers as given by $I = \frac{\Delta q}{\Delta t}$
- that the electric potential difference V is the work done per unit charge on moving a positive charge between two points along the path of the current as given by $V = \frac{W}{q}$
- the properties of electrical conductors and insulators in terms of mobility of charge carriers
- electric resistance and its origin
- electrical resistance R as given by $R = \frac{V}{I}$
- resistivity as given by $\rho = \frac{RA}{L}$
- Ohm's law
- the ohmic and non-ohmic behaviour of electrical conductors, including the heating effect of resistors
- electrical power P dissipated by a resistor as given by $P = IV = I^2R = \frac{V^2}{R}$
- the combinations of resistors in series and parallel circuits

Series circuits	Parallel circuits
$I = I_1 = I_2 = \Omega$	$I = I_1 + I_2 + \Omega$
$V = V_1 + V_2 + \Omega$	$V = V_1 = V_2 = \Omega$
$R_s = R_1 + R_2 + \Omega$	$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \Omega$

- that electric cells are characterized by their emf ε and internal resistance r as given by $\varepsilon = I(R + r)$
- that resistors can have variable resistance.

Additional higher level

There is no additional higher level content in B.5.

Guidance

Advantages and disadvantages of difference sources of electrical energy are required.

Refer to the *Physics data booklet* for the electrical circuit symbols that are required.

Alternating current (ac) circuits are not required.

Unless otherwise stated, ammeters and voltmeters will be considered as ideal. In cases where non-ideal meters are used, the resistance will be constant.

A metal conductor at a constant temperature will be considered an ohmic device.

Variable resistors will be limited to thermistors, light-dependent resistors (LDR) and potentiometers.

Linking questions

In what ways can an electrical circuit be described as a system like the Earth's atmosphere or a heat engine?

How are the fields in other areas of physics similar to and different from each other?

How can the heating of an electrical resistor be explained using other areas of physics?

What are the advantages of cells as a source of electrical energy?

How does a particle model allow electrical resistance to be explained? (NOS)

What are the parallels in the models for thermal and electrical conductivity? (NOS)

C. Wave behaviour

C.1 Simple harmonic motion

Guiding questions

What makes the harmonic oscillator model applicable to a wide range of physical phenomena?

Why must the defining equation of simple harmonic motion take the form it does?

How can the energy and motion of an oscillation be analysed both graphically and algebraically?

Understandings

Standard level and higher level: 3 hours

Students should understand:

- conditions that lead to simple harmonic motion
- the defining equation of simple harmonic motion as given by $a = -\omega^2 x$
- a particle undergoing simple harmonic motion can be described using time period T, frequency f, angular frequency ω, amplitude, equilibrium position, and displacement
- the time period in terms of frequency of oscillation and angular frequency as given by $T = \frac{1}{f} = \frac{2\pi}{\omega}$

- the time period of a mass–spring system as given by $T = 2\pi\sqrt{\frac{m}{k}}$
- the time period of a simple pendulum as given by $T = 2\pi\sqrt{\frac{l}{g}}$
- a qualitative approach to energy changes during one cycle of an oscillation.

Additional higher level: 4 hours

Students should understand:

- that a particle undergoing simple harmonic motion can be described using phase angle
- that problems can be solved using the equations for simple harmonic motion as given by

  $x = x_0 \sin(\omega t + \phi)$

  $v = \omega x_0 \cos(\omega t + \phi)$

  $v = \pm\omega\sqrt{x_0^2 - x^2}$

  $E_T = \frac{1}{2}m\omega^2 x_0^2$

  $E_p = \frac{1}{2}m\omega^2 x^2.$

Guidance

The significance of the minus sign in the defining equation for simple harmonic motion should be understood.

Energy changes during simple harmonic motion (kinetic, potential and total) should be described qualitatively.

A quantitative approach to energy changes during simple harmonic motion is required at higher level only.

Radians are used for phase angle calculations.

Linking questions

How can greenhouse gases be modelled as simple harmonic oscillators?

How can circular motion be used to visualize simple harmonic motion?

How does damping affect periodic motion?

How can the understanding of simple harmonic motion apply to the wave model? (NOS)

What physical explanation leads to the enhanced greenhouse effect? (NOS)

C.2 Wave model

Guiding questions

What are the similarities and differences between different types of waves?

How can the wave model describe the transmission of energy as a result of local disturbances in a medium?

What effect does a change in the frequency of oscillation or medium through which the wave is travelling have on the wavelength of a travelling wave?

Understandings

Standard level and higher level: 3 hours

Students should understand:

- transverse and longitudinal travelling waves
- wavelength λ, frequency f, time period T, and wave speed v applied to wave motion as given by

  $v = f\lambda = \frac{\lambda}{T}$
- the nature of sound waves

- the nature of electromagnetic waves
- the differences between mechanical waves and electromagnetic waves.

Additional higher level

There is no additional higher level content in C.2.

Guidance

Problems will involve describing the motion of particles of a medium when a wave passes through it for both transverse and longitudinal waves. This will be in terms of displacement with respect to the position along the wave and with time.

Travelling waves transfer energy, even if there is no resultant displacement of the medium.

Refer to the *Physics data booklet* for the approximate orders of magnitude of the wavelengths of radio, microwave, infrared, visible, ultraviolet, X-rays and gamma rays.

The wave model should be applied to both mechanical waves and electromagnetic waves.

Linking questions

How can light be modelled as an electromagnetic wave?

What happens when waves overlap or coincide?

How can the length of a wave be determined using concepts from kinematics?

Why does the intensity of an electromagnetic wave decrease with distance according to the inverse square law?

How are electromagnetic waves able to travel through a vacuum?

How were X-rays discovered? (NOS)

Can the wave model inform the understanding of quantum mechanics? (NOS)

How are waves used in technology to improve society? (NOS)

C.3 Wave phenomena

Guiding questions

How are observations of wave behaviours at a boundary between different media explained?

How is the behaviour of waves passing through apertures represented?

What happens when two waves meet at a point in space?

Understandings

Standard level and higher level: 5 hours

Students should understand:

- that waves travelling in two and three dimensions can be described through the concepts of wavefronts and rays
- wave behaviour at boundaries in terms of reflection, refraction and transmission
- wave diffraction around a body and through an aperture
- wavefront-ray diagrams showing refraction and diffraction
- Snell's law, critical angle and total internal reflection
- Snell's law as given by $\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$ where n is the refractive index and θ is the angle between the normal and the ray
- superposition of waves and wave pulses
- that double-source interference requires coherent sources
- the condition for constructive interference as given by $\text{path difference} = n\lambda$

- the condition for destructive interference as given by $\text{path difference} = (n + \frac{1}{2})\lambda$
- Young's double-slit interference as given by $s = \frac{\lambda D}{d}$ where s is the separation of fringes, d is the separation of the slits, and D is the distance from the slits to the screen.

Additional higher level: 6 hours

Students should understand:

- single-slit diffraction including intensity patterns as given by $\theta = \frac{\lambda}{b}$ where b is the slit width
- that the single-slit pattern modulates the double slit interference pattern
- interference patterns from multiple slits and diffraction gratings as given by $n\lambda = d \sin \theta$.

Guidance

Problems may involve sketching and interpreting wavefronts and rays. These will be limited to incident, reflected, and transmitted waves.

Interference and diffraction patterns will be limited to those produced at normal incidence.

The effect of slit width on the intensity of the single-slit diffraction pattern should be considered qualitatively.

The discussion of single-slit diffraction will be limited to monochromatic light and rectangular slits.

Multiple slit and diffraction grating patterns produced from white light and a range of monochromatic light wavelengths should be discussed.

Linking questions

What can an understanding of the results of Young's double-slit experiment reveal about the nature of light?

What evidence is there that particles possess wave-like properties such as wavelength? (NOS)

C.4 Standing waves and resonance

Guiding questions

What distinguishes standing waves from travelling waves?

How does the form of standing waves depend on the boundary conditions?

How can the application of force result in resonance within a system?

Understandings

Standard level and higher level: 4 hours

Students should understand:

- the nature and formation of standing waves in terms of superposition of two identical waves travelling in opposite directions
- nodes and antinodes, relative amplitude and phase difference of points along a standing wave
- standing waves patterns in strings and pipes
- the nature of resonance including natural frequency and amplitude of oscillation based on driving frequency
- the effect of damping on the maximum amplitude and resonant frequency of oscillation
- the effects of light, critical and heavy damping on the system.

Additional higher level

There is no additional higher level content in C.4.

Guidance

The formation of standing waves from the superposition of more than two waves should not be considered.

Pipes will be referred to as open or closed.

End corrections for open pipes are not required.

Boundary conditions for strings include two fixed boundaries, one fixed and one free boundary, and two free boundaries.

Boundary conditions for air in pipes include two closed ends, one closed and one open end, and two open ends.

Vibration modes of air in pipes will be discussed in terms of displacement nodes and antinodes.

For standing waves in air, pressure nodes and antinodes are not required.

The lowest frequency mode of a standing wave will be referred to as the first harmonic. The terms fundamental and overtone are not to be used in this course.

A determination of the wavelength and the frequency of the nth harmonic given the length of the string or pipe and the speed of the wave is required.

Only a qualitative analysis is required concerning the impact of damping on the frequency response of a driven oscillator.

Knowledge of the useful and destructive effects of resonance is required.

Linking questions

How does the amplitude of vibration at resonance depend on the dissipation of energy in the driven system?

What is the relationship between resonance and simple harmonic motion?

How can resonance be explained in terms of conservation of energy?

How can the idea of resonance of gas molecules be used to model the greenhouse effect? (NOS)

C.5 Doppler effect

Guiding questions

How can the Doppler effect be explained both qualitatively and quantitatively?

What are some practical applications of the Doppler effect?

Why are there differences when applying the Doppler effect to different types of waves?

Understandings

Standard level and higher level: 2 hours

Students should understand:

- the nature of the Doppler effect for sound waves and electromagnetic waves
- the representation of the Doppler effect in terms of wavefront diagrams when either the source or the observer is moving
- the relative change in frequency or wavelength observed for a light wave due to the Doppler effect where the speed of light is much larger than the relative speed between the source and the observer as given by $\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$
- that shifts in spectral lines provide information about the motion of bodies like stars and galaxies in space.

Additional higher level: 2 hours

Students should understand:

- the observed frequency for sound waves and mechanical waves due to the Doppler effect as given by:

moving source $f' = f\left(\frac{v}{v \pm u_s}\right)$ where u_s is the velocity of the source

moving observer $f' = f\left(\frac{v \pm u_o}{v}\right)$ where u_o is the velocity of the observer.

Guidance

Problems will not include situations where both source and observer are moving.

Problems can involve the determination of the velocity of the source/observer.

The use of the Doppler effect in medical physics and in radars should be considered as examples.

Linking questions

What are the similarities and difference between light and sound waves?

How can the Doppler effect be utilized to measure the rotational speed of extended bodies?

What happens if the speed of light is not much larger that the relative speed between the source and the observer?

What gives rise to emission spectra and how can they be used to determine astronomical distances?

How can the use of Doppler effect for light be used to calculate speed? (NOS)

D. Fields

D.1 Gravitational fields

Guiding questions

How are the properties of a gravitational field quantified?

How does an understanding of gravitational fields allow for humans to explore the solar system?

Understandings

Standard level and higher level: 5 hours

Students should understand:

- Kepler's three laws of orbital motion
- Newton's universal law of gravitation as given by $F = G\frac{m_1 m_2}{r^2}$ for bodies treated as point masses
- conditions under which extended bodies can be treated as point masses
- that gravitational field strength g at a point is the force per unit mass experienced by a small point mass at that point as given by $g = \frac{F}{m} = G\frac{M}{r^2}$
- gravitational field lines.

Additional higher level: 7 hours

Students should understand:

- that the gravitational potential energy E_p of a system is the work done to assemble the system from infinite separation of the components of the system
- the gravitational potential energy for a two-body system as given by $E_p = -G\frac{m_1 m_2}{r}$ where r is the separation between the centre of mass of the two bodies
- that the gravitational potential V_g at a point is the work done per unit mass in bringing a mass from infinity to that point as given by $V_g = -G\frac{M}{r}$

- the gravitational field strength g as the gravitational potential gradient as given by $g = -\frac{\Delta V_g}{\Delta r}$
- the work done in moving a mass m in a gravitational field as given by $W = m\Delta V_g$
- equipotential surfaces for gravitational fields
- the relationship between equipotential surfaces and gravitational field lines
- the escape speed v_{esc} at any point in a gravitational field as given by $v_{esc} = \sqrt{\frac{2GM}{r}}$
- the orbital speed $v_{orbital}$ of a body orbiting a large mass as given by $v_{orbital} = \sqrt{\frac{GM}{r}}$
- the qualitative effect of a small viscous drag force due to the atmosphere on the height and speed of an orbiting body.

Guidance

For calculations involving orbital motion the orbits will be assumed to be circular.

Newton's universal law of gravitation should be extended to spherical masses of uniform density by assuming that their mass is concentrated at their centre.

Determination of the resultant gravitational field strength will be restricted to points along a line joining two bodies.

Sketching and interpretation of gravitational field lines is required.

Gravitational potential is defined as being zero at infinity.

Problems may include, but are not limited to, determining the:

- speed to maintain orbit
- changes in energy when a satellite changes orbit
- energetics of a satellite going into orbit around a non-rotating planet starting from rest on its surface
- energy conditions for an orbiting satellite to escape the gravitational influence of a planet.

Gravitational fields will include the radial fields around point or spherical masses and the (assumed) uniform field close to the surface of massive celestial bodies and planetary bodies.

The orbital motion of a satellite around a planet is restricted to a consideration of circular orbits.

An ability to map fields using potential is required.

Linking questions

What measurements of a binary star system need to be made in order to determine the nature of the two stars?

How is uniform circular motion like—and unlike—real-life orbits?

How is the amount of fuel required to launch rockets into space determined by considering energy?

How can air resistance be used to alter the motion of a satellite orbiting Earth?

What are the benefits of using consistent terminology to describe different types of fields? (NOS)

How can the motion of electrons in the atom be modelled on planetary motion and in what ways does this model fail? (NOS)

Physics utilizes a number of constants such as G. What is the purpose of these constants and how are they determined? (NOS)

D.2 Electric and magnetic fields

Guiding questions

Which experiments provided evidence to determine the nature of the electron?

How can the properties of fields be understood using both an algebraic approach and a visual representation?

What are the consequences of interactions between electric and magnetic fields?

Understandings

Standard level and higher level: 8 hours

Students should understand:

- the direction of forces between the two types of electric charge
- Coulomb's law as given by $F = k\frac{q_1 q_2}{r^2}$ for charged bodies treated as point charges where $k = \frac{1}{4\pi\varepsilon_0}$
- the conservation of electric charge
- Millikan's experiment as evidence for quantization of electric charge
- that the electric charge can be transferred between bodies using friction, electrostatic induction and by contact, including the role of grounding (earthing)
- the electric field strength as given by $E = \frac{F}{q}$
- electric field lines
- the relationship between field line density and field strength
- the uniform electric field strength between parallel plates as given by $E = \frac{V}{d}$
- magnetic field lines.

Additional higher level: 6 hours

Students should understand:

- the electric potential energy E_p in terms of work done to assemble the system from infinite separation
- the electric potential energy for a system of two charged bodies as given by $E_p = k\frac{q_1 q_2}{r}$
- that the electric potential is a scalar quantity with zero defined at infinity
- that the electric potential V_e at a point is the work done per unit charge to bring a test charge from infinity to that point as given by $V_e = \frac{kQ}{r}$
- the electric field strength E as the electric potential gradient as given by $E = -\frac{\Delta V_e}{\Delta r}$
- the work done in moving a charge q in an electric field as given by $W = q\Delta V_e$
- equipotential surfaces for electric fields
- the relationship between equipotential surfaces and electric field lines.

Guidance

Electric fields will include:

- the radial field around single point charge
- inside and outside a single spherical conducting body
- the field between two point charges
- two oppositely charged parallel plates, including edge effects.

Sketching and interpretation of electric field lines is required.

Magnetic field patterns will be restricted to a bar magnet, a current-carrying straight wire, a current-carrying circular coil and an air-core solenoid.

Sketching and interpretation of magnetic field lines is required.

The determination of the direction of the magnetic field based in the current direction in a current-carrying straight wire is required.

Work done in electric fields can be expressed in both joules and electronvolts.

A range of permittivity values for Coulomb's law are required.

Electric potential is defined as being zero at infinity.

No work is done in moving charge or mass on an equipotential surface.

Equipotential surfaces should be recognized:

- for a point charge
- for a collection of up to four point charges
- inside and outside a solid charged conducting sphere
- inside and outside a hollow charged conduction sphere
- between two oppositely charged parallel plates.

Linking questions

How are electric and magnetic fields like gravitational fields?

What are the relative strengths of the four fundamental forces?

How can moving charges in magnetic fields help probe the fundamental nature of matter?

Charge is quantized. Which other physical quantities are quantized? (NOS)

D.3 Motion in electromagnetic fields

Guiding questions

How do charged particles move in magnetic fields?

What can be deduced about the nature of a charged particle from observations of it moving in electric and magnetic fields?

Understandings

Standard level and higher level: 6 hours

Students should understand:

- the motion of a charged particle in a uniform electric field
- the motion of a charged particle in a uniform magnetic field
- the motion of a charged particle in perpendicularly orientated uniform electric and magnetic fields
- the magnitude and direction of the force on a charge moving in a magnetic field as given by $F = qvB \sin\theta$
- the magnitude and direction of the force on a current-carrying conductor in a magnetic field as given by $F = BIL \sin\theta$
- the force per unit length between parallel wires as given by $\frac{F}{L} = \mu_0 \frac{I_1 I_2}{2\pi r}$ where r is the separation between the two wires.

Additional higher level

There is no additional higher level content in D.3.

Guidance

The kinetic energy of a charged particle stays constant in a magnetic field.

The determination of the charge to mass ratio for a charged particle by investigating its path in a uniform magnetic field is required.

The determination of the direction of the magnetic field based in the current direction in a current-carrying straight wire is required.

For parallel current carrying wires, the force is attractive when the current is flowing in the same direction.

Linking questions

What causes circular motion of charged particles in a field?

How can the orbital radius of a charged particle moving in a field be used to determine the nature of the particle?

How can conservation of energy be applied to motion in electromagnetic fields?

How are the concepts of energy, forces and fields used to determine the size of an atom?

How are the properties of electric and magnetic fields represented? (NOS)

D.4 Induction

Guiding questions

What are the effects of relative motion between a conductor and a magnetic field?

How can the power output of electrical generators be increased?

How did the discovery of electromagnetic induction effect industrialization?

Understandings

Standard level and higher level

There is no standard level content in D.4.

Additional higher level: 6 hours

Students should understand:

- magnetic flux $\mathbf{\Phi}$ as given by $\mathbf{\Phi} = BA\cos\theta$
- that a time-changing magnetic flux induces an emf ε as given by Faraday's law of induction $\varepsilon = -N\frac{\Delta\mathbf{\Phi}}{\Delta t}$
- that a uniform magnetic field induces an emf in a straight conductor moving perpendicularly to it as given by $\varepsilon = BvL$
- that the direction of induced emf is determined by Lenz's law and is a consequence of energy conservation
- that a uniform magnetic field induces a sinusoidal varying emf in a coil rotating within it
- the effect on induced emf caused by changing the frequency of rotation.

Guidance

Examples of production of an induced emf should include:

- time-varying magnetic fields
- coils rotating within a uniform magnetic field
- relative motion between a conductor and a magnetic field (for example, a magnet oscillating on a spring above a conducting coil, or a coil moved in or out of the region of a magnetic field).

A quantitative treatment of induced emf will be restricted to straight conductors moving at right angles to magnetic fields and rectangular coils moving in and out of fields and rotating in fields.

Only a qualitative treatment of self-induction is required.

A discussion of inductance and resistance-inductor (RL) circuits is not required.

Linking questions

How is the efficiency of electricity generation dependent on the source of energy?

Faraday's law of induction includes a rate of change. Which other areas of physics relate to rates of change? (NOS)

E. Nuclear and quantum physics

E.1 Structure of the atom

Guiding questions

What is the current understanding of the nature of an atom?

What is the role of evidence in the development of models of the atom?

In what ways are previous models of the atom still valid despite recent advances in understanding?

Understandings

Standard level and higher level: 6 hours

Students should understand:

- the Geiger–Marsden–Rutherford experiment and the discovery of the nucleus
- nuclear notation ${}^{A}_{Z}\mathrm{X}$ where A is the nucleon number Z is the proton number and X is the chemical symbol
- that emission and absorption spectra provide evidence for discrete atomic energy levels
- that photons are emitted and absorbed during atomic transitions
- that the frequency of the photon released during an atomic transition depends on the difference in energy level as given by $E = hf$
- that emission and absorption spectra provide information on the chemical composition.

Additional higher level: 3 hours

Students should understand:

- the relationship between the radius and the nucleon number for a nucleus as given by $R = R_0 A^{\frac{1}{3}}$ and implications for nuclear densities
- deviations from Rutherford scattering at high energies
- the distance of closest approach in head-on scattering experiments
- the discrete energy levels in the Bohr model for hydrogen as given by $E = -\frac{13.6}{n^2}\ \mathrm{eV}$
- that the existence of quantized energy and orbits arise from the quantization of angular momentum in the Bohr model for hydrogen as given by $mvr = \frac{nh}{2\pi}$.

Guidance

Recall of chemical symbols is not required.

Only a qualitative approach to the Geiger–Marsden–Rutherford experiment is required for standard level.

Rutherford's simple energy conservation considerations can be used to determine the distance of closest approach.

For scattering experiments, energy values will be low enough so as only to consider the particle being repelled by the electric force.

Linking questions

How can emission spectra allow for the properties of stars to be deduced?

How is the distance of closest approach calculated using conservation of energy?

How can emission spectra be used to calculate the distances and velocities of celestial bodies?

Under what circumstances does the Bohr model fail? (NOS)

How have observations led to developments in the model of the atom? (NOS)

E.2 Quantum physics

Guiding questions

How can light be used to create an electric current?

What is meant by wave–particle duality?

Understandings

Standard level and higher level

There is no standard level content in E.2.

Additional higher level: 8 hours

Students should understand:

- the photoelectric effect as evidence of the particle nature of light
- that photons of a certain frequency, known as the threshold frequency, are required to release photoelectrons from the metal
- Einstein's explanation using the work function and the maximum kinetic energy of the photoelectrons as given by $E_{\text{max}} = hf - \Phi$ where Φ is the work function of the metal
- diffraction of particles as evidence of the wave nature of matter
- that matter exhibits wave–particle duality
- the de Broglie wavelength for particles as given by $\lambda = \frac{h}{p}$
- Compton scattering of light by electrons as additional evidence of the particle nature of light
- that photons scatter off electrons with increased wavelength
- the shift in photon wavelength after scattering off an electron as given by $\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta)$.

Guidance

A discussion of which features of the photoelectric effect cannot be explained using the classical wave theory of light is required.

A description of a scattering experiment including the location of minimum intensity for the diffracted particles based on their de Broglie wavelength is required.

The derivation of the Compton formula is not required

Linking questions

How can particles diffract?

What are the defining features and behaviours of waves?

What evidence indicates the diffraction of a wave?

How is photon scattering off an electron similar to and how is it different from the collision of two solid balls?

Can the Bohr model help explain the photoelectric effect? (NOS)

How did the explanation of the photoelectric effect lead to the falsification that light was purely a wave? (NOS)

Why is Compton scattering more convincing evidence for the particle nature of light than that from the photoelectric effect? (NOS)

E.3 Radioactive decay

Guiding questions

Why are some isotopes more stable than others?

In what ways can a nucleus undergo change?

How do large, unstable nuclei become more stable?

How can the random nature of radioactive decay allow for predictions to be made?

Understandings

Standard level and higher level: 7 hours

Students should understand:

- isotopes
- nuclear binding energy and mass defect
- the variation of the binding energy per nucleon with nucleon number
- the mass-energy equivalence as given by $E = mc^2$ in nuclear reactions
- the existence of the strong nuclear force, a short-range, attractive force between nucleons
- the random and spontaneous nature of radioactive decay
- the changes in the state of the nucleus following alpha, beta and gamma radioactive decay
- the radioactive decay equations involving α, β^-, β^+, γ
- the existence of neutrinos ν and antineutrinos $\bar{\nu}$
- the penetration and ionizing ability of alpha particles, beta particles and gamma rays
- the activity, count rate and half-life in radioactive decay
- the changes in activity and count rate during radioactive decay using integer values of half-life
- the effect of background radiation on count rate.

Additional higher level: 5 hours

Students should understand:

- the evidence for the strong nuclear force
- the role of the ratio of neutrons to protons for the stability of nuclides
- the approximate constancy of binding energy curve above a nucleon number of 60
- that the spectrum of alpha and gamma radiations provides evidence for discrete nuclear energy levels
- the continuous spectrum of beta decay as evidence for the neutrino
- the decay constant λ and the radioactive decay law as given by $N = N_0 e^{-\lambda t}$
- that the decay constant approximates the probability of decay in unit time only in the limit of sufficiently small λt
- the activity as the rate of decay as given by $A = \lambda N = \lambda N_0 e^{-\lambda t}$
- the relationship between half-life and the decay constant as given by $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$.

Guidance

An interpretation of binding energy curves is required.

Nuclear masses will be expressed in kg, in $\mathrm{MeVc^{-2}}$ and in (unified) atomic mass units u.

Real-life contexts for this topic should include the choice of isotope in medical use, leaks in underground pipes, thickness of materials, and radioactive dating based on the penetration of the decay particle and half-life.

The weak nuclear force is not considered in this course.

An application of the radioactive decay equations for arbitrary time intervals is required for additional higher level.

The determination of the half-life of a nuclide is required.

Linking questions

Are there differences between the photons emitted as a result of atomic versus nuclear transitions?

How does equilibrium within a star compare to stability within the nucleus of an atom?

Would a nucleus be able to exist if only gravitational and electric forces were considered?

How did conservation lead to experimental evidence of the neutrino? (NOS)

Which areas of physics involve exponential change? (NOS)

E.4 Fission

Guiding questions

In which form is energy stored within the nucleus of the atom?

How can the energy released from the nucleus be harnessed?

Understandings

Standard level and higher level: 4 hours

Students should understand:

- that energy is released in spontaneous and neutron-induced fission
- the role of chain reactions in nuclear fission reactions
- the role of control rods, moderators, heat exchangers and shielding in a nuclear power plant
- the properties of the products of nuclear fission and their management.

Additional higher level

There is no additional higher level content in E.4.

Guidance

Calculations to determine the energy released in fission reactions are required.

The impact of the long-term storage of nuclear waste should be considered.

Linking questions

In which form is energy released as a result of nuclear fission?

How is binding energy used to determine the rate of energy production in a nuclear power plant?

To what extent is there a role for fission in addressing climate change? (NOS)

E.5 Fusion and stars

Guiding questions

How are elements created?

What physical processes lead to the evolution of stars?

Can observations of the present state of the universe predict the future outcome of the universe?

Understandings

Standard level and higher level: 6 hours

Students should understand:

- that the stability of stars relies on an equilibrium between outward radiation pressure and inward gravitational forces
- that fusion is a source of energy in stars
- the conditions leading to fusion in stars in terms of density and temperature
- the effect of stellar mass on the evolution of a star

- the main regions of the Hertzsprung–Russell (HR) diagram and how to describe the main properties of stars in these regions
- the use of stellar parallax as a method to determine the distance d to celestial bodies as given by $d(\text{parsec}) = \dfrac{1}{p(\text{arc-second})}$
- how to determine stellar radii.

Guidance

Energy release calculations are required.

The conversion between astronomical units (AU), light years (ly) and parsecs (pc) is required.

The sketching and interpretation of HR diagrams, including the location of main sequence stars, red giants, super giants, white dwarfs, the instability strip and lines of constant radius, is required.

HR diagrams will be labelled with luminosity on the vertical axis and temperature on the horizontal axis.

The surface temperature and composition of a star can be determined from the stellar spectrum.

The determination of stellar radii using luminosity and surface temperature is required.

Cepheid variables are not required.

Linking questions

How is fusion like—and unlike—fission?

How can the understanding of black-body radiation help determine the properties of stars?

How do emission spectra provide information about observations of the cosmos?

HR diagrams have been helpful in the classification of stars by finding patterns in their properties. Which other areas of physics use classification to help our understanding? (NOS)

In which ways has technology helped to collect data from observations of distant stars? (NOS)

How can gas laws be used to model stars? (NOS)

Assessment in the Diploma Programme

General

Assessment is an integral part of teaching and learning. The most important aims of assessment in the Diploma Programme (DP) are that it should support curricular goals and encourage appropriate student learning. Both external and internal assessments are used in the DP. IB examiners mark work produced for external assessment, while work produced for internal assessment is marked by teachers and externally moderated by the IB.

There are two types of assessment identified by the IB.

- Formative assessment informs both teaching and learning. It is concerned with providing accurate and helpful feedback to students and teachers on the kind of learning taking place and the nature of students' strengths and weaknesses in order to help develop students' understanding and capabilities. Formative assessment can also help to improve teaching quality, as it can provide information to monitor progress towards meeting the course aims and objectives (0404-01).
- Summative assessment gives an overview of previous learning and is concerned with measuring student achievement at, or towards the end, of the course of study (0404-04).

A comprehensive assessment policy is viewed as being integral with teaching, learning and course organization. For further information, see the IB *Programme standards and practices* publication.

The approach to assessment used by the IB is criterion-related, not norm-referenced. This approach to assessment judges students' work by their performance in relation to identified levels of attainment, and not in relation to the work of other students. For further information on assessment within the DP, please refer to the publication *Assessment principles and practices—Quality assessments in a digital age.*

To support teachers in the planning, delivery and assessment of the DP courses, a variety of resources can be found on the Programme Resource Centre or purchased from the IB store (store.ibo.org). Additional publications such as specimen papers and markschemes, teacher support material (TSM), subject reports and grade descriptors can also be found on the Programme Resource Centre. Past examination papers as well as markschemes can be purchased from the IB store.

Methods of assessment

The IB uses several methods to assess work produced by students.

Assessment criteria

Assessment criteria are used when the assessment task is open-ended. Each criterion concentrates on a particular skill that students are expected to demonstrate. An assessment objective describes what students should be able to do, and assessment criteria describe how well they should be able to do it. Using assessment criteria allows discrimination between different answers and encourages a variety of responses. Each criterion comprises a set of hierarchically ordered level descriptors. Each level descriptor is worth one or more marks. Each criterion is applied independently using a best-fit model. The maximum marks for each criterion may differ according to the criterion's importance. The marks awarded for each criterion are added together to give the total mark for the piece of work.

Markbands

Markbands are a comprehensive statement of expected performance against which responses are judged. They represent a single holistic criterion divided into level descriptors. Each level descriptor corresponds to a range of marks to differentiate student performance. A best-fit approach is used to ascertain which particular mark to use from the possible range for each level descriptor.

Analytic markschemes

Analytic markschemes are prepared for those examination questions that expect a particular kind of response and/or a given final answer from students. They give detailed instructions to examiners on how to break down the total mark for each question for different parts of the response.

Marking notes

For some assessment components marked using assessment criteria, marking notes are provided. Marking notes give guidance on how to apply assessment criteria to the particular requirements of a question.

Inclusive access arrangements

Inclusive access arrangements are available for candidates with access requirements. Standard assessment conditions may put candidates with assessment access requirements at a disadvantage by preventing them from demonstrating their attainment level. Inclusive access arrangements enable candidates to demonstrate their ability under assessment conditions that are as fair as possible.

The IB document *Access and inclusion policy* provides details on all the inclusive access arrangements available to candidates. The IB document *Learning diversity and inclusion in IB programmes: Removing barriers to learning* outlines the position of the IB with regard to candidates with diverse learning needs in the IB programmes. For candidates affected by adverse circumstances, the publication *Diploma Programme Assessment procedures* (updated annually), which includes the general regulations, provides details on access consideration.

Responsibilities of the school

The school is required to ensure that equal access arrangements and reasonable adjustments are provided to candidates with learning support requirements that are in line with the IB documents *Access and inclusion policy* and *Learning diversity and inclusion in IB programmes: Removing barriers to learning*.

Assessment outline—SL

First assessment 2025

Assessment component	Weighting
External assessment (3 hours)	**80%**
Paper 1 (1 hour and 30 minutes) Paper 1A—Multiple-choice questions Paper 1B—Data-based questions (Total 45 marks)	**36%**
Paper 2 (1 hour and 30 minutes) Short-answer and extended-response questions on standard level material only. (Total 55 marks)	**44%**
Internal assessment (10 hours)	**20%**
The internal assessment consists of one task: the scientific investigation. This component is internally assessed by the teacher and externally moderated by the IB at the end of the course. (Total 24 marks)	

Assessment outline—HL

First assessment 2025

Assessment component	Weighting
External assessment (4 hours 30 minutes)	**80%**
Paper 1 (2 hours) Paper 1A—Multiple-choice questions Paper 1B—Data-based questions (Total 60 marks)	**36%**
Paper 2 (2 hour and 30 minutes) Short-answer and extended-response questions on standard level and additional higher level material. (Total 90 marks)	**44%**
Internal assessment (10 hours)	**20%**
The internal assessment consists of one task: the scientific investigation. This component is internally assessed by the teacher and externally moderated by the IB at the end of the course. (Total 24 marks)	

External assessment

Detailed markschemes specific to each examination paper (paper 1 and paper 2) are used to assess students.

Some aspects of the examination are to be linked to a general understanding of the nature of science (NOS). Specific NOS items in the guide can be associated with examination content but knowledge of definitions within a NOS aspect will not be assessed.

External assessment details—SL

Paper 1

Duration: 1 hour and 30 minutes

Weighting: 36%

Marks: 45

Paper 1 is presented as two separate booklets

Paper 1A—25 marks

- 25 multiple-choice questions on standard level material only.

  No marks are deducted for incorrect answers.

Paper 1B—20 marks

- Data-based questions.

Paper 1A and paper 1B are to be completed together without interruptions.

The questions on paper 1 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

Each student must have access to a clean copy of the *Physics data booklet* during the examination. It is the responsibility of the school to download a copy from IBIS or the Programme Resource Centre and to ensure that there are sufficient copies available for all students.

Paper 2

Duration: 1 hour and 30 minutes

Weighting: 44%

Marks: 55

- Short-answer and extended-response questions on standard level material only.

The questions on paper 2 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

Each student must have access to a clean copy of the *Physics data booklet* during the examination. It is the responsibility of the school to download a copy from IBIS or the Programme Resource Centre and to ensure that there are sufficient copies available for all students.

External assessment details—HL

Paper 1

Duration: 2 hours

Weighting: 36%

Marks: 60

Paper 1 is presented as two separate booklets

Paper 1A—40 marks

- 40 multiple-choice questions on standard level and additional higher level material.

  No marks are deducted for incorrect answers.

Paper 1B—20 marks

- Data-based questions.

Paper 1A and paper 1B are to be completed together without interruptions.

The questions on paper 1 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

Each student must have access to a clean copy of the *Physics data booklet* during the examination. It is the responsibility of the school to download a copy from IBIS or the Programme Resource Centre and to ensure that there are sufficient copies available for all students.

Paper 2

Duration: 2 hours and 30 minutes

Weighting: 44%

Marks: 90

- Short-answer and extended-response questions on standard level and additional higher level material.

The questions on paper 2 test assessment objectives 1, 2 and 3.

The use of calculators is permitted. See the *Calculators guidance for examinations booklet* on the Programme Resource Centre.

Each student must have access to a clean copy of the *Physics data booklet* during the examination. It is the responsibility of the school to download a copy from IBIS or the Programme Resource Centre and to ensure that there are sufficient copies available for all students.

Internal assessment

Purpose of internal assessment

Internal assessment is an integral part of the course and is compulsory for both SL and HL students. It enables students to demonstrate the application of their skills and knowledge, and to pursue their personal interests, without the time limitations and other constraints that are associated with written examinations. The internal assessment should, as far as possible, be woven into normal classroom teaching and not be a separate activity conducted after a course has been taught.

The internal assessment requirements at SL and at HL are the same.

Guidance and authenticity

The scientific investigation (SL and HL) submitted for internal assessment must be the student's own work. However, it is not the intention that students should decide upon a title or topic and be left to work on the internal assessment component without any further support from the teacher. The teacher should play an important role during both the planning stage and the period when the student is working on the internally assessed work. It is the responsibility of the teacher to ensure that students are familiar with:

- the requirements of the type of work to be internally assessed
- the *Sciences experimentation guidelines* publication
- the assessment criteria. Students must understand that the work submitted for assessment must address these criteria effectively.

Teachers and students must discuss the internally assessed work. Students should be encouraged to initiate discussions with the teacher to obtain advice and information, and students must not be penalized for seeking guidance. As part of the learning process, teachers should read and give advice to students on one draft of the work. The teacher should provide oral or written advice on how the work could be improved, but not edit the draft. The next version handed to the teacher must be the final version for submission.

It is the responsibility of teachers to ensure that all students understand the basic meaning and significance of concepts that relate to academic integrity, especially authenticity and intellectual property. Teachers must ensure that all student work for assessment is prepared according to the requirements and must explain clearly to students that the internally assessed work must be entirely their own. Where collaboration between students is permitted, it must be clear to all students what the difference is between collaboration and collusion.

All work submitted to the IB for moderation or assessment must be authenticated by a teacher, and must not include any known instances of suspected or confirmed malpractice. Each student must confirm that the work is their authentic work and constitutes the final version of that work. Once a student has officially submitted the final version of the work, it cannot be retracted. The requirement to confirm the authenticity of work applies to the work of all students, not just the sample work that will be submitted to the IB for the purpose of moderation. For further details, refer to the IB publications *Academic integrity policy*, *Diploma Programme: From principles into practice* and the relevant general regulations (in *Diploma Programme Assessment procedures*).

Authenticity may be checked by discussion with the student on the content of the work, and by scrutiny of one or more of the following.

- The student's initial proposal
- The first draft of the written work
- The references cited

- The style of writing compared with work known to be that of the student
- The analysis of the work by a web-based plagiarism detection service such as www.turnitin.com

The same piece of work cannot be submitted to meet the requirements of both the IA and the EE.

Time allocation

Internal assessment is an integral part of the physics course, contributing 20% to the final assessment in the SL and the HL courses. This weighting should be reflected in the time that is allocated to teaching the knowledge, skills and understanding required to undertake the work, as well as the total time allocated to carry out the work.

It is recommended that a total of approximately 10 hours (SL and HL) of teaching time should be allocated to the work. This should include:

- time for the teacher to explain to students the requirements of the internal assessment
- class time for students to work on the internal assessment component and ask questions
- time for consultation between the teacher and each student
- time to review and monitor progress, and to check authenticity.

Safety requirements and recommendations

It is the responsibility of everyone involved in science education to make an ongoing commitment to safe and healthy practical work.

The working practices and protocols should be effective in safeguarding students and protecting the environment. Schools are responsible for following national or local guidelines, which differ from country to country. The *Physics teacher support material* provides some further guidance.

Using assessment criteria for internal assessment

For internal assessment, a number of assessment criteria have been identified. Each assessment criterion has level descriptors describing specific achievement levels, together with an appropriate range of marks. The level descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Teachers must judge the internally assessed work at SL and at HL against the criteria using the level descriptors.

- The same assessment criteria are provided for SL and HL.
- The aim is to find, for each criterion, the descriptor that conveys most accurately the level attained by the student, using the best-fit model. A best-fit approach means that compensation should be made when a piece of work matches different aspects of a criterion at different levels. The mark awarded should be one that most fairly reflects the balance of achievement against the criterion. It is not necessary for every single aspect of a level descriptor to be met for that mark to be awarded.
- When assessing a student's work, teachers should read the level descriptors for each criterion until they reach a descriptor that most appropriately describes the level of the work being assessed. If a piece of work seems to fall between two descriptors, both descriptors should be read again and the one that more appropriately describes the student's work should be chosen.
- Where there are two marks available within a level, teachers should award the upper marks if the student's work demonstrates the qualities described to a great extent; the work may be close to achieving marks in the level above. Teachers should award the lower marks if the student's work demonstrates the qualities described to a lesser extent; the work may be close to achieving marks in the level below.
- Only whole numbers should be recorded; partial marks (fractions and decimals) are not acceptable.

- Teachers should not think in terms of a pass or fail boundary but should concentrate on identifying the appropriate descriptor for each assessment criterion.
- The highest level descriptors do not imply faultless performance but should be achievable by a student. Teachers should not hesitate to use the extremes if they are appropriate descriptions of the work being assessed.
- A student who attains a high achievement level in relation to one criterion will not necessarily attain high achievement levels in relation to the other criteria. Similarly, a student who attains a low achievement level for one criterion will not necessarily attain low achievement levels for the other criteria. Teachers should not assume that the overall assessment of the students will produce any particular distribution of marks.
- It is recommended that the assessment criteria be made available to students.

Internal assessment details—SL and HL

The scientific investigation

Duration: 10 hours

Weighting: 20%

The IA requirement is the same for biology, chemistry and physics. The IA, worth 20% of the final assessment, consists of one task—the scientific investigation.

The scientific investigation is an open-ended task in which the student gathers and analyses data in order to answer their own formulated research question.

The outcome of the scientific investigation will be assessed through the form of a written report. The maximum overall word count for the report is 3,000 words.

The following are not included in the word count.

- Charts and diagrams
- Data tables
- Equations, formulas and calculations
- Citations/references (whether parenthetical, numbered, footnotes or endnotes)
- Bibliography
- Headers

The following details should be stated at the start of the report.

- Title of the investigation
- IB candidate code (alphanumeric, for example, xyz123)
- IB candidate code for all group members (if applicable)
- Number of words

There is no requirement to include a cover page or a contents page.

Facilitating the scientific investigation

The research question should be of interest to the student, but it is not necessary that it encompasses concepts beyond those described by the understandings within the guide.

The scientific investigation undertaken must have sufficient extent and depth to allow for all the descriptors of the assessment criteria to be meaningfully addressed.

The investigation of the research question must involve the collection and analysis of quantitative data that should be supported by qualitative observations where appropriate.

The scientific investigation allows a wide range of techniques for data gathering and analysis to be employed. The approaches that could be used in isolation or in conjunction with each other are as follows.

- Hands-on practical laboratory work

- Fieldwork
- Use of a spreadsheet for analysis and modelling
- Extraction and analysis of data from a database
- Use of a simulation.

The *Physics teacher support material* contains further guidance on these possible approaches.

Teachers must:

- ensure that students are familiar with the assessment criteria
- ensure that students are able to investigate their individual research question
- counsel the students on whether their proposed methodology is feasible in consideration of available time and resources
- ensure that students have given appropriate consideration to safety, ethical and environmental factors before undertaking the action phase
- remind students of the requirements for academic integrity and the consequences of academic malpractice. The difference between collaboration and collusion must be made clear.

Developing the research question

Each student is expected to formulate, investigate and answer a unique research question, seeking advice from their teacher.

A student must not present the same set of raw data as another student.

Methodology for individual work

Each student develops their own methodology to answer their individual research question. The student investigates by:

- manipulating an independent variable

or

- selecting variables during fieldwork

or

- selecting different data from external databases.

The student might seek support from peers when collecting data.

Methodology for collaborative work

Collaborative work is optional and where it is facilitated the groups formed must be no larger than three students. Students may organize their own groups. The teacher must provide guidance to ensure that all students are fully engaged in the collaborative activity. Students must clearly understand the requirement to conduct an individual investigation.

The methodology developed to answer their individual research question may be in part the outcome of collaborative activity. A student within the group investigates their individual research question by manipulating:

- a different independent variable from those selected by other group members

or

- the same independent variable with a different dependent variable from those selected by other group members

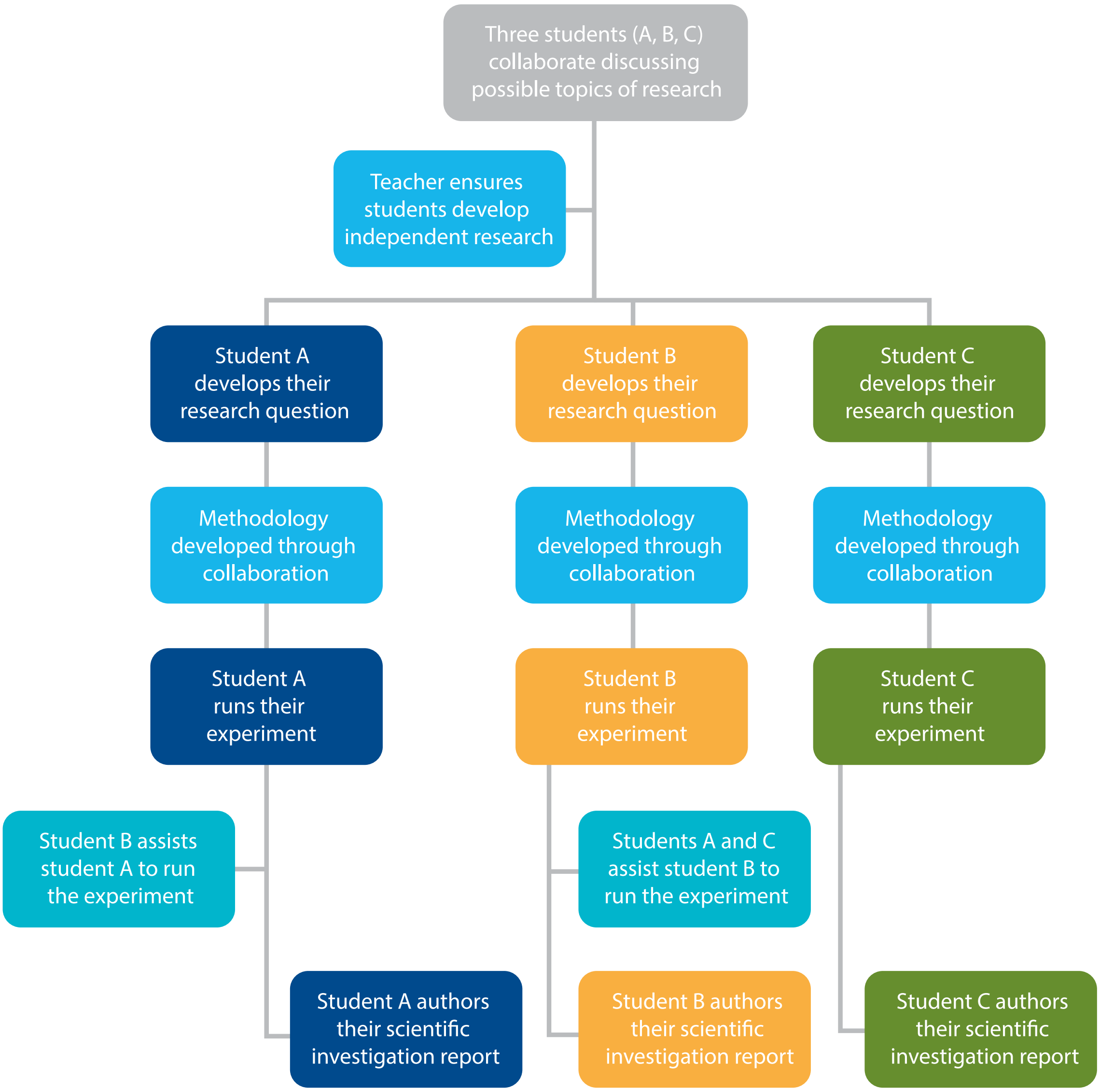
or

- different data from those selected by other group members from within a larger communally acquired data set.

In this context, collaborative work is permitted under the understanding that the final report presented for assessment is that of the individual student. A report by the group is not permitted. All authoring, including the description of the methodology, must be done individually. This diagram illustrates a possible route through the IA process where students collaborate.

Figure 3

A possible route through collaborative work



Class collaboration to set up a database

A school may take part in a large-scale activity collecting data to generate a database using standardized protocols. If a student decides to utilize this database in order to answer their research question, then the investigation must be treated as a database investigation. In such a case the methodology should be focused on the way the data is filtered and sampled from the whole database in the same way as if the data was wholly acquired from an external source.

Assessing the scientific investigation

The performance in IA at both SL and HL is marked against common assessment criteria, with a total mark out of 24. Student work is internally assessed by the teacher and externally moderated by the IB.

The four assessment criteria are as follows.

- Research design

- Data analysis
- Conclusion
- Evaluation

Each assessment criterion has level descriptors describing specific achievement levels, together with an appropriate range of marks. The level descriptors concentrate on positive achievement, although for the lower levels failure to achieve may be included in the description.

Teachers must judge the internally assessed work at SL and at HL against the same criteria using the level descriptors and aided by the clarifications. The criteria must be applied systematically using a best-fit approach—when a piece of work matches different aspects of a criterion at different levels the mark awarded should be one that most fairly reflects the balance of achievement against the criterion. It is not necessary for every single aspect of a level descriptor to be met for that mark to be awarded. The highest level descriptors do not imply faultless performance.

Where there are two or more marks available within a level, teachers should award the upper mark if the student's work largely satisfies the qualities described; the work may be close to achieving marks in the level above. Teachers should award the lower marks if the student's work demonstrates the qualities described to a lesser extent; the work may be close to achieving marks in the level below.

Only whole numbers must be recorded; partial marks (fractions and decimals) are not acceptable.

The criteria should be considered independently. A student who attains a high achievement level in relation to one criterion will not necessarily attain high achievement levels in relation to the other criteria. Similarly, a student who attains a low achievement level for one criterion will not necessarily attain low achievement levels for the other criteria. Teachers should not assume that the overall assessment of the students will produce any particular distribution of marks.

Where command terms are used in the level descriptors, they are to be interpreted as indicated in the "Glossary of command terms" section of this guide. These command terms indicate the depth of treatment required. Command terms used within the descriptors are provided in the following table.

Assessment objective	Command term	Descriptor
AO1	State	Give a specific name, value or other brief answer without explanation or calculation.
AO2	Identify	Provide an answer from a number of possibilities.
AO2	Outline	Give a brief account or summary.
AO2	Describe	Give a detailed account.
AO3	Explain	Give a detailed account including reasons or causes.
AO3	Justify	Give valid reasons or evidence to support an answer or conclusion.

Referencing and academic integrity

Appropriate referencing to sourced information used in the report of the scientific investigation is expected. Omitted or improper referencing will be considered to be academic malpractice.

Students must ensure their assessment work adheres to the IB's academic integrity policy and that all sources are appropriately referenced. A student's failure to appropriately acknowledge a source will be investigated by the IB as a potential breach of regulations that may result in a penalty imposed by the IB Final Award Committee. See the "Academic integrity" section of this guide for full details.

Internal assessment criteria—SL and HL

Download: Internal assessment criteria—SL and HL (PDF)

There are four IA criteria for the scientific investigation. The marks and weightings are as follows.

Criterion	Maximum number of marks available	Weighting (%)
Research design	6	25
Data analysis	6	25
Conclusion	6	25
Evaluation	6	25
Total	**24**	**100**

Research design

This criterion assesses the extent to which the student effectively communicates the methodology (purpose and practice) used to address the research question.

Marks	Level descriptor
0	The report does not reach the standard described by the descriptors below.
1–2	• The research question is stated without context. • Methodological considerations associated with collecting data relevant to the research question are stated. • The description of the methodology for collecting or selecting data lacks the detail to allow for the investigation to be reproduced.
3–4	• The research question is outlined within a broad context. • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are described. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced with few ambiguities or omissions.
5–6	• The research question is described within a specific and appropriate context. • Methodological considerations associated with collecting relevant and sufficient data to answer the research question are explained. • The description of the methodology for collecting or selecting data allows for the investigation to be reproduced.

Clarifications for research design
A research question with context should contain reference to the dependent and independent variables or two correlated variables, include a concise description of the system in which the research question is embedded, and include background theory of direct relevance. Methodological considerations include: • the selection of the methods for measuring the dependent and independent variables • the selection of the databases or model and the sampling of data • the decisions regarding the scope, quantity and quality of measurements (e.g. the range, interval or frequency of the independent variable, repetition and precision of measurements) • the identification of control variables and the choice of method of their control • the recognition of any safety, ethical or environmental issues that needed to be taken into account. The description of the methodology refers to presenting sufficiently detailed information (such as specific materials used and precise procedural steps) while avoiding unnecessary or repetitive information, so that

Clarifications for research design
the reader may readily understand how the methodology was implemented and could in principle repeat the investigation.

Data analysis

This criterion assesses the extent to which the student's report provides evidence that the student has recorded, processed and presented the data in ways that are relevant to the research question.

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	• The recording and processing of the data is communicated but is neither clear nor precise. • The recording and processing of data shows limited evidence of the consideration of uncertainties. • Some processing of data relevant to addressing the research question is carried out but with major omissions, inaccuracies or inconsistencies.
3–4	• The communication of the recording and processing of the data is either clear or precise. • The recording and processing of data shows evidence of a consideration of uncertainties but with some significant omissions or inaccuracies. • The processing of data relevant to addressing the research question is carried out but with some significant omissions, inaccuracies or inconsistencies.
5–6	• The communication of the recording and processing of the data is both clear and precise. • The recording and processing of data shows evidence of an appropriate consideration of uncertainties. • The processing of data relevant to addressing the research question is carried out appropriately and accurately.

Clarifications for data analysis
Data refers to quantitative data or a combination of both quantitative and qualitative data. **Communication** • Clear communication means that the method of processing can be understood easily. • Precise communication refers to following conventions correctly, such as those relating to the annotation of graphs and tables or the use of units, decimal places and significant figures. Consideration of uncertainties is subject specific and further guidance is given in the *Physics teacher support material*. Major omissions, inaccuracies or inconsistencies impede the possibility of drawing a valid conclusion that addresses the research question. Significant omissions, inaccuracies or inconsistencies allow the possibility of drawing a conclusion that addresses the research question but with some limit to its validity or detail.

Conclusion

This criterion assesses the extent to which the student successfully answers their research question with regard to their analysis and the accepted scientific context.

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	• A conclusion is stated that is relevant to the research question but is not supported by the analysis presented. • The conclusion makes superficial comparison to the accepted scientific context.
3–4	• A conclusion is described that is relevant to the research question but is not fully consistent with the analysis presented. • A conclusion is described that makes some relevant comparison to the accepted scientific context.
5–6	• A conclusion is justified that is relevant to the research question and fully consistent with the analysis presented. • A conclusion is justified through relevant comparison to the accepted scientific context.

Clarifications for conclusion
A conclusion that is fully consistent requires the interpretation of processed data including associated uncertainties. Scientific context refers to information that could come from published material (paper or online), published values, course notes, textbooks or other outside sources. The citation of published materials must be sufficiently detailed to allow these sources to be traceable.

Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation methodology and has suggested improvements.

Marks	Level descriptor
0	The report does not reach a standard described by the descriptors below.
1–2	• The report states generic methodological weaknesses or limitations. • Realistic improvements to the investigation are stated.
3–4	• The report describes specific methodological weaknesses or limitations. • Realistic improvements to the investigation that are relevant to the identified weaknesses or limitations, are described.
5–6	• The report explains the relative impact of specific methodological weaknesses or limitations. • Realistic improvements to the investigation, that are relevant to the identified weaknesses or limitations, are explained.

Clarifications for evaluation
Generic is general to many methodologies and not specifically relevant to the methodology of the investigation being evaluated. Methodological refers to the overall approach to the investigation of the research question as well as procedural steps. Weaknesses could relate to issues regarding the control of variables, the precision of measurement or the variation in the data.

Clarifications for evaluation
Limitations could refer to how the conclusion is limited in scope by the range of the data collected, the confines of the system or the applicability of assumptions made.

Glossary of command terms

Command terms for physics

Students must be familiar with the following key terms and phrases used in examination questions, which are to be understood as described in this section. Although these terms will be used frequently in examination questions, other terms may be used to direct students to present an argument in a specific way. These command terms indicate the depth of treatment required.

Assessment objective 1

Command term	Definition
Draw	Represent by means of a labelled, accurate diagram or graph, using a pencil. A ruler (straight edge) should be used for straight lines. Diagrams should be drawn to scale. Graphs should have points correctly plotted (if appropriate) and joined in a straight line or smooth curve.
State	Give a specific name, value or other brief answer without explanation or calculation.

Assessment objective 2

Command term	Definition
Annotate	Add brief notes to a diagram or graph.
Calculate	Obtain a numerical answer showing the relevant stages in the working.
Describe	Give a detailed account.
Estimate	Obtain an approximate value.
Outline	Give a brief account or summary.

Assessment objective 3

Command term	Definition
Analyse	Break down in order to bring out the essential elements or structure.
Determine	Obtain the only possible answer.
Discuss	Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence.
Explain	Give a detailed account including reasons or causes.
Predict	Give an expected result.
Show	Give the steps in a calculation or derivation.

Command term	Definition
Sketch	Represent by means of a diagram or graph (labelled as appropriate). The sketch should give a general idea of the required shape or relationship, and should include relevant features.
Suggest	Propose a solution, hypothesis or other possible answer.

Bibliography

This bibliography lists the principal works used to inform the curriculum review. It is not an exhaustive list and does not include all the literature available: judicious selection was made in order to better advise and guide teachers. This bibliography is not a list of recommended textbooks.

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