National Curriculum of Pakistan
2022-23

PHYSICS

Grades 9-12

NATIONAL CURRICULUM COUNCIL SECRETARIAT
MINISTRY OF FEDERAL EDUCATION AND
PROFESSIONAL TRAINING, ISLAMABAD
GOVERNMENT OF PAKISTAN

بسم اللہ الرحمن الرحیم

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It is with great pride that we, at the National Curriculum Council Secretariat, present the first core curriculum in Pakistan's 75-year history. Consistent with the right to education guaranteed by Article 25-A of our Constitution, the National Curriculum of Pakistan (2022-23) aspires to equip every child with the necessary tools required to thrive in and adapt to an ever-evolving globalized world.

The National Curriculum is in line with international benchmarks, yet sensitive to the economic, religious, and social needs of young scholars across Pakistan. As such, the National Curriculum aims to shift classroom instruction from rote learning to concept-based learning.

Concept-based learning permeates all aspects of the National Curriculum, aligning textbooks, teaching, classroom practice, and assessments to ensure compliance with contemplated student learning outcomes. Drawing on a rich tapestry of critical thinking exercises, students will acquire the confidence to embark on a journey of lifelong learning. They will further be able to acknowledge their weaknesses and develop an eagerness to build upon their strengths.

The National Curriculum was developed through a nationwide consultative process involving a wide range of stakeholders, including curriculum experts from the public, private, and non-governmental sectors. Representatives from provincial education departments, textbook boards, assessment departments, teacher training departments, *deeni madaris*, public and private publishers, private schools, and private school associations all contributed their expertise to ensure that the National Curriculum could meet the needs of all Pakistani students.

The experiences and collective wisdom of these diverse stakeholders enrich the National Curriculum, fostering the core, nation-building values of inclusion, harmony, and peace, making the National Curriculum truly representative of our nation's educational aspirations and diversity.

I take this opportunity to thank all stakeholders, including students, teachers, and parents who contributed to developing the National Curriculum of Pakistan (2022-23)

Dr. Mariam Chughtai
Director
National Curriculum Council Secretariat
Ministry of Federal Education and Professional Training

Cross-Cutting Themes

Guidance for the Reader

The idea of Science, Technology, Engineering, The Arts and Mathematics (STEAM) is an overarching idea for how to break up the study of Physics into core disciplinary knowledge (that students need to learn in order to pass examination at each grade level) and cross-cutting themes (interdisciplinary connections and recurring ideas that are best reinforced in every chapter in order to promote student critical thinking and curiosity, but that is not expected to be assessed in standardized exams).

Cross-cutting themes must be appropriately included into every chapter of schools textbooks that are aligned with these standards. This does not mean that every subcomponent of every theme must be included in every chapter, rather that where connections are appropriate and would enhance the study of the core disciplinary knowledge these should be incorporated.

The themes presented below are adapted from the Next Generation Science Standards:

Science: theoretical understandings about science in general, experimental skills and their mutual overlaps in the methods of scientific inquiry

Engineering and Technology: applications of science to create solutions that improve standards of living, along with the design thinking approach of engineering applied to scientific problems and vice versa

Mathematics: the connections of mathematics with the natural world, and its interconnectedness with the methods of the natural sciences

The Arts: What can be understood about the nature of science from the fine arts, performing arts and the humanities

Theme	Components	Elaboration and Guidance
Science	**A) Scientific Knowledge (these themes are applied across the conceptual SLOs)** **1. Patterns** i) Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. ii) Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. iii) Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. iv) Mathematical representations are needed to identify some patterns. v) Empirical evidence is needed to identify patterns **2. Cause and Effect: Mechanism and Prediction** i) Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ii) Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. iii) Systems can be designed to cause a desired effect. iv) Changes in systems may have various causes that may not have equal effects. **3. Scale, Proportion, and Quantity** i) The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ii) Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. iii) Patterns observable at one scale may not be observable or exist at other scales. iv) Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. v) Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). **4. Systems and System Models** i) Systems can be designed to do specific tasks. ii) When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. iii) Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. iv) Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. **5. Energy and Matter: Flows, Cycles, and Conservation** i) The total amount of energy and matter in closed systems is conserved. ii) Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.	**Elaborations on (A) Scientific Knowledge):** 1. Patterns: Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them. 2. Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering. 3. Scale, Proportion and Quantity: In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change. 4. Systems and System Models: A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems. 5. Energy and Matter: Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior 6. Structure and Function: The way an object is shaped or structured determines many of its properties and functions. 7. Stability and Change: For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand. **Elaborations on (B) Scientific Practices:** 1. Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world(s) works and which can be empirically tested. Engineering questions clarify problems to determine criteria for successful solutions and identify constraints to solve problems about the designed world. Both scientists and engineers also ask questions to clarify ideas. 2. Developing and Using Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling tools are used to develop questions, predictions and

	iii) Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. iv) Energy drives the cycling of matter within and between systems. v) In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. **6. Structure and Function** i) Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. ii) The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. **7. Stability and Change** i) Much of science deals with constructing explanations of how things change and how they remain stable. ii) Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. iii) Feedback (negative or positive) can stabilize or destabilize a system. iv) Systems can be designed for greater or lesser stability. **B) Scientific Practices** **1. Asking Questions and Defining Problems** i) Ask questions: - that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information - that arise from examining models or a theory, to clarify and/or seek additional information and relationships. - to determine relationships, including quantitative relationships, between independent and dependent variables. - to clarify and refine a model, an explanation, or an engineering problem. ii) Evaluate a question to determine if it is testable and relevant. iii) Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. iii) Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. iv) Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical and/or environmental considerations.	explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used to revise models and designs. 3. Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. Engineering investigations identify the effectiveness, efficiency, and durability of designs under different conditions. 4. Analyzing and Interpreting Data: Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis. Engineering investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria—that is, which design best solves the problem within given constraints. Like scientists, engineers require a range of tools to identify patterns within data and interpret the results. Advances in science make analysis of proposed solutions more efficient and effective. 5. Using Mathematics and Computational Thinking: In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; solving equations exactly or approximately; and recognizing, expressing, and applying quantitative relationships. Mathematical and computational approaches enable scientists and engineers to predict the behavior of systems and test the validity of such predictions. 6. Constructing Explanations and Designing Solutions: The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories. The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired

	2. Developing and Using Models i) Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. ii) Design a test of a model to ascertain its reliability. iii) Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. iv) Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. v) Develop a complex model that allows for manipulation and testing of a proposed process or system. vi) Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. **3. Planning and Carrying Out Investigations** i) Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. ii) Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. iii) Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts. iv) Select appropriate tools to collect, record, analyze, and evaluate data. v) Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. vi) Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables. **4. Analyzing and Interpreting Data** i) Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.	functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. The optimal choice depends on how well the proposed solutions meet criteria and constraints. 7. Engaging in Argument from Evidence: In science and engineering, reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem. Scientists and engineers use argumentation to listen to, compare, and evaluate competing ideas and methods based on merits. Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to evaluate claims. 8. Obtaining, Evaluating and Communicating Information: Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity. Communicating information and ideas can be done in multiple ways: using tables, diagrams, graphs, models, and equations as well as orally, in writing, and through extended discussions. Scientists and engineers employ multiple sources to obtain information that is used to evaluate the merit and validity of claims, methods, and designs. 9. Illustrate, with examples of achievements made by scientists in both theoretical and experimental physics, that the 'scientific method' in practice is not a linear process that goes from hypothesis to theory to law.

	ii) Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. iii) Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. iv) Compare and contrast various types of data sets (e.g., selfgenerated, archival) to examine consistency of measurements and observations. v) Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. vi) Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. **5. Using Mathematics and Computational Thinking** i) Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. ii) Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. iii) Apply techniques of algebra and functions to represent and solve scientific and engineering problems. iv) Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. v) Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m3 , acre-feet, etc.). **6. Constructing Explanations and Designing Solutions** i) Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. ii) Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. iii) Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. iv) Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.	

	v) Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. **7. Engaging in Argument from Evidence** i) Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. ii) Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. iii) Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining what additional information is required to resolve contradictions. iv) Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. v) Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence. vi) Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations). **8. Obtaining, Evaluating and Communicating Information** i) Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. ii) Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. iii) Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. iv) Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. v) Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).	

Technology & Engineerin g	**1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.** i) Analyze complex real-world problems by specifying criteria and constraints for successful solutions. ii) Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. iii) Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. iv) All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment v) New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. 2. **Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.** i) Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. ii) Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. **3. Evaluate a solution to a complex real-world problembased on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.** **i)** Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. ii) When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. **4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.** i) Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems.	The Engineering Design cycle can be considered to consist of the below three iterative steps in a global problem solving context: Define: Attend to a broad range of considerations in criteria and constraints for problems of social and global significance Develop solutions: Break a major problem into smaller problems that can be solved separately Optimize: Prioritize criteria, consider tradeoffs, and assess social and environmental impacts as a complex solution is tested and refined

	ii) Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. iii) Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows— within and between systems at different scales. **5. Interdependence of Science, Engineering, and Technology** i) Science and engineering complement each other in the cycle known as research and development (R&D). ii) Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. **6. Influence of Engineering, Technology, and Science on Society and the Natural World** i) Modern civilization depends on major technological systems, such as agriculture, health, water, energy, transportation, manufacturing, construction, and communications. ii) Engineers continuously modify these systems to increase benefits while decreasing costs and risks. iii) New technologies can have deep impacts on society and the environment, including some that were not anticipated. iv) Analysis of costs and benefits is a critical aspect of decisions about technology.	

The Arts and Mathematics	**A) Mathematical Knowledge in Science** (these are embedded int the conceptual SLOs, as well as is in the prerequisite mathematical knowledge requirements) **B) Nature of Science** **1. Scientific Investigations Use a Variety of Methods** i) Science investigations use diverse methods and do not always use the same set of procedures to obtain data. ii) New technologies advance scientific knowledge. iii) Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. iv) The discourse practices of science are organized around disciplinary domains that share examples for making decisions regarding the values, instruments, methods, models, and evidence to adopt and use. v) Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge. **2. Science knowledge is based on empirical evidence.** i) Science disciplines share common rules of evidence used to evaluate explanations about natural systems. ii) Science includes the process of coordinating patterns of evidence with current theory. iii) Science arguments are strengthened by multiple lines of evidence supporting a single explanation. **3. Scientific Knowledge is Open to Revision in Light of New Evidence** i) Scientific explanations can be probabilistic. ii) Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. iii) Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation. **4. Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** i) Theories and laws provide explanations in science, but theories do not with time become laws or facts. ii) A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. iii) Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. iv) Laws are statements or descriptions of the relationships among observable phenomena. v) Scientists often use hypotheses to develop and test theories and explanations.	

	5. Science is a Way of Knowing i) Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge. ii) Science is a unique way of knowing and there are other ways of knowing. iii) Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. iv) Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time. **6. Scientific Knowledge Assumes an Order and Consistency in Natural Systems** i) Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. ii) Science assumes the universe is a vast single system in which basic laws are consistent. **7. Science is a Human Endeavor** i) Scientific knowledge is a result of human endeavor, imagination, and creativity. ii) Individuals and teams from many nations and cultures have contributed to science and to advances in engineering. iii) Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings. iv) Technological advances have influenced the progress of science and science has influenced advances in technology. v) Science and engineering are influenced by society and society is influenced by science and engineering. **8. Science Addresses Questions About the Natural and Material World** i) Not all questions can be answered by science. ii) Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. iii) Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. iv) Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.	

Theoretical Concepts ▪rogression Grid

Guidance for the Reader

Assumption of Prior Knowledge: It is assumed that students will already have knowledge (and be able to apply it as needed in their current class) of what they learned in their previous grades, so SLOs from previous grades are not repeated in the higher grades. In practice, teachers may want to refresh concepts with their students as appropriate.

Organization of the SLOs in the Progression Grid: Inside a grade, teachers are free to teach the content in any order of preference. Textbook publishers are also free to organize the contents of their books in any manner that they consider most effective, as long as all the SLOs in the Progression Grid and Cross-Cutting themes are covered. The SLOs inside a grade do not need to be taught in the order presented in a grade in this PG. The Nature of Science domain would, for example, be best taught by being integrated into the teaching of all the chapters of the curriculum.

Nature of Science Domain Guidance for the Reader: Nature of Science learning objectives have been added to the Progression Grid. The purpose of studying science at the high school level is not only to prepare students for further study in the sciences. Many students will in fact not go on to study further science or STEM fields. The science that they learn in school may well remain their understanding of the subject for the rest of their lives. Hence these curricula must consider what citizens in a democratic society ought to know about the nature of science. "Nature of Science" (NOS) means teaching about science's underlying assumptions, and its methodologies. This involves some integrated study of the history of science, and some of the broad concepts from the philosophy of science. It is important to study NOS because it helps students become critical thinkers about the scientific information they consume from the world around them. Teaching NOS in the study of Physics, Biology, Chemistry is a cutting-edge international trend.

In the Nature of Science domain SLOs, unless explicitly stated, where the SLO begins with the phrase 'explain with examples' it is enough that students study 2-3 examples and can use them in their answers for examination questions.

There is no need to extensively or comprehensively study the history of science or its applications in other fields.

The purpose here is that students are able to develop an appreciation of these aspects of the field of physics with some rigor (hence these SLOs are expected to be assessed), but not to become so extensive that it take a lot of time out from building competence in rest of the domains on physics skills and knowledge.

Assessment Criterion for Domain G

Assessment of Nature of Science in standardized board exams will be kept to objective knowledge; students will not be expected to write argumentative essays or express subjective perspectives. Rather assessment in the standardized exams will occur through multiple choice questions and/or through short answer questions that require two-three sentence responses. Sample questions are provided in the Curriculum Guidelines. In their regular classroom study, teachers *are* encouraged to teach these topics through learner-centered activities that promote curiosity, inquiry, creativity, critical discussion and collaboration.

Optional SLOs: SLOs that are italicized are optional, as they may be advanced or too much to cover with the rest of the content in the grade.

<table>
<tr><th>Grade 9</th><th>Grade 10</th><th>Grade 11</th><th>Grade 12</th></tr>
<tr><td colspan="4">Domain A: Measurement

Physics is the study of relationships between physical quantities. This involved quantifying them by developing units of measurement, taking readings with instruments to make measurements, and expressing how certain or uncertain one is about the soundness of the readings taken.</td></tr>
<tr><td colspan="4">Standard: Students will be able to:
- express and mathematically manipulate basic and derived physical quantities
- identify and explain the reasons for common sources of human and systematic error in experiments
- identify, explain and describe the utility of measuring instruments in terms of precision
- quantify the uncertainty in readings taken and calculations made through those raw readings</td></tr>
<tr><td colspan="2">Benchmark I: Describe that physical quantities can be classified into basic and derived quantities. Physical quantities can be measured, but empirical measurements are accompanied by sources of error.</td><td colspan="2">Benchmark I: Describe that physical equations must be dimensionally consistent, and sources of error in measurements can be quantified. These errors can be compounded when measured quantities are used to calculate further derived quantities.</td></tr>
<tr><td>Physical Quantities:

[SLO: P-09-A-01]
Differentiate between physical and non-physical quantities

[SLO: P-09-A-02]
Explain with examples that physics is based on physical quantities

[Including that these consist of a magnitude and a unit]

[SLO: P-09-A-03]
Differentiate between base and derived physical quantities and units.</td><td>N/A</td><td>Physical Quantities:

[SLO: P-11-A-01]
Make reasonable estimates of physical quantities

[Of those quantities that are discussed in the topics of this grade]

[SLO: P-11-A-02]
Express derived units as products or quotients of the SI base units

[SLO: P-11-A-03]
Analyze the homogeneity of</td><td>N/A</td></tr>
</table>

[SLO: P-09-A-04] Apply the seven units of System International (SI) [along with their symbols and physical quantities (standard definitions of SI units are not required)] [SLO: P-09-A-05] Analyse and express numerical data using scientific notation [In measurements and calculations.] [SLO: P-09-A-06] Analyse and express numerical data using prefixes [Including use of their symbols to indicate decimal submultiples or multiples of both base and derived units. Specifically: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T). This also includes] Interconverting the prefixes and their symbols to indicate multiple and sub-multiple for both base and derived units.] [SLO: P-09-A-07] Differentiate between scalar and vector quantities [A scalar has magnitude (size) only and that a vector quantity has magnitude and direction. Students		physical equations [Through dimensional analysis] [SLO: P-11-A-04] Derive formulae in simple cases [Through using dimensional analysis] **Uncertainties in Measurement:** [SLO: P-11-A-05] Analyse and critique the accuracy and precision of data collected by measuring instruments [SLO: P-11-A-06] Assess the uncertainty in a derived quantity [By simple addition of absolute, fractional or percentage uncertainties] [SLO: P-11-A-07] Justify why all measurements contain some uncertainty.	

should be able to represent vectors graphically] [SLO: P-09-A-08] Justify that distance, speed, time, mass, energy, and temperature are scalar quantities. [SLO: P-09-A-09] Justify that displacement, force, weight, velocity, acceleration, momentum, electric field strength and gravitational field strength are vector quantities. [SLO: P-09-A-10] Determine, by calculation or graphically, the resultant of two vectors at right angles *[SLO: P-09-A-11]* *Make reasonable estimates of physical quantities* [Of those that are discussed in the topics of this grade level] Theory of Measurement: [SLO: P-09-A-12] Justify and illustrate the use of common lab instruments to measure length [Including how to measure a variety of lengths with appropriate precision using tapes, rulers, micrometers, and vernier calipers (including reading the			

scale on analogue calipers and micrometers)] [SLO: P-09-A-13] Justify and illustrate the use of measuring cylinders to measure volume [Including both measurement of volumes of liquids and determining the volume of a solid by displacement] [SLO: P-09-A-14] Justify and illustrate how to measure time intervals using lab instruments [Including clocks and digital timers. [SLO: P-09-A-15] Determine an average value for an empirical reading [Including small distance and for a short interval of time by measuring multiples (including the period of oscillation of a pendulum)] [SLO: P-09-A-16] Round off and justify calculational estimates [Based on empirical data to an appropriate number of significant figures] [SLO: P-09-A-17] Critique and analyze experiments for sources of error			

[Including identifying sources of systematic and random error in measurements and suggesting steps to correct them] [SLO: P-09-A-18] Differentiate between precision and accuracy [SLO: P-09-A-19] Determine the least count of a data collection instrument (analog) from its scale			

Domain B: Mechanics

Mechanics is the study of the motion of mechanical points, bodies and systems with or without consideration of their associated physical properties and the forces acting on them.

Standard: Students will be able to:
- Differentiate between and mathematically manipulate scalar and vector quantities
- Describe and analytically and graphically analyze distance, displacement, speed, velocity, and acceleration
- Differentiate between different kinds of forces and their effects
- Use Newton's laws to analyze motion and equilibrium
- Analyze circular and rotational motion in terms of forces and momentum
- differentiate between work, energy and power
- use the law of conservation of energy to analyze the viability and efficiency of systems
- differentiate between and mathematically analyze kinetic and gravitational potential energy

Benchmark I: Describe and analyze translatory motion in one dimension through analytical and graphical manipulation of scalar and vector quantities **Benchmark II**: Describe and analyze the effects of forces and momentum on the translational and rotational motion of bodies in one dimension **Benchmark III**: Describe and analyze the dynamics of rotational motion	**Benchmark** I: Describe and analyze translatory and rotational motion in a plane through analytical and graphical manipulation of scalar and vector quantities **BenchmarkII**: Explain events in terms of Newton's laws, including the Law of Gravitation, and the law of conservation of momentum in up to two dimensions

quantitatively and circular motion qualitatively in terms of forces in one dimension **Benchmark VI**: Describe and analyze in one dimension, analytically and graphically, how forces can cause solids to stretch and compress **Benchmark V**: Describe and analyze the effects of energy transfers and energy transformations on a body, along with the advantages and disadvantages of harnessing energy from natural resources		**BenchmarkIII**: Describe and analyze the dynamics of rotational and circular motion in terms of forces and momentum in one dimension **BenchmarkIV**: Describe and analyze the deformation of solids, analytically and graphically, in terms of how forces and pressure can cause stretching, compression, stress and strain **BenchmarkV**: Describe and analyze analytically and graphically the effects of energy transfers and energy transformations on a body	
Kinematics: [SLO: P-09-B-01] Differentiate between different types of motion [i.e; translatory, (linear, random, and circular); rotatory and vibratory motions and distinguish among them.] [SLO: P-09-B-02] Differentiate between distance and displacement, speed and velocity. [SLO: P-09-B-03] Define and calculate speed [Using the equation speed = distance/time,$v = \Delta s/\Delta t$(this should include an understanding of the term instantaneous speed)] [SLO: P-09-B-04] Define and calculate average speed [average speed = (total distance traveled)/(total time taken)] [SLO: P-09-B-05] Differentiate between average and	N/A	**Translatory motion:** Differentiate between scalar and vector quantities [SLO: P-11-B-01] Represent a vector in 2-D as two perpendicular components [SLO: P-11-B-02] Describe the product of two vectors (dot and cross-product) along with their properties [SLO: P-11-B-03] Derive the equations of motion [For uniform acceleration cases only. Derive from the definitions of velocity and acceleration as well as graphically] [SLO: P-11-B-04] Solve problems using the equations of motion [For the cases of uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance. This also	N/A

instantaneous speed [SLO: P-09-B-06] Differentiate between uniform velocity and non-uniform velocity [SLO: P-09-B-07] Define and calculate acceleration [Includes deriving the units of acceleration as ms^{-2} from the formula a = Δv/Δt and using the formula to solve problems. This also includes knowing that that deceleration is negative acceleration and using fact in calculations.] [SLO: P-09-B-08] Differentiate between uniform acceleration and non-uniform acceleration [SLO: P-09-B-09] Sketch, plot and interpret distance–time and speed–time graphs [This includes determining from the shape of a distance–time graph when an object is: [(a) at rest, (b) moving with constant speed, (c) accelerating, (d) decelerating. Students are also required to know how to calculate speed from the gradient of a distance–		includes situations where the equations of motion need to be resolved into into vertical and horizontal components for 2-D motion] [SLO: P-11-B-05] Evaluate and analyse projectile motion in the absence of air resistance [This includes solving problems making use of the below facts: (i) Horizontal component (V_H) of velocity is constant. (ii) Acceleration is in the vertical direction and is the same as that of a vertically free falling object. (iii) The horizontal motion and vertical motion are independent of each other. Situations may require students to determine for projectiles: - How high does it go? - How far would it go along the level land? - Where would it be after a given time? - How long will it remain in flight? Situations may also require students to calculate for]a projectile launched from ground height the - launch angle that results in the maximum range. - relation between the launch angles	

time graph. It also includes determining from the shape of a speed–time graph when an object is: (a) at rest, (b) moving with constant speed, (c) moving with constant acceleration (d) moving with changing acceleration.] [SLO: P-09-B-10] Use the approximate value 9.8 $9.8 m/s^2$ for free fall acceleration near Earth to solve problems [SLO: P-09-B-11] Justify how the gradient of a distance vs time graph gives the speed [Without using calculus] [SLO: P-09-B-12] Analyze the distance traveled in speed vs time graphs [By determining the area under the graph for cases of motion with constant speed or constant acceleration] [SLO: P-09-B-13] Derive how the area beneath a speed vs time graph gives the distance traveled (without calculus) [SLO: P-09-B-14] Calculate acceleration from the		that result in the same range.] [SLO: P-11-B-06] Predict qualitatively how air resistance affects projectile motion [This includes analysis of both the horizontal component and vertical component of velocity and hence predicting qualitatively the range of the projectile.] **Rotational motion:** [SLO: P-11-B-07] Express angles in radians [SLO: P-11-B-08] Define and calculate angular displacement, angular velocity and angular acceleration [This involves use of $S = r\theta$, $v = r\omega,\ \omega = 2\pi/T$, $a = r\,\omega^2$, and $a = v^2/r$ to solve problems] [SLO: P-11-B-09] Use equations of angular motion to solve problems involving rotational motions. [SLO: P-11-B-10] Analyse qualitatively motion in a	

gradient of a speed–time graph [SLO: P-09-B-15] Justify how the gradient of the speed vs time graph gives the acceleration [Without using calculus] Relativity: [SLO: P-09-B-16] State that there is a universal speed limit for any object in the universe that is approximately $3 \times 10^{8} ms^{-1}$ [Students should just be aware that this phenomenon is true; they do not need to study relativity in any depth. The purpose is that students appreciate that there is a universal speed limit.]		curved path due to a perpendicular force.	
DYNAMICS Mass, Weight and Gravity: [SLO: P-09-B-17] Illustrate that mass is a measure of the quantity of matter in an object [SLO: P-09-B-18] Explain that the mass of an object resists change from its state of rest or motion (inertia) [SLO: P-09-B-19] Define and calculate weight	N/A	**Dynamics** Momentum: [SLO: P-11-B-11] Apply the principle of conservation of momentum to solve simple problems [Including elastic and inelastic interactions between objects in both one and two dimensions. Knowledge of the concept of coefficient of restitution is not required.	[SLO: P-12-B-01] Define and calculate gravitational field strength [this will include more challenging problems than in Grade 9. It will involve use of $g = GM/r^{2}$] [SLO: P-12-B-02] Analyse gravitational fields by means of field lines. [This includes knowing that for a point outside a uniform sphere, the mass of the sphere may be considered to be a point mass at its center.]

[Weight is the force exerted on an object with mass by a planet's gravity, and use $W = mg$] [SLO: P-09-B-20] Define and calculate gravitational field strength [This includes being able to state that a gravitational field is a region in which a mass experiences a force due to gravitational attraction. Students should be able to define gravitational field strength (g) as force per unit mass use the equation gravitational field strength = weight/mass $g = W/m$ (and know that this is equivalent to the acceleration of free fall)] [SLO: P-09-B-21] Justify and illustrate the use electronic balances to measure mass [understanding the internal workings of the electronic balance is not required; just how to practically use the instrument in appropriate situations] [SLO: P-09-B-22] Justify and illustrate the use of a force meter to measure weight **Forces:** Types of Forces and Newton's Laws		Examples of applications include: - karate chops to break a pile of bricks - car crashes - ball & bat - the motion under thrust of a rocket in a straight line considering short thrusts during which the mass remains constant] [SLO: P-11-B-12] Predict and analyse motion for elastic collisions [This include making use of the fact that for an elastic collision, total kinetic energy is conserved and the relative speed of approach is equal to the relative speed of separation] [SLO: P-11-B-13] Justify why though the momentum of a closed system is always conserved, some change in kinetic energy may take place.	[SLO: P-12-B-03] Apply Newton's law of gravitation to solve problems [$F = G\frac{m_1 m_2}{r^2}$ for the force between two point masses to solve problems] [SLO: P-12-B-04] Analyze circular orbits in gravitational fields [By relating the gravitational force to the centripetal acceleration it causes] [SLO: P-12-B-05] Analyze the motion of geostationary satellites [This includes knowing that a geostationary orbit remains at the same point above the Earth's surface, with an orbital period of 24 hours, orbiting from west to east, directly above the Equator] [SLO: P-12-B-06] Derive the equation for gravitational field strength [From Newton's law of gravitation and the definition of gravitational field, the equation $g = GM/r^2$ for the gravitational field strength due to a point mass]

[SLO: P-09-B-23] Differentiate between contact and non-contact forces [SLO: P-09-B-24] Differentiate between different types of forces [including weight (gravitational force), friction, drag, air resistance, tension (elastic force), electrostatic force, magnetic force, thrust (driving force), and contact force] [SLO: P-09-B-25] State that there are three fundamental forces and describe them in terms of their relative strengths [these are the gravitational, strong and electroweak forces. Students should know that Pakistani Scientist won the Nobel Prize for helping prove that the weak force and the electromagnetic force are actually unified] [SLO: P-09-B-26] Represent the forces acting on a body using free body diagrams [SLO: P-09-B-27] Stateand applyNewton's first law [SLO: P-09-B-28]			[SLO: P-12-B-07] Analyse why g is approximately constant for small changes in height near the Earth's surface [SLO: P-12-B-08] Define and calculate gravitational potential [Use $\phi = -G\frac{M}{r}$ for the gravitational potential in the field due to a point mass] [At a point as the work done per unit mass in bringing a small test mass from infinity to the point] [SLO: P-12-B-09] Justify how the concept of gravitational potential leads to the gravitational potential energy of two point masses [Use of $E_p = -G\frac{Mm}{r}$ $in\ problems\ is\ expected$]]

Identify the effect of force on velocity [It may change the velocity of an object by changing its direction of motion or its speed] [SLO: P-09-B-29] Determine the resultant of two or more forces acting along the same straight line [SLO: P-09-B-30] State and apply Newton's second law in terms of acceleration [SLO: P-09-B-31] State and apply Newton's third law [SLO: P-09-B-32] Explain with examples how Newton's third law describes pairs of forces of the same type acting on different objects [SLO: P-09-B-33] State the limitations of Newton's laws of motion [That they are not exact but provide a good approximation, unless an object is moving close to the speed of light or is small enough that quantum effects become significant (for example, In the case of high speed bodies, the theory of relativistic mechanics is used. In the case of very small objects at the subatomic level, quantum mechanics			

is used).] [SLO: P-09-B-34] Describe and identify states of equilibrium [This includes the types, conditions, and states of equilibrium and identifying examples of them daily life examples.] **Friction**: [SLO: P-09-B-35] Analyse the dissipative effect of friction [This include identifying where dissipation may occur and giving examples such as rubbing hands together produces heat, asteroids that enter the Earth's atmosphere disintegrate due to high temperature generated from air resistance] [SLO: P-09-B-36] Analyse the dynamics of an object reaching terminal velocity [SLO: P-09-B-37] Differentiate qualitatively between rolling and sliding friction [no need for coefficients of friction] [SLO: P-09-B-38] Justify methods to reduce friction.			

Momentum [SLO: P-09-B-39] Define and calculate momentum [SLO: P-09-B-40] Define and calculate impulse [Use the equation Impulse = $F\Delta t = m\Delta V$] [SLO: P-09-B-41] Apply the principle of the conservation of momentum to solve simple problems in one dimension [SLO: P-09-B-42] Define resultant forcein terms of momentum [As the change in momentum per unit time; recall and use the equation resultant force = change in momentum/time taken F = $\Delta p/\Delta t$]			
Turning Effects: [SLO: P-09-B-43] Differentiate between like and unlike parallel forces. [SLO: P-09-B-44] Analyze problems involving turning effects of forces	N/A	**Circular Motion & Centripetal Force**: [SLO: P-11-B-14] Define and calculate centripetal force [Use $F = mr\omega^2$, $F = mv^2/r$] [SLO: P-11-B-15]	N/A

[Student should know that moment of a force = force × perpendicular distance from the pivot and be able to use this in simple problems and be able to give examples and applications of turning effects in real life] [SLO: P-09-B-45] Analyse objects in equilibrium using the principle of moments [SLO: P-09-B-46] Justify experiment to verify the principle of moments [SLO: P-09-B-47] State what is meant by center of mass and center of gravity [SLO: P-09-B-48] Describe how to determine the position of the center of gravity of a plane lamina using a plumb line [SLO: P-09-B-49] Analyse, qualitatively, the effect of the position of the center of gravity on the stability of simple objects [SLO: P-09-B-50] Propose how the stability of an object can be improved [by lowering the center of mass and increasing the base area of the object] [SLO: P-09-B-51]		Analyze situations involving circular motion in terms of centripetal force [e.g. situations in which centripetal acceleration is caused by a tension force, a frictional force, a gravitational force, or a normal force.] [SLO: P-11-B-16] Explain why the objects in orbiting satellites appear to be weightless. [SLO: P-11-B-17] Describe how artificial gravity is created to counter weightlessness. [SLO: P-11-B-18] Define and calculate moment of inertia of a body and angular momentum. [SLO: P-11-B-19] Derive and apply the relation between torque, moment of inertia and angular acceleration. [SLO: P-11-B-20] State and apply the law of conservation of angular momentum. Illustrate the applications of conservation of angular momentum in real life [such as by flywheels to store rotational energy, by gyroscopes in	

Illustrate the applications of stability physics in real life [Such as this concept is central to engineering technology such as balancing toys and racing cars [SLO: P-09-B-52] Predict qualitatively the motion of rotating bodies [Describe qualitatively that, analogous to Newton's 1st law for translational motion, an object that is rotating will continue to do so at the same rate unless acted upon by a resultant moment (in which case it would begin to accelerate or decelerate its rotational motion)] **Centripetal Force** [SLO: P-09-B-53] Describe qualitatively motion in a circular path due to a centripetal force, [SLO: P-09-B-54] Identify the sources of centripetal force in real life examples [e.g. tension in a string for a stone being swirled around, gravity for the Moon orbiting the Earth]		navigation systems, by ice skaters to adjust their angular velocity] [SLO: P-11-B-21] Justify how a centrifuge is used to separate materials using centripetal force	
Deformation of Solids: [SLO: P-09-B-55] Illustrate that forces may produce a	N/A	**Deformation of Solids:** [SLO: P-11-B-22] Distinguish between the structures	N/A

change in size and shape of an object [SLO: P-09-B-56] Define and calculate the spring constant [Apply the equation, spring constant = force/extension $k = F/x$ to solve problems involving simple springs] [SLO: P-09-B-57] Sketch, plot and interpret load–extension graphs for an elastic solid and describe the associated experimental procedures [SLO: P-09-B-58] Define and use the term 'limit of proportionality' for a load–extension graph [Including identifying this point on the graph (an understanding of the elastic limit is not required)] [SLO: P-09-B-59] Illustrate the applications of Hooke's law [Such as that it is the fundamental principle behind engineering many measurement instruments such as the spring scale, the galvanometer, and the balance wheel of the mechanical clock.]		of crystalline, glassy, amorphous, and polymeric solids. [SLO: P-11-B-23] Describe that deformation of solids in one dimension [That it is caused by a force and that in one dimension, the deformation can be tensile or compressive.] [SLO: P-11-B-24] Define and use the terms stress, strain and the Young modulus [SLO: P-11-B-25] Describe an experiment to determine the Young modulus of a metal wire. [SLO: P-11-B-26] Describe and use the terms elastic deformation, plastic deformation and elastic limit [SLO: P-11-B-27] Justify why and apply the fact that the area under the force–extension graph represents the work done [SLO: P-11-B-28] Determine the elastic potential energy of a material [That is deformed within its limit of proportionality from the area under the force–extension graph. Also]	

		state and use $E_p = \frac{1}{2}Fx = \frac{1}{2}kx^2$ for a material deformed within its limit of proportionality]	
[SLO: P-09-B-60] Define work done. [SLO: P-09-B-61] Use the equation work done = force × distance moved in the direction of the force $W = F \times d$ to solve problems [SLO: P-09-B-62] Define energy as the ability to do work [SLO: P-09-B-63] Explain that energy may be stored [Such as in gravitational potential, chemical, elastic (strain), nuclear, electrostatic, and internal (thermal) energies] [SLO: P-09-B-64] Prove that Kinetic Energy $E_k = \frac{1}{2}mv^2$ [use of equations of motion not needed; proof through kinematic graphs will suffice] [SLO: P-09-B-65] Prove and use the formula for gravitational potential energy [SLO: P-09-B-66] Use the formulas for kinetic and gravitational potential energy to solve	N/A	[SLO: P-11-B-29] Derive the formula for kinetic [using the equations of motion] [SLO: P-11-B-30] Deduce the work done from force-displacement graph [SLO: P-11-B-31] differentiate between conservative and non conservative forces [SLO: P-11-B-32] Utilize the work – energy theorem in a resistive medium to solve problems.	N/A

problems involving simple energy conversions [make use of the conversion of energy from one form to the other, including cases involving loss of energy to the surroundings] [SLO: P-09-B-67] Describe how energy is transferred and stored during events and processes [e.g. work done during transfer by mechanical work done, electrical work done, and heat] [SLO: P-09-B-68] State and apply the principle of the conservation of energy [SLO: P-09-B-69] Justify why perpetual energy machines do not work [SLO: P-09-B-70] Differentiate between and list renewable and non-renewable energy sources [SLO: P-09-B-71] Describe how useful energy may be obtained from natural resources			

[including the cases of (a) chemical energy stored in fossil fuels, (b) chemical energy stored in biofuels, (c) hydroelectric resources, (d) solar radiation, (e) nuclear fuel, (f) geothermal resources, (g) wind, (h) tides, (i) waves in the sea while including references to a boiler, turbine and generator where they are used] [SLO: P-09-B-72] Describe advantages and disadvantages of methods of energy generation [limited to whether it is renewable, when and whether it is available, and its impact on the environment] [SLO: P-09-B-73] Define and calculate power [as work done per unit time and also as energy transferred per unit time. This also includes applying the equations: (a) power = work done/time taken P = W/t (b) power = energy transferred/time taken $P = \frac{}{t}$ to solve simple problems]			

[SLO: P-09-B-74] Define and calculate efficiency [including: (a) (%) efficiency = (useful energy output)/(total energy input) (× 100%) (b) (%) efficiency = (useful power output)/(total power input) (× 100%)] [SLO: P-09-B-75] Apply the concept of efficiency to simple problems involving energy transfer [SLO: P-09-B-76] State that a system cannot have an efficiency of 100% due to unavoidable energy losses that occur $\frac{}{t}$			
[SLO: P-09-B-77] Define and calculate pressure [As force per unit area. Use the equation pressure = force/area $P = F/A$ to solve simple problems] [SLO: P-09-B-78] Describe how pressure varies with force and area in the context of everyday examples [SLO: P-09-B-79] Analyse in situations how pressure at a surface produces a force in a	NA	[SLO: P-11-B-33] Justify and use Archimedes's principle of flotation [SLO: P-11-B-34] Justify how ships are engineered to float in the sea [SLO: P-11-B-35] Define and apply the terms: steady (streamline or laminar) flow, incompressible flow and non viscous flow as applied to the motion of an ideal fluid.	

direction at right angles to the surface [can make reference to experiments to verify this principle] [SLO: P-09-B-80] Justify that the atmosphere exerts a pressure. [SLO: P-09-B-81] describe that atmospheric pressure decreases with the increase in height above the Earth's surface. [SLO: P-09-B-82] explain that changes in atmospheric pressure in a region may indicate a change in the weather. [SLO: P-09-B-83] Analyse the workings and applications of a liquid barometer [SLO: P-09-B-84] Just why and analyse quantitatively how pressure varies with depth in a liquid [SLO: P-09-B-85] Analyse the workings and applications of a manometer [SLO: P-09-B-86] Define and apply Pascal's law [Apply Pascal's law to systems such as the transmission of pressure in hydraulic systems with particular		[SLO: P-11-B-36] Use equation of continuity to solve problems [SLO: P-11-B-37] Explain that squeezing the end of a rubber pipe results in increase in flow velocity [SLO: P-11-B-38] Justify that the continuity is a form of the principle of conservation of mass. [SLO: P-11-B-39] Justify that the pressure difference can arise from different rates of flow of a fluid [Bernoulli effect] [SLO: P-11-B-40] Explainand applyBernoulli's equation for horizontal and vertical fluid flow. [SLO: P-11-B-41] Explain why real fluids are viscous fluids. [SLO: P-11-B-42] Describe how viscous forces in a fluid cause a retarding force on an object moving through it. [SLO: P-11-B-43] Describe superfluidity	

reference to the hydraulic press and hydraulic brakes on vehicles.]		[As the state in which a liquid will experience zero viscosity.Students should know the implications of this state e.g. this allows for superfluids to creep over the walls of containers to 'empty' themselves. It also implies that if you stir a superfluid, the vortices will keep spinning indefinitely.] [SLO: P-11-B-44] Analyze the real world applications of the Bernoulli effect [For example, atomisers in perfume bottles, the swinging trajectory of a spinning cricket ball and the lift of a spinning golf ball (the magnus effect), the use of Ventur ducts in filter pumps and car engineers to adjust the flow of fluid, etc]	
Domain C: Heat and Thermodynamics			
Standard: Students should be able to describe and analyze: - the effects of heat on the physical properties of matter by making reference to the kinetic theory of matter - how heat can be transferred through different modes			
Benchmark I: Use the kinetic theory of matter to explain the physical properties of matter and how these transform upon changes in state **Benchmark II:** Explain how heat can be transferred through convection, conduction and radiation and the effects and applications of these modes of transfer		**Benchmark I**: Use the kinetic theory of matter to account for the properties of an ideal gas	
Density: [SLO: P-09-C-01]	**Heat Capacity:**	[SLO: P-11-C-01]	[SLO: P-12-C-01] explain how molecular movement causes the pressure exerted by a

Define and calculate density [SLO: P-09-C-02] Justify and illustrate how to determine the density of a substance [Including for a liquid, of a regularly shaped solid and of an irregularly shaped solid which sinks in a liquid (volume by displacement), including appropriate calculations] **Particle Theory of Matter:** [SLO: P-09-C-03] Describe, qualitatively, the particle structure of solids, liquids and gasses [Including relating their properties to the forces and distances between particles and to the motion of the particles (atoms, molecules, ions and electrons) [SLO: P-09-C-04] Describe plasma as a fourth state of matter [in which a significant portion of the material is made up of ions or electrons e.g. in stars, neon lights and lightning streamers] Temperature:	[SLO: P-10-C-01] Define and calculate specific heat [SLO: P-10-C-02] Suggest experiments to measure the specific heat capacity [of a solid and of a liquid] [SLO: P-10-C-03] Analyse everyday effects due to the large specific heat of water. **Thermal Expansion and Kinetic Theory of Matter:** [SLO: P-10-C-04] Use the terms for the changes in state between solids, liquids and gasses [including deposition and sublimation] [SLO: P-10-C-05] Explain thermal expansion in terms of kinetic theory [For solids, liquids and gasses. This includes stating the relative order of magnitudes of the expansion of solids, liquids and gasses.] [SLO: P-10-C-06] Analyze the applications and	State that regions of equal temperature are in thermal equilibrium [SLO: P-11-C-02] Relate a rise in temperature of an object to an increase in its internal energy [SLO: P-11-C-03] Apply the equation of state for an ideal gas [expressed as pV = nRT, where n = amount of substance (number of moles) and as pV = NkT, where N = number of molecules] [SLO: P-11-C-04] state that the Boltzmann constant k is given by $k = R/N_A$ [SLO: P-11-C-05] Describe the basic assumptions of the kinetic theory of gasses. [Including understanding the temperature, pressure and density conditions under which an ideal gas is a good approximation of a real gas.] [SLO: P-11-C-06] Use W = pΔV for the work done when the volume of a gas changes	gas [SLO: P-12-C-02] Derive and use the relationship $pV = \frac{1}{3}Nm < c^2 >$ [where $< c^2 >$ is the mean-square speed (a simple model considering one-dimensional collisions and then extending to three dimensions using $\frac{1}{3} < c^2 > = < c_x{}^2 >$ is sufficient)] [SLO: P-12-C-03] Calculate the the root-mean-square speed of an ideal gas [SLO: P-12-C-04] Derive and use the formula for the average translational kinetic energy of a gas [SLO: P-12-C-05] Illustrate that the model of ideal gasses is used a base from which the field of statistical mechanics emerged [and has helped explain the behavior of 'non-ideal' gasses through modifications to the model e.g. the behavior of stars] [SLO: P-12-C-06] *State that under extreme physical conditions, atoms can break down*

[SLO: P-09-C-05] Describe the relationship between the motion of particles and temperature [including the idea that there is a lowest possible temperature (approx −273°C), known as absolute zero, where the particles have least kinetic energy] [SLO: P-09-C-06] State that an increase in the temperature of an object increases its internal energy [SLO: P-09-C-07] Explain, with examples, how a physical property which varies with temperature may be used for the measurement of temperature [SLO: P-09-C-08] Justify the need for fixed points in the calibration of thermometers [including what is meant by the ice point and steam point.] [SLO: P-09-C-09] Illustrate what is meant by the sensitivity, range and linearity of thermometers. [SLO: P-09-C-10] Differentiate between the structure	consequences of thermal expansion in real life [SLO: P-10-C-07] Analyze melting, solidification, boiling and condensation in terms of energy transfer without a change in temperature [SLO: P-10-C-08] state the melting and boiling temperatures for water at standard atmospheric pressure [SLO: P-10-C-09] Describe qualitatively the thermal expansion of solids [linear and volumetric expansion] [SLO: P-10-C-10] Explain the thermal expansion of liquids [real and apparent expansion]. Gases, Pressure, and Thermal Expansion: [SLO: P-10-C-11] Analyse the pressure and the changes in pressure of a gas in terms of particles [the forces exerted by particles	at constant pressure. [SLO: P-11-C-07] Describe the difference between the work done by a gas and the work done on a gas. [SLO: P-11-C-08] Define and use the first law of thermodynamics [$Q = \Delta U + W$ expressed in terms of the increase in internal energy, the heating of the system (energy transferred to the system by heating) and the work done on the system] [SLO: P-11-C-09] Explain qualitatively, in terms of particles, the relationship between the pressure, temperature and volume of a gas [Specifically the below case: (a) pressure and temperature at constant volume. (b) volume and temperature at constant pressure (c) pressure and volume at a constant temperature] [SLO: P-11-C-10] Use the equation, including a graphical representation of the relationship between pressure and volume for a gas at constant temperature.	*into sub-atomic particles that can form unusual states of matter* *[Such as degenerate matter. Usually made of any one kind of subatomic particle such as neutron degenerate matter in neutron stars under strong gravity and heat) and Bose-Einstein condensates (created when certain materials are taken to very low temperatures and then exhibit remarkable properties like superconductivity and superfluidity)]*

and function of liquid-in-glass and of thermocouple thermometers [SLO: P-09-C-11] Analyze how the structure of a liquid-in-glass thermometer affects its sensitivity, range and linearity	colliding with surfaces, creating a force per unit area.] **Changes in State:** [SLO: P-10-C-12] Differentiate between boiling and evaporation [SLO: P-10-C-22] Describe evaporation in terms of particles [in terms of the escape of more energetic particles from the surface of a liquid] [SLO: P-10-C-23] Analyze how temperature, humidity, surface area and air movement over a surface affect evaporation. [SLO: P-10-C-24] Explain how evaporation causes cooling [SLO: P-10-C-25] Describe the use of cooling caused by evaporation in the refrigeration process without using harmful CFCs. [SLO: P-10-C-26] Explain latent heat [as the energy required to change the state of a substance and	[SLO: P-11-C-11] Justify how the first law of thermodynamics expresses the conservation of energy. [SLO: P-11-C-12] Relate a rise in temperature of a body to an increase in its internal energy. [SLO: P-11-C-13] State the working principle ofaheat engine. [SLO: P-11-C-14] Describe the concept of reversible and irreversible processes. [SLO: P-11-C-15] State and explain the second law of thermodynamics. [SLO: P-11-C-16] State the working principle of Carnot's engine [SLO: P-11-C-17] Describe that refrigerator is a heat engine operating in reverse as that of an ideal heat engine. [SLO: P-11-C-18] Explain that an increase in temperature increases the disorder	

	explain it in terms of particle behavior and the forces between particles.] [SLO: P-10-C-27] Justify experiments to determine latent heat of fusion and latent heat of vaporization of ice and water [including illustrating the analysis of data by sketching temperature-time graph on heating ice.] [SLO: P-10-C-28] State that certain materials, when cooled to near absolute zero, can exhibit superconductivity [SLO: P-10-C-29] Describe superconductivity [as when atoms are in this state, their kinetic energy is low, so there is little (or no) resistance to the flow of electrons.]	of the system. [SLO: P-11-C-19] Explain that increase in entropy means degradation of energy. [SLO: P-11-C-20] Explain that energy is degraded during all natural processes. [SLO: P-11-C-21] Identifying that system tends to become less orderly over time. [SLO: P-11-C-22] Explain that Entropy, S, is a thermodynamic quantity that relates to the degree of disorder of the particles in a system. [SLO: P-11-C-23] State that the Carnot cycle sets a limit for the efficiency of a heat engine at the temperatures of its heat reservoirs give by Efficiency= $1 - \frac{T_{cold\ reservoir}}{T_{hot\ reservoir}}$	
		N/A	
N/As	**Modes of Heat Transfer:** [SLO: P-10-C-30] Justify experiments to distinguish	N/A	N/A

	between good and bad thermal conductors [SLO: P-10-C-31] Explain thermal conduction in all solids [in terms of atomic or molecular lattice vibrations and also in terms of the movement of free (delocalised) electrons in metallic conductors] [SLO: P-10-C-32] Explain convection in liquids and gasses [in terms of density changes] Justify experiments to illustrate convection [SLO: P-10-C-33] Explain convection in seawater to support marine life [SLO: P-10-C-34] Describe the role of land breezes and sea breezes in maintaining moderate coastal climates [SLO: P-10-C-35] Explain how birds are able to fly for hours without flapping their wings and gliders are able to rise by riding on thermal currents [SLO: P-10-C-36]		

	Describe the process of thermal energy transfer by radiation [and know that it does not require a medium] [SLO: P-10-C-37] Describe the effect of surface color and texture on the emission, absorption and reflection of infrared radiation [SLO: P-10-C-38] Justify qualitatively how the rate of emission of radiation depends on the surface temperature and surface area of an object [SLO: P-10-C-39] Justify Experiments to distinguish between good and bad emitters and absorbers of infrared radiation [SLO: P-10-C-40] Analyze the consequence of heat radiation in the greenhouse effect and its effect in global warming. [SLO: P-10-C-41] Analyze everyday applications of conduction, convection and radiation [Including: (a) heating objects such as kitchen pans (b) heating a room by convection		

	(c) measuring temperature using an infrared thermometer (d) using thermal insulation to maintain the temperature of a liquid and to reduce thermal energy transfer in buildings (e) the mechanism of a household hot-water system]		

Domain D: Waves

In this field students study the physical nature of waves and how the propagate, with a special look at the cases of sound and light

Standard: Students should be able to

- mathematically describe how waves propagate and the general properties of reflection, refraction and diffraction
- explain how the wave theory of light can help explain various optical phenomena

Benchmark I: Explain wave motion in terms of oscillations and energy and apply the basic principles of wave reflection, refraction and diffraction to solve problems Benchmark II: Use the principles of reflection and refraction from the wave model of light to create and analyse ray diagrams that help explain images generated by simple mirrors, lenses and total internal reflection		Benchmark I: Analytically and graphically explain the nature and effects of simple harmonic motion, the doppler effect, and attenuation of sound wave intensity in media Benchmark II: Use wave theory to analyse diffraction patterns, interference and polarization in the context of light and sound and other waves	
N/A	**Wave Theory:** [SLO: P-10-D-01] Prove that waves transfer energy without transferring matter [SLO: P-10-D-02] Describe what is meant by wave motion [as illustrated by vibrations in ropes	[SLO: P-11-D-01] Use intensity = power/area to solve problems Use intensity $\propto$ (amplitude)^2 for a progressive wave to solve problems. [SLO: P-11-D-02]	Simple Harmonic Motion: [SLO: P-12-D-01] describe simple examples of free oscillations. [SLO: P-12-D-02] use the terms displacement, amplitude, period, frequency, angular frequency and phase difference in the context of

	and springs and by experiments using water waves.] [SLO: P-10-D-03] Describe the features of a wave [in terms of wavefront, wavelength, frequency, time period, crest (peak), trough, compression, rarefaction, amplitude and wave speed] [SLO: P-10-D-04] Define the terms frequency, wavelength, and amplitude. [SLO: P-10-D-05] Recall and apply the equation wave speed = frequency × wavelength($v = f \cdot \lambda$) [SLO: P-10-D-06] Illustrate that for a transverse wave, the direction of vibration is at right angles to the direction of the energy transfer [including giving examples such as electromagnetic radiation, waves on the surface of water, and seismic S-waves (secondary)] [SLO: P-10-D-07] Illustrate that for a longitudinal wave, the direction of vibration is parallel to the direction of the energy transfer	Explain that when a source of sound waves moves relative to a stationary observer, the observed frequency is different from the source frequency [describing of the Doppler effect for a stationary source and a moving observer is not required] [SLO: P-11-D-03] Use the expression $f_0 = \frac{f_s \cdot v}{v \pm v_s}$ for the observed frequency when a source of sound waves moves relative to a stationary observer. [SLO: P-11-D-04] Explain the applications of the Doppler effect [such as radar, sonar, astronomy, satellite, radar speed traps and studying cardiac problems in humans]	oscillations [SLO: P-12-D-03] Express the period of simple harmonic motion in terms of both frequency and angular frequency [SLO: P-12-D-04] Explain that simple harmonic motion occurs when acceleration is proportional to displacement from a fixed point and in the opposite direction [SLO: P-12-D-05] use $a = -\omega^2 x$ to solve problems [SLO: P-12-D-06] use the equations $v = v_0 \cos(\omega t)$ and $v = \pm\omega\sqrt{(x_0{}^2 - x^2)}$ to solve problems [SLO: P-12-D-07] Analyze graphical representations of the variations of displacement, velocity and acceleration for simple harmonic motion [SLO: P-12-D-08] Analyse the interchange between kinetic and potential energy during simple harmonic motion [SLO: P-12-D-09] Apply $\frac{1}{2}\, m\omega^2 x_0{}^2$ for the total energy of a system undergoing simple harmonic motion

	[including give examples such as sound waves and seismic P-waves (primary)] [SLO: P-10-D-08] Describe how waves can undergo reflection, refraction and diffraction [SLO: P-10-D-09] Describe how wavelength affects diffraction at an edge [SLO: P-10-D-10] Analyse the phenomenon of tsunamis generated under the surface of water [in terms of underwater earthquakes/volcanic activity generating waves that increase in frequency and amplitude as they encounter increasingly shallow water] [SLO: P-10-D-11] Describe how wavelength and gap size affects diffraction through a gap **Sound:** [SLO: P-10-D-12] Describe the production of sound [SLO: P-10-D-13] Describe the longitudinal nature of sound waves		[SLO: P-12-D-10] describe that a resistive force acting on an oscillating system causes damping [SLO: P-12-D-11] use the terms light, critical and heavy damping [SLO: P-12-D-12] sketch displacement–time graphs to illustrate light, critical and heavy damping [SLO: P-12-D-13] State that resonance involves a maximum amplitude of oscillations and that this occurs when an oscillating system is forced to oscillate at its natural frequency. [SLO: P-12-D-14] Describe practical examples of free and forced oscillations. [SLO: P-12-D-15] Describe practical examples of damped oscillations [with particular reference to the efforts of the degree of damping and the importance of critical damping in cases such as a car suspension system.] [SLO: P-12-D-16] Justify qualitatively the factors

	[SLO: P-10-D-14] State the approximate range of frequencies audible to humans as 20Hz to 20000Hz [SLO: P-10-D-15] Justify why sound waves cannot travel in a vacuum [including describing experiments to demonstrate this] [SLO: P-10-D-16] Describe how changes in amplitude and frequency affect the loudness and pitch of sound waves [SLO: P-10-D-17] Describe how different sound sources produce sound waves with different timbres [including making reference to the shape of the traces on an oscilloscope] [SLO: P-10-D-18] Describe an echo as the reflection of sound waves [SLO: P-10-D-19] Justify simple experiments to show the reflection of sound waves [SLO: P-10-D-20] Illustrate a method involving a measurement of distance and time		which determine the frequency response and sharpness of the resonance. [SLO: P-12-D-17] identify the use of standing waves and resonance in applications [such as rubens tubes, *chladni* plates and acoustic levitation (knowledge of wave harmonic modes is not required)] [SLO: P-12-D-18] Justify the importance of critical damping in a car suspension system [SLO: P-12-D-19] Justify that there are some circumstances in which resonance is useful [such as tuning a radio, microwave oven and other circumstances in which resonance should be avoided such as airplane's wing or a suspension bridge]

	for determining the speed of sound in air [SLO: P-10-D-21] State that the speed of sound in air is approximately 330–350m/s [SLO: P-10-D-22] Describe that, in general, sound travels faster in solids than in liquids and faster in liquids than in gasses. [SLO: P-10-D-23] Define ultrasound as sound with a frequency higher than 20kHz [SLO: P-10-D-24] Illustrate and analyze the uses of ultrasound [in cleaning, prenatal and other medical scanning, and in sonar (including calculation of depth or distance from time and wave speed)] [SLO: P-10-D-25] Illustrate the use of infrasound [e.g. by elephants in communication, and in the study of seismic activity] [SLO: P-10-D-26] Analzye the effects of noise pollution on the environment		

	[SLO: P-10-D-27] Justify the importance of acoustic protection [SLO: P-10-D-28] Describe how knowledge of the properties of sound waves is applied in the design of buildings with respect to acoustics [SLO: P-10-D-29] Explain the use of soft materials to reduce echo sounding [such as in classroom studies, and other public gathering buildings] [SLO: P-10-D-30] Explain, with examples, how sound can reflect, refract and diffract. [SLO: P-10-D-31] Explain how sound is converted by the eardrum and nerves into electrical signals that are then interpreted by the brain		
N/A	[SLO: P-10-D-32] Define and use the terms normal, angle of incidence and angle of reflection [SLO: P-10-D-33] Describe an experiment to find the	[SLO: P-11-D-05] Explain that polarization is a phenomenon associated with transverse waves. [SLO: P-11-D-06] Define and apply Malus's law	**Diffraction and Interference:** [SLO: P-12-D-20] Explain experiments that demonstrate two-source interference using water waves in a ripple tank, sound, light and microwaves

	position and characteristics of an optical image formed by a plane mirror. [same size, same distance from mirror as object and virtual] [SLO: P-10-D-34] Use the law of reflection to solve simple optical problems [SLO: P-10-D-35] Define the terms normal, angle of incidence and angle of refraction [SLO: P-10-D-36] Apply the qualitative principle that a wave refracts towards the normal when it slows down while entering a medium, and that it refracts away from the normal if it speeds up when it enters a new medium [in the case the angle of incidence is zero, then the waves continues parallel to the normal] [SLO: P-10-D-37] Define and use the refractive index from a vacuum to a medium for light as c/v [SLO: P-10-D-38] Define refractive index n as $n = \frac{sin(i)}{sin(r)}$ Apply Snell's law, $n_i \ sin\ (i) = n_r\ sin\ (r)$ to solve simple problems.	[$I = I_0\ cos^2\ \theta$ to calculate the intensity of a plane-polarized electromagnetic wave after transmission through a polarizing filter or a series of polarizing filters. (calculation of the effect of a polarizing filter on the intensity of an unpolarized wave is not required).] [SLO: P-11-D-07] Use the principle of superposition of waves to solve problems [SLO: P-11-D-08] Differentiate between constructive and destructive interference. [SLO: P-11-D-09] Apply the principle of superposition to explain the working of noise canceling headphones. [SLO: P-11-D-10] Illustrate experiments that demonstrate stationary waves [using microwaves, stretched strings and air columns (it will be assumed that end corrections are negligible; knowledge of the concept of end corrections is not required)] [SLO: P-11-D-11] Explain the formation of a stationary	[SLO: P-12-D-21] describe the conditions required if two-source interference fringes are to be observed [SLO: P-12-D-22] use $\Delta y = \frac{\lambda L}{d}$ for double-slit interference using light to solve problems [SLO: P-12-D-23] use $d\ sin\ (\theta) = n\lambda$ to solve problems [SLO: P-12-D-24] describe the use of a diffraction grating to determine the wavelength of light [the structure and use of the spectrometer are not included] [SLO: P-12-D-25] with the context of the electron diffraction double slit experiment, explain the below two of the many interpretations of quantum mechanics: (i) copenhagen interpretation (ii) many worlds interpretation

	[SLO: P-10-D-39] Describe an experiment to show refraction of light by transparent blocks of different shapes [SLO: P-10-D-40] Define the terms critical angle and total internal reflection [SLO: P-10-D-41] Derive the equation $n = 1/sin\,(c)$ [SLO: P-10-D-42] Apply the equation $n = 1/sin\,(c)$ to solve simple problems [SLO: P-10-D-43] Describe experiments to show internal reflection and total internal reflection [SLO: P-10-D-44] Evaluate and illustrate the use of optical fibers [particularly in telecommunications, stating the advantages of their use in each context] [SLO: P-10-D-45] Analyze the action of thin converging and thin diverging lenses on a parallel beam of light	wave using graphical representation [SLO: P-11-D-12] Explain the formation of harmonics in stationary waves. [SLO: P-11-D-13] Analyze experiments that demonstrate diffraction [including the qualitative effect of the gap width relative to the wavelength of the wave; for example diffraction of water waves in a ripple tank] [SLO: P-11-D-14] Explain the term coherence. [SLO: P-11-D-15] Explain beats [as the pulsation caused by two waves of slightly different frequencies interfering with each other] [SLO: P-11-D-16] Illustrate examples of how beats are generated in musical instruments [SLO: P-11-D-17] Explain the use of polaroids in sky photography and stress analysis of materials	

	[SLO: P-10-D-46] Define and use the terms focal length, principal axis and principal focus (focal point) [SLO: P-10-D-47] Draw ray diagrams to illustrate the formation of real and virtual images of an object by a converging lens [SLO: P-10-D-48] Differentiate between real and virtual images [SLO: P-10-D-49] Define and calculate linear magnification [as the ratio of image length to object length; state and use the equation linear magnification = image length/object length] [SLO: P-10-D-50] Describe the use of a single lens as a magnifying glass [SLO: P-10-D-51] Explain the dispersion of light by a prism [including the detection of non-visible spectra by a thermometer] [SLO: P-10-D-52] State the traditional seven colors of the visible spectrum in order of	[SLO: P-11-D-18] Describe qualitatively gravitational waves [as waves of the intensity of gravity generated by the accelerated masses of an orbital binary system that propagate as waves outward from their source at the speed of light] [SLO: P-11-D-19] State that as a gravitational wave passes a body with mass the distortion in spacetime can cause the body to stretch and compress periodically [SLO: P-11-D-20] State that gravitational waves pass through the Earth due to far off celestial events, but they are very minute amplitude [SLO: P-11-D-21] Describe the use of interferometers in detecting gravitational waves [Interferometers are very sensitive detection devices that make use of the interference of laser beams (working and set up details are not required) and were used to first detect the existence of gravitational waves]	

	frequency and in order of wavelength [SLO: P-10-D-53] Describe the use of a single lens as in various optical device applications [specifically in the case of a magnifying glass, a camera, projector, and a photographic enlarger. This includes drawing ray diagrams to show how each forms an image.] [SLO: P-10-D-54] Draw ray diagrams to show the formation of images in the normal eye, a short-sighted eye and a long-sighted eye [SLO: P-10-D-55] Describe the use of converging and diverging lenses to correct long-sightedness and short-sightedness [SLO: P-10-D-56] Illustrate with examples how the biological eye processes color in various organisms [a. role of rods and cones in the eye, along with the brain, in detecting light and discerning color in combinations of 3 channels (red, yellow, blue) b. know that different living organisms may see more and less		

	colors e.g. the mantis shrimp has 12 channels of color and view ultraviolet light.] [SLO: P-10-D-57] State that extreme gravity from interstellar objects like blackholes can cause light to bend (from the perspective of the observer) in a way that is analogous to a simple lens [This is called 'gravitational lensing'.] [SLO: P-10-D-58] State that 'acoustic lenses' are made of materials and shapes that work to focus or diverge sound		

Domain E: Electricity and Magnetism

This is the field that studies the physical properties of electric and magnetic phenomena, along with the nature of electromagnetism

Standard: Students should be able to: - describe mathematically the nature of static magnetic and electric fields - analyze and account for the distribution of current, voltage and resistance in simple DC circuits - explain how power can be generated through electromagnetic induction - account for how motors make use of electromagnetism to generate kinetic energy - analyse AC circuits in terms of current, resistance, reactance, voltage, and impedance		

Benchmark I: Explain qualitatively the origin, properties, phenomena and applications of static magnetic and electric fields in terms of magnetic domain theory and electric charges. Benchmark II: Apply knowledge of the relationships between electric	Benchmark I: Analyze quantitatively the interactions of electric fields in terms of electric force, field strength, potential and potential energy Benchmark II: Derive and use Kirchhoff's laws to describe the design and application of simple circuits

current, voltage, resistance and power in simple circuits to describe their applications (in technology and in nature) and the need for safety measures in electric appliances		Benchmark III: Apply quantitatively the principles of magnetic flux, electromagnetic forces, induction and radiation to describe: (1) how electricity can be generated (2) how alternating current in circuits can be regulated (3) the applications of electromagnetic radiation in medical technology	
[SLO: P-09-E-01] Describe the forces between magnetic poles and between magnets and magnetic materials [Including the use of the terms north pole (N pole), south pole (S pole), attraction and repulsion, magnetized and unmagnetized] [SLO: P-09-E-02] Describe induced magnetism [SLO: P-09-E-03] State the difference between magnetic and non-magnetic materials [SLO: P-09-E-04] Differentiate between temporary and permanent magnets [SLO: P-09-E-05] Describe magnetic fields [as a region in which a magnetic pole experiences a force] [SLO: P-09-E-06] Illustrate the plotting of magnetic field lines with a compass or iron filings	[SLO: P-10-E-01] State that there are positive and negative charges [and charge is measured in coulombs] [SLO: P-10-E-02] State that unlike charges attract and like charges repel [SLO: P-10-E-03] Describe experiments to show electrostatic charging by friction [SLO: P-10-E-04] Explain that charging of solids by friction involves only a transfer of negative charge (electrons) [SLO: P-09-E-05] Explain how and why an insulator can be discharged by (a) putting it above a flame, and (b) exposing it to damp conditions [SLO: P-10-E-06] Explain how a conductor can be charged by electric induction and then "earthing"	[SLO: P-11-E-01] state that an electric field is an example of a field of force [SLO: P-11-E-02] Define and calculate electric field strength [Use $F = qE$ for the force on a charge in an electric field. Use $E = \frac{\Delta V}{\Delta d}$ to calculate the field strength of the uniform field between charged parallel plates] [SLO: P-11-E-03] Represent an electric field by means of field lines [SLO: P-11-E-04] describe the effect of a uniform electric field on the motion of charged particles [SLO: P-11-E-05] state that, for a point outside a spherical conductor, the charge on the sphere may be considered to be a point charge at its center	[SLO: P-12-E-01] define and calculate electric potential [At a point as the work done per unit positive charge in bringing a small test charge from infinity to the point. Use $V = \frac{1}{4\pi\epsilon_0 r}$ for the electric potential in the field due to a point charge] [SLO: P-12-E-02] use the fact that the electric field at a point is equal to the negative of potential gradient at that point [SLO: P-12-E-03] state how the concept of electric potential leads to the electric potential energy of two point charges and use $E_p = \frac{Qq}{4\pi\epsilon_0 r}$ [SLO: P-12-E-04] define and calculate capacitance [as applied to both isolated spherical conductors and to parallel plate capacitors]

[SLO: P-09-E-07] Draw the pattern and direction of the magnetic field lines around a bar magnet [SLO: P-09-E-08] State that the direction of the magnetic field at a point is the direction of the force on the N pole of a magnet at that point [SLO: P-09-E-09] state that the relative strength of a magnetic field is represented by the spacing of the magnetic field lines [SLO: P-09-E-10] Describe uses of permanent magnets and electromagnets [SLO: P-09-E-11] Explain qualitatively in terms of the domain theory of magnetism how materials can be magnetized and demagnetized [stroking method, heating, orienting in north-south direction and striking, use of a solenoid] [SLO: P-09-E-12] Differentiate between ferromagnetic, paramagnetic and diamagnetic materials [by making reference to the domain theory of magnetism and the effects of	[SLO: P-10-E-07] Describe examples where charging could be a problem e.g. lightning. [SLO: P-10-E-08] Suggest how charging and discharging is used in the application of various devices [e.g. photocopier and electrostatic precipitator] [SLO: P-10-E-09] Describe an electric field as a region in which an electric charge experiences a force [SLO: P-10-E-10] State that the direction of an electric field line at a point is the direction of the force on a positive charge at that point [SLO: P-10-E-11] Analye and illustrate simple electric field patterns [including the direction of the field: (a) around a point charge (b) around a charged conducting sphere (c) between two oppositely charged parallel conducting plates (end effects will not be examined)] [SLO: P-10-E-12] State examples of electrical conductors and insulators	[SLO: P-11-E-06] Explain how a Faraday cage works [by inducing internal electric fields that work to shield the inside from the influence of external electric fields] [SLO: P-11-E-07] State and apply Coulomb's law [$F = k\frac{Q_1Q_2}{r^2}$ for the force between two point charges in free space, where $k = \frac{1}{4\pi\epsilon_0}$] [SLO: P-11-E-08] Use $E = k\frac{Q}{r^2}$ for the electric field strength due to a point charge in free space. [SLO: P-09-E-09] Describe how ferrofluids work [they make use of temporary soft magnetic materials suspended in liquids to develop fluids that react to the poles of a magnet and have many applications in fields such as electronics]	[SLO: P-12-E-05] Derive and apply formulae for the combined capacitance of capacitors in series and in parallel [SLO: P-12-E-06] use the capacitance formula for capacitors in series and in parallel [SLO: P-12-E-07] determine the electric potential energy stored in a capacitor from the area under the potential–charge graph [Use $W = \frac{1}{2}QV = \frac{1}{2}CV^2$ to solve physics related problems] [SLO: P-12-E-08] analyze graphs of the variation with time of potential difference, charge and current for a capacitor discharging through a resistor [use $\tau = RC$ for the time constant for a capacitor discharging through a resistor] [SLO: P-12-E-09] Use equations of the form $x = x_0($ $exp\left(\frac{-t}{RC}\right))$

external magnetic fields on these materials] [SLO: P-09-E-13] Describe the nature of the Earth's magnetic field [specifically that: - is opposite to its geographical north-south orientation - protects life on the planet from cosmic radiation - allows animals that make use of biomagnetism (e.g. many birds and turtles) to navigate during migration)] [SLO: P-09-E-14] Analyze applications of magnets in recording technology [and illustrate how electronic devices need to be kept safe from strong magnetic fields] [SLO: P-09-E-15] State that soft magnetic materials (such as soft iron) can be used to provide shielding from magnetic fields	[SLO: P-10-E-13] Describe an experiment to distinguish between electrical conductors and insulators [SLO: P-10-E-14] state and use a simple electron model to explain the difference between electrical conductors and insulators [SLO: P-10-E-15] Explain how a lightning rod can protect humans [SLO: P-10-E-16] Explain electrical breakdown [it occurs when a strong electric field passes through a gas and causes its atoms to ionize] [SLO: P-10-E-17] State that Corona discharge and Lichtenberg figures are visible examples of electrical breakdown. [SLO: P-10-E-18] Explain how lightning is generated (including the below steps of formation: - through friction between the water molecules suspended in clouds in the case of thunderstorms, and from between smoke particles in		[where x could represent current, charge or potential difference for a capacitor discharging through a resistor] [SLO: P-12-E-10] list the use of capacitors in various household appliances [such as in flash guns, refrigerators, electric fans, rectification circuits, etc.] **Bioelectricity:** [SLO: P-10-E-11] Illustrate how bioelectricity is generated in animals [- cells control the flow of specific charged elements across the membrane with proteins that sit on the cell surface and create an opening for certain ions to pass through. These proteins are called ion channels. - When a cell is stimulated, it allows positive charges to enter the cell through open ion channels. The inside of the cell then becomes more positively charged, which triggers further electrical currents that can turn into electrical pulses, called action potentials. - The bodies of many organisms use certain patterns of action

	the case of volcanic lightning - lightning streamers are created through the process of electrical breakdown and this provided a path for the electric current from one charged object to the other - in the case of cloud-ground lightning a strong electric field from the clouds induces an opposite net charge in the conducting material present in the ground, and when this field becomes strong enough it generates lightning streams that provide the path for cloud-to-ground and ground-to-cloud discharge) [SLO: P-10-E-19] State that there are many kinds of atmospheric lightning [e.g. sprites, jets, elves, trolls, pixies, ghosts, ball lightning) that are still being researched]		potentials to initiate the correct movements, thoughts and behaviors.] [SLO: P-10-E-12] State that there are several species of aquatic life, such as Electrophorus Electricus, that can naturally generate external electric shocks through internal biological mechanisms that act as batteries [SLO: P-10-E-13] Explain, with examples of animals with this ability, that electroreception is the ability to detect weak naturally occurring electrostatic fields in the environment
N/A	**Electric Current and Ohm's Law:** [SLO: P-10-E-20] Define and calculate electric current [Use the equation electric current = charge/time I = Q/t to solve simple problems]	[SLO: P-09-E-10] use, for a current-carrying conductor, the expression $I = Anvq$ [where n is the number of charge carriers per unit volume.] [SLO: P-09-E-11]	N/A

	[SLO: P-10-E-21] Explain electrical conduction [in metals in terms of the movement of free electrons] [SLO: P-10-E-22] state that current is measured in amps (amperes) and that the amp is given by coulomb per second (C/s) [SLO: P-10-E-23] Differentiate between direct current (d.c.) and alternating current (a.c.) [SLO: P-10-E-24] Differentiate between conventional and actual current [SLO: P-10-E-25] Justify and illustrate the use of ammeters [(analogue and digital) with different ranges] [SLO: P-10-E-26] Define e.m.f. [as the electrical work done by a source in moving a unit charge around a complete circuit. Use the equation e.m.f. = work done (by a source) per unit charge E = W/Q]	state and use $V = W/Q$ [SLO: P-09-E-12] state and use $P = IV$, $P = I^2R$ and $P = V^2/R$ [SLO: P-09-E-13] state and use $R = \rho L/A$ [SLO: P-09-E-14] State that the resistance of a light-dependent resistor (LDR) decreases as the light intensity increases [SLO: P-09-E-15] define and use the electromotive force (e.m.f.) [of a source as energy transferred per unit charge in driving charge around a complete circuit] [SLO: P-09-E-16] Distinguish between e.m.f. and potential difference (p.d.) in terms of energy considerations [SLO: P-09-E-17] Explain the effects of the internal resistance of a source of e.m.f. on the terminal potential difference [SLO: P-09-E-18] state Kirchhoff's first law and describe that it is a consequence of	

	[SLO: P-10-E-27] Define p.d. (potential difference) [As the work done by a unit charge passes through a component. Use the equation p.d. = work done (on a component) charge V = W/Q to solve simple problems] [SLO: P-10-E-28] State that e.m.f. and p.d. are measured in volts and that the volt is given by joule per coulomb (J/C) [SLO: P-10-E-29] Justify and illustrate the use of voltmeters [(analogue and digital) with different ranges] [SLO: P-10-E-30] Calculate the total e.m.f. where several sources are arranged in series [SLO: P-10-E-31] State that the e.m.f of identical sources connected in parallel is equal to the e.m.f. of one of the sources [SLO: P-10-E-32] Describe an experiment to determine resistance	conservation of charge [SLO: P-09-E-19] state Kirchhoff's second law and describe that it is a consequence of conservation of energy [SLO: P-09-E-20] Derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in series [SLO: P-09-E-21] Derive and apply a formula for the combined resistance of two or more resistors in parallel [SLO: P-09-E-22] use Kirchhoff's laws to solve simple circuit problems [SLO: P-09-E-23] state and use the principle of the potentiometer as a means of comparing potential differences [SLO: P-09-E-24] Explain the use of a galvanometer in null methods [SLO: P-09-E-25] explain the use of thermistors and light-dependent resistors in potential dividers [to provide a potential difference	

	[using a voltmeter and an ammeter and do the appropriate calculations] [SLO: P-10-E-33] Define and calculate resistivity [Use for a wire, the direct proportionality between resistance and length, and the inverse proportionality between resistance and cross-sectional area] [SLO: P-10-E-34] Define and apply Ohm's law [Including reference to constant temperature. Use the equation resistance = p.d./current R = V/I to solve simple problems.] [SLO: P-10-E-35] Describe the effect of temperature increase on the resistance of a resistor [such as the filament in a filament lamp] [SLO: P-10-E-36] Interpret current–voltage graphs [including for a resistor of constant resistance, a filament lamp and a diode] **Circuit Diagrams:**	that is dependent on temperature and light intensity[[SLO: P-09-E-26] explain the internal resistance of sources and its consequences for external circuits [SLO: P-09-E-27] Explain how inspectors can easily check the reliability of a concrete bridge with carbon fibers as the fibers conduct electricity	

	[SLO: P-10-E-37] Draw circuit diagrams [with cells, batteries, power supplies, generators, potential dividers, switches, resistors (fixed and variable), heaters, thermistors (NTC only), light-dependent resistors (LDRs), lamps, motors, ammeters, voltmeters, transformers, fuses, relays, diodes and light-emitting diodes (LEDs)] [SLO: P-10-E-38] Use common rules regarding current and voltage distribution in circuits to solve problems [specifically: (a) the current at every point in a series circuit is the same (b) the sum of the currents entering a junction in a parallel circuit is equal to the sum of the currents that leave the junction (c) the total p.d. across the components in a series circuit is equal to the sum of the individual p.d.s across each component (d) the p.d. across an arrangement of parallel resistances is the same as the p.d. across one branch in the arrangement of the parallel resistances] [SLO: P-10-E-39] Calculate the combined resistance		

	of two or more resistors in series [SLO: P-10-E-40] Calculate the combined resistance of two resistors in parallel [SLO: P-10-E-41] Calculate current, voltage and resistance in parts of a circuit or in the whole circuit [SLO: P-10-E-42] Describe the action of negative temperature coefficient (NTC) thermistors and light-dependent resistors [including explaining their use as input sensors] [SLO: P-10-E-43] Analyze the function of variable potential dividers in circuits [including using the equation for two resistors used as a potential divider R1/R2= V1/V2] [SLO: P-10-E-44] Justify and illustrate the use of color codes for resistors [SLO: P-10-E-45] Describe the working of a diode		

	[SLO: P-10-E-46] Describe the action of a light-emitting diode in passing current in one direction only and emitting light. [SLO: P-10-E-47] Describe and explain the action of relays in switching circuits. **Electric Appliances and Transmission:** [SLO: P-10-E-48] State common uses of electricity [including heating, lighting, battery charging and powering motors and electronic systems.] [SLO: P-10-E-49] Justify the advantages of connecting lamps in parallel in a lighting circuit [SLO: P-10-E-50] Use the equation, power = current × voltage $P = IV$ to solve simple problems [SLO: P-10-E-51] Use the equation energy = current × voltage × time $E = IVt$ to solve simple problems [SLO: P-10-E-52] Define the kilowatt-hour (kWh)		

	[SLO: P-10-E-53] Explain the need to choose components with suitable power ratings. [SLO: P-10-E-54] Calculate the cost of using electrical appliances where the energy unit is the kWh [SLO: P-10-E-55] State common electric hazards that may be caused from malpractice and lack of maintenance [specifically: (a) damaged insulation (b) overheating cables (c) damp conditions (d) excess current from overloading of plugs, extension leads, single and multiple sockets when using a mains supply] [SLO: P-10-E-56] Explain the use and operation of trip switches and fuses and choose appropriate fuse ratings and trip switch settings [SLO: P-10-E-57] Explain what happens when a live wire touches a metal case that is earthed [SLO: P-10-E-58] Explain why the outer casing of an electrical appliance must be either		

	non-conducting (double-insulated) or earthed [SLO: P-10-E-59] state that a mains circuit consists of a live wire (line wire), a neutral wire and an earth wire. [SLO: P-10-E-60] Explain why fuses and circuit breakers are connected into the live wire for the circuit to be switched off safely. [SLO: P-10-E-61] Explain why domestic supplies are connected in parallel. [SLO: P-10-E-62] Explain the damage that electric shock could do to a human being [in terms of burns, cardio-respiratory failure and seizures] **Electronics:** [SLO: P-10-E-63] Explain that electronic devices are built from digital logic circuits [that can act as switches that can convert incoming voltage into binary electrical pulses of high and low (or 1 and 0)]		

	[SLO: P-10-E-64] Explain that Boolean logic is the basis for converting analogue data to digital data [this includes knowing that 'bit' is the smallest unit of data in computing; either 1 or 0. Eight bits make up a byte.] [SLO: P-10-E-65] State in words and in truth table form, the action of logic gates [specifically of AND, OR, NAND, NOR and NOT] [SLO: P-10-E-66] Identify the use of logic gates for security purposes [e.g; burglar alarm, fire extinguisher etc.] [SLO: P-10-E-67] Use circuit symbols for the logic gates [SLO: P-10-E-68] Identify in given problems how Boolean switches can be put into combinations that then allow them to achieve logical operations [SLO: P-10-E-69] Describe the action of a bipolar npn		

	transistor as a switch. [SLO: P-10-E-70] Explain that transistors are commonly used in digital devices because they are both economical and act as rapid-response switches [To enrich this concept students should be given an overview of how with advances in engineering, the number of transistors that can be fit per unit area onto a circuit board has continued to increase dramatically; this has rapidly enhanced computing power. They also be given an overview of how - breakthroughs in quantum physics are causing a new revolution in computing that are enabling computers to make exponentially more logical operations per unit time than with traditional computers] [SLO: P-10-E-71] State that circuits that maintain their 'state' after receiving an input can be said to exhibit 'memory' [since they retain the effect of the last action upon them (this should be taught to them with the context provided that circuit systems that allow for logical processing and memory functions form the basis of programmable electronics)]		

	[SLO: P-10-E-72] State that quantum computers are still in early stages of development, and have to overcome manufacturing challenges such core components only functioning at very cold temperatures that are at almost absolute zero [SLO: P-10-E-73] Compare analogue and digital electronics.		
N/A	[SLO: P-10-E-74] Describe an experiment to demonstrate electromagnetic induction [SLO: P-10-E-75] Use the fact that the magnitude of an induced e.m.f. is affected by (a) the rate of change of the magnetic field or the rate of cutting of magnetic field lines, and (b) the number of turns in a coil, to solve simple electromagnetic problems [SLO: P-10-E-76] Use the fact that the effect of the current produced by an induced e.m.f. is to oppose the change producing it (Lenz's law) [SLO: P-10-E-77] Describe how a.c. generators work	[SLO: P-09-E-28] Define and explain magnetic fields [SLO: P-09-E-29] state that a force might act on a current-carrying conductor placed in a magnetic field [SLO: P-09-E-30] use the equation $F = BIL\ \sin(\theta)$ [with directions as interpreted by Fleming's left-hand rule to solve problems] [SLO: P-09-E-31] Define magnetic flux density [as the force acting per unit current per unit length on a wire placed at right angles to the magnetic field]	AC circuits: [SLO: P-10-E-14] use the terms period, frequency and peak value as applied to an alternating current or voltage [SLO: P-10-E-15] use equations of the form $x = x_0 \sin(\omega t)$ representing a sinusoidally alternating current or voltage [SLO: P-10-E-16] use the fact that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current [SLO: P-10-E-17] distinguish between root-mean-square (r.m.s.) and peak values [including stating and using

	[(rotating coil or rotating magnet setup) and the use of slip rings and brushes where needed] [SLO: P-10-E-78] Sketch and interpret graphs of e.m.f. against time for simple a.c. generators [including relating the position of the generator coil to the peaks, troughs and zeros of the e.m.f.] [SLO: P-10-E-79] Describe the pattern and direction of the magnetic field due to currents in straight wires and in solenoids. [SLO: P-10-E-80] State the effect on the magnetic field of changing the magnitude and direction of the current [SLO: P-10-E-81] Describe how the magnetic effect of a current is used in relays and loudspeakers [including giving examples of their application] [SLO: P-10-E-82] Describe an experiment to show that a force acts on a current-carrying conductor in a magnetic	[SLO: P-09-E-32] use $F = BQV\ sin\,(\theta)$ to solve problems [SLO: P-09-E-33] describe the motion of a charged particle moving in a uniform magnetic field perpendicular to the direction of motion of the particle [SLO: P-09-E-34] explain how electric and magnetic fields can be used in velocity selection [SLO: P-09-E-35] sketch magnetic field patterns due to the currents in a long straight wire, a flat circular coil and a long solenoid [SLO: P-09-E-36] state that the magnetic field due to the current in a solenoid is increased by a ferrous core. [SLO: P-09-E-37] explain the origin of the forces between current-carrying conductors and determine the direction of the forces. [SLO: P-09-E-38] define magnetic flux [as the product of the magnetic flux density and the cross-sectional area	$I_{rms} = I_0/\sqrt{2}$ and $V_{rms} = V_0/\sqrt{2}$ for a sinusoidal alternating current] [SLO: P-10-E-18] Distinguish graphically between half-wave and full-wave rectification [SLO: P-12-E-19] explain the use of a single diode for the half-wave rectification of an alternating current [SLO: P-12-E-20] explain the use of four diodes (bridge rectifier) for the full-wave rectification of an alternating current [SLO: P-12-E-21] analyze the effect of a single capacitor in smoothing current flow [including the effect of the values of capacitance and the load resistance] [SLO: P-12-E-22] define mutual inductance (M) and self-inductance (L), and their unit henry. [SLO: P-12-E-23] describe the phase of A.C and how phase lags and leads in A.C Circuits.

	field [including the effect of reversing: (a) the current (b) the direction of the field] [SLO: P-10-E-83] state and use the relative directions of force, magnetic field and current [SLO: P-10-E-84] Describe the magnetic field patterns between currents in parallel conductors and relate these to the forces on the conductors [excluding the Earth's field] [SLO: P-10-E-85] state that a current-carrying coil in a magnetic field may experience a turning effect and that the turning effect is increased by increasing: (a) the number of turns on the coil (b) the current (c) the strength of the magnetic field [SLO: P-10-E-86] Describe the operation of an electric motor, including the action of a split-ring commutator and brushes [SLO: P-10-E-87] State that it is theorized that the Earth's magnetic field is generated by the rotation of the Earth and its	perpendicular to the direction of the magnetic flux density] [SLO: P-09-E-39] use $\Phi = BA$ to solve problems [SLO: P-09-E-40] use the concept of magnetic flux linkage [SLO: P-09-E-41] explain experiments that demonstrate Faraday's and Lenz's laws [(a) that a changing magnetic flux can induce an e.m.f. in a circuit, (b) that the induced e.m.f. is in such a direction as to oppose the change producing it, (c) the factors affecting the magnitude of the induced e.m.f.] [SLO: P-09-E-42] Use Faraday's and Lenz's laws of electromagnetic induction to solve problems [SLO: P-09-E-43] explain how seismometers make use of electromagnetic induction to the earthquake detection [specifically in terms of: (i) any movement or vibration of the rock on which the seismometer rests (buried in a protective case) results in relative motion between the magnet and the coil	[SLO: P-12-E-24] identify inductors as important components of A.C circuits termed as chokes [devices which present a high resistance to alternating current] [SLO: P-12-E-25] Calculate the reactances of capacitors and inductors. [SLO: P-12-E-26] describe impedance as vector summation of resistances and reactances.

	molten iron core that contains charged particles in motion [SLO: P-10-E-88] Explain the principle of operation of a simple iron-cored transformer [SLO: P-10-E-89] Use the terms primary, secondary coils and step-up and step-down transformer [SLO: P-10-E-90] Use the equation $V_p/V_s = N_p/N_s$ [where P and S refer to primary and secondary, to solve problems] [SLO: P-10-E-91] Justify the advantages of high-voltage transmission [including explaining why power losses in cables are smaller when the voltage is greater] [SLO: P-10-E-92] Describe the deflection of an electron beam by electric fields and magnetic fields. [SLO: P-10-E-93] Interpret waveforms on oscilloscopes Electromagnetic Waves:	(suspended by a spring from the frame.) (ii) the emf induced in the coil is directly proportional to the displacement associated]	

	[SLO: P-10-E-94] state the main regions of the electromagnetic spectrum in order of frequency and in order of wavelength [SLO: P-10-E-95] state that the speed of all electromagnetic waves in: (a) a vacuum is 3.0×10^8 m/s (b) air is approximately the same as in a vacuum [SLO: P-10-E-96] Describe the applications of electromagnetic waves in society [specifically: (a) radio waves – radio and television communications, astronomy (b) microwaves – satellite television, mobile (cell) phone, Bluetooth, microwave ovens (c) infrared – household electrical appliances, remote controllers, intruder alarms, thermal imaging, optical fibers (d) visible light – photography, vision (e) ultraviolet – security marking, detecting counterfeit bank notes, sterilizing water (f) X-rays – hospital use in medical imaging, security scanners, killing cancerous cells, engineering applications such as detecting		

	cracks in metal (g) gamma rays – medical treatment in detecting and killing cancerous cells, sterilizing food and medical equipment, engineering applications such as detecting cracks in metal] [SLO: P-10-E-97] Describe the damage caused by electromagnetic radiation [including (a) excessive exposure causing heating of soft tissues and burns and (b) ionizing effects caused by ultraviolet (skin cancer and cataracts), X-rays and gamma rays (cell mutation and cancer)] [SLO: P-10-E-98] Explain qualitatively, how scattering of light by molecules in the air give the sky its blue color during the day and its shades of red during sunset [use of the terms Rayleigh and Mei scattering are not required] [SLO: P-10-E-99] State that theoretically light can also be considered to be made of massless particles that carry energy and momentum called 'photons'. [Students should know as an example of this particle nature, light exerts pressure on objects (very		

<table>
<tr><td></td><td>slight) and this has been used by satellites that have 'solar sails' that accelerate with the help of force from light rays.]</td><td></td><td></td></tr>
<tr><td colspan="4">

Domain F: Modern Physics

This domain focuses on new fields of Physics that were developed in the 19th and 20th centuries. These include nuclear physics, relativity and quantum physics.</td></tr>
<tr><td colspan="4">Standard: Students will be able to:
- Describe the standard model of particle physics
- Analyze radioactive decay processes
- Explain the processes of nuclear fusion and fission
- Explain the postulates and implications of special relativity
- Use the quantum mechanical model of photons to explain phenomena</td></tr>
<tr><td colspan="2">Benchmark I: Describe and explain, with reference to broad qualitative ideas from relativity, quantum mechanics and particle physics:
(1) the structure of atoms and atomic nuclei
(2) the origin of radioactivity and its uses and hazards.</td><td colspan="2">Benchmark I: Explain and apply knowledge of the basic inter-related postulates of and discoveries from:
(1) the special theory of relativity
(2) the standard model of particle physics
(3) quantum theory
Benchmark II: Describe and explain, with reference to broad qualitative ideas from relativity, quantum mechanics and particle physics:
(1) the structure of atoms and atomic nuclei
(2) the origin of radioactivity and its uses and hazards.</td></tr>
<tr><td>N/A</td><td>[SLO: P-10-F-01]
Describe the structure of the atom

[in terms of a positively charged nucleus and negatively charged electrons that go around the nucleus. This should include an understanding of the below big ideas:

- These electrons do not go around in predictable circular paths in the</td><td>Relativity:
[SLO: P-11-F-01]
distinguish between inertial and non-inertial frames of reference.

[SLO: P-11-F-02]
describe the significance of Einstein's assumption of the constancy of the speed of light.

SLO: P-11-F-03]</td><td>Quantum Physics:

[SLO: P-12-F-01]
state that electromagnetic radiation has a particulate nature

[SLO: P-12-F-02]
Explain and apply the photonic model of light to solve problems

[use $E = hf$ to solve problems, and use the electronvolt (eV) as a unit</td></tr>
</table>

	way that planets go around the sun. The electrons behave as 'quantum particles' and their location and momentum at any point in time is governed by probability; one cannot predict the motion of an electron. - The 'shells' in which electrons 'orbit' refer to the level of kinetic energy the electrons possess; the further the shell is from the nucleus, the more energy the electron has. - If one were to 'look' at an atom, one would see a fuzzy 'cloud' of electrons with a very small nucleus in the center (akin to a football with flies around it in a boundary of several football fields).] [SLO: P-10-F-02] Justify the findings of the alpha-particle scattering experiments [Specifically that it provides evidence for: (a) a very small nucleus surrounded by mostly empty space (b) a nucleus containing most of the mass of the atom (c) a nucleus that is positively charged] [SLO: P-10-F-03] Define the terms proton number (atomic number) Z and nucleon number (mass number) A and be able to calculate the number of neutrons in a nucleus	Describe that if c is constant then space and time become relative. [SLO: P-11-F-04] State the postulates of Special relativity [SLO: P-11-F-05] Explain qualitatively and quantitatively the consequences of special relativity [Specifically in the case of: a– the relativity of simultaneity. b– the equivalence between mass and energy. c– length contraction. d– time dilation. e– mass increase] [SLO: P-11-F-06] State that spacetime is a mathematical model in relativity that treats time as a fourth dimension of the traditional three dimensions of space (It can be thought of as a metaphorical sheet of paper that can bend, and when it bends it can cause effects such as stretching and compression seen when gravitational waves pass through objects.) **Particle Physics:**	of energy] [SLO: P-12-F-05] Explain that a photon has momentum [including that the momentum is given by $p = E/c$(connect with the idea that light can exert a force)] [SLO: P-12-F-06] describe that photoelectrons may be emitted from a metal surface when it is illuminated by electromagnetic radiation [SLO: P-12-F-07] describe and use the terms threshold frequency and threshold wavelength [SLO: P-12-F-08] explain photoelectric emission in terms of photon energy and work function energy [SLO: P-12-F-09] state and apply$hf = \Phi + \frac{1}{2}mv_{max}{}^2$ [SLO: P-12-F-10] explain why the maximum kinetic energy of photoelectrons is independent of intensity, whereas the photoelectric current is proportional to intensity [SLO: P-12-F-11] Juxtapose the evidence for light as

	[SLO: P-10-F-04] Recall the term nuclide and use the nuclide notation ${}^{A}_{Z}X$ [SLO: P-10-F-05] Explain what is meant by an isotope and state that an element may have more than one isotope [SLO: P-10-F-06] Explain what is meant by background radiation [SLO: P-10-F-07] state the sources that make a significant contribution to background radiation [including: (a) radon gas (in the air) (b) rocks and buildings (c) food and drink (d) cosmic rays] [SLO: P-10-F-08] Describe the emission of radiation from a nucleus as spontaneous and random [SLO: P-10-F-09] Describe α-particles, β-particles and γ-radiation [SLO: P-10-F-10] Justify qualitatively the order of strength for α-particles, β-particles	[SLO: P-11-F-07] state that nucleon number and charge are conserved in nuclear processes [SLO: P-11-F-08] describe the composition, mass and charge of α-, β- and γ-radiations [both β– (electrons) and β+ (positrons) are included] [SLO: P-11-F-09] Explain that an antiparticle has the same mass but opposite charge to the corresponding particle [give the example that a positron is the antiparticle of an electron] [SLO: P-11-F-10] state that (electron) antineutrinos are produced during β–decay and (electron) neutrinos are produced during β+ decay [SLO: P-11-F-11] Explain that α-particles have discrete energies but that β-particles have a continuous range of energies because (anti)neutrinos are emitted in β-decay [SLO: P-11-F-12] Describe quarks and anitquarks (as a fundamental	a wave and as a particle [Explain that the photoelectric effect provides evidence for a particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for a wave nature] [SLO: P-12-F-12] Analyze qualitatively the evidence provided by electron diffraction for the wave nature of particles [SLO: P-12-F-13] Explain and apply the de Broglie wavelength to solve problems [use $\lambda = h/p$ to solve problems] [SLO: P-12-F-14] State that there are discrete electron energy levels in isolated atoms (e.g. atomic hydrogen) [SLO: P-12-F-15] explain the appearance and formation of emission and absorption line spectra [SLO: P-12-F-16] use $hf = \Delta E$ to solve problems [SLO: P-12-F-17] Describe the Compton effect qualitatively.

	and γ-radiation in terms of their (a) their relative ionizing effects (b) their relative penetrating powers [SLO: P-10-F-11] Describe the deflection of α-particles, β-particles and γ-radiation in electric fields and magnetic fields [SLO: P-10-F-12] Explain that radioactive decay is a change in an unstable nucleus that can result, most commonly [there are other kinds of decay as well but students are not required to study those at this level), in the emission of α-particles or β-particles and/or γ-radiation] [SLO: P-10-F-13] Use decay equations, using nuclide notation, to show the emission of α-particles, β-particles and γ-radiation [SLO: P-10-F-14] Describe nuclear reactions (fission & fusion) with examples [fusion as the formation of a larger nucleus by combining two smaller nuclei with the release of energy, and recognise fusion as the energy source for stars] [SLO: P-10-F-14] Recognise that matter can be	[including that there are six flavors (types) of quark: up, down, strange, charm, top and bottom] [SLO: P-11-F-13] describe protons and neutrons in terms of their quark composition [SLO: P-11-F-14] state that a hadron may be either a baryon (consisting of three quarks) or a meson (consisting of one quark and an antiquark) [SLO: P-11-F-15] describe the changes to quark composition that take place during β– and β+ decay [SLO: P-11-F-16] state that electrons and neutrinos are fundamental particles called leptons [SLO: P-11-F-17] State, W, Z, gluon, and photons as fundamental particles called exchange particles or force carriers [SLO: P-11-F-18] State the Higgs Boson as a fundamental particle which is	[SLO: P-12-F-18] Explain the phenomena of pair production and pair annihilation. [SLO: P-12-F-19] Explain how electron microscopes achieve very high resolution. [SLO: P-12-F-20] State and explain Heisenberg's uncertainty principle qualitatively [SLO: P-12-F-21] Use the uncertainty principle to explain why empirical measurements must necessarily have uncertainty in them Particle Physics: [SLO: P-12-F-22] Recognize the equivalence between energy and mass as represented by $E = \Delta m\, c^2$ and state and use this equation [SLO: P-12-F-23] define and use the terms mass defect and binding energy [SLO: P-12-F-24] sketch the variation of binding energy per nucleon with nucleon

	converted to energy and vice versa (in this way the law of conservation of energy still holds). [SLO: P-10-F-15] Apply the equation $E = mc^2$ to calculate the energy released in the process of nuclear reactions. [SLO: P-10-F-16] Describe the activity of a radioactive material in terms of counts per unit time [SLO: P-10-F-17] Define and infer the half-life of materials [Half life as the time taken for half the nuclei of an isotope in any sample to decay. Use this definition of half-life in calculations, which may involve information in tables or decay curves] [SLO: P-10-F-18] Explain and apply the concept of Carbon dating to solve problems [SLO: P-10-F-19] Explain how the type of radiation emitted and the half-life of the isotope determine which isotope is used for applications	responsible for the particle's mass. [SLO: P-11-F-19] Explain that every subatomic particle has a corresponding antiparticle [that has the same mass as a given particle but opposite electric or magnetic properties according to the Standard Model of Particle Physics)] [SLO: P-11-F-20] describe protons and neutrons in terms of their quark composition [SLO: P-11-F-21] state that a hadron may be either a baryon (consisting of three quarks) or a meson (consisting of one quark and an antiquark) [SLO: P-11-F-22] Explain that there are various contending theories about what 'mass' and 'force' are generated from [e.g. that these are generated from quantum fields when they are energized, or from multidimensional	number [SLO: P-12-F-25] Recall what is meant by nuclear fusion and nuclear fission [SLO: P-12-F-26] Explain the relevance of binding energy per nucleon to nuclear reactions, including nuclear fusion and nuclear fission [SLO: P-09-F-26] Explain how the neutrons produced in fission create a chain reaction and that this is controlled in a nuclear reactor [including the action of coolant, moderators and control rods] [SLO: P-12-F-27] calculate the energy released in nuclear reactions using $E = \Delta m/c^2$ [SLO: P-12-F-28] Explain that fluctuations in count rate provide evidence for the random nature of radioactive decay [SLO: P-12-F-29] explain that radioactive decay is both spontaneous and random [SLO: P-12-F-30] define activity and decay constant,

	[including: (a) household fire (smoke) alarms (b) irradiating food to kill bacteria (c) sterilization of equipment using gamma rays (d) measuring and controlling thicknesses of materials with the choice of radiations used linked to penetration and absorption (e) diagnosis and treatment of cancer using gamma rays] [SLO: P-10-F-20] State the effects of ionizing nuclear radiations on living things, including cell death, mutations and cancer [SLO: P-10-F-21] Explain how radioactive materials are moved, used and stored in a safe way [(with reference to: (a) reducing exposure time (b) increasing distance between source and living tissue (c) use of shielding to absorb radiation]	'strings' that vibrate in higher dimensions to give rise to particles (no further technical knowledge beyond these simple descriptions is expected at this level)] [SLO: P-11-F-23] Explain the working principle of particle accelerators and also their uses. [SLO: P-11-F-24] Explain that antimatter is the counterpart of matter [e.g. a positron is the antimatter counterpart to an electron] [SLO: P-11-F-25] Illustrate that antiparticles usually have the same weight, but opposite charge, compared to their matter counterparts [SLO: P-11-F-26] State that most of the matter in the observable universe is matter [SLO: P-11-F-27] Describe the asymmetry of matter and antimatter in the universe as an unsolved mystery [SLO: P-11-F-28] Describe annihilation reactions [a particle meets its corresponding antiparticle, they undergo	and state and use $A = \lambda N$ [SLO: P-12-F-31] Explain half-life with examples [SLO: P-12-F-32] use λ = 0.693/t21 to solve numerical problems [SLO: P-12-F-33] state the exponential nature of radioactive decay [SLO: P-12-F-34] use the relationship $x = x_0 e^{\lambda t}$ [where x could represent activity, number of undecayed nuclei or received count rate) to solve problems analytically and graphically] [SLO: P-12-F-35] describe the function of the principle components of a water moderated power reactor [core, fuel, rods, moderator, control rods, heat exchange, safety rods and shielding] [SLO: P-12-F-36] explain why uranium fuel needs to be enriched before use [SLO: P-12-F-37] compare the amount of energy released in a fission reaction with

		annihilation reactions in which either all the mass is converted to heat and light energy, or some mass is left over in the form of new subatomic particles.]	the (given) energy released in a chemical reaction. [SLO: P-12-F-38] Explain what is a medical tracer [a substance containing radioactive nuclei that can be introduced into the body and is then absorbed by the tissue being studied] [SLO: P-12-F-39] Explain annihilation reactions [they occur when a particle interacts with its antiparticle and that mass–energy and momentum are conserved in the process] [SLO: P-12-F-40] Illustrate how PET scanning works [positrons emitted by the decay of the tracer annihilate when they interact with electrons in the tissue, producing a pair of gamma-ray photons traveling in opposite directions] [SLO: P-12-F-41] calculate the energy of the gamma-ray photons emitted during the annihilation of an electron-positron pair [SLO: P-12-F-42] Explain that the gamma-ray

			photons from an annihilation event travel outside the body and can be detected [including that an image of the tracer concentration in the tissue can be created by processing the arrival times of the gamma-ray photons]
[SLO: P-09-F-01] Define and calculate average orbital speed [from the equation v = 2π r/T where r is the average radius of the orbit and T is the orbital period; apply this equation to solve numerical problems] [SLO: P-09-F-02] Interpret and compare given planetary data [about orbital distance, orbital period, density, surface temperature and uniform gravitational field strength at the planet's surface]	[SLO: P-10-F-22] Explain the nature of the Sun [as a star of medium size it consists mostly of hydrogen and helium, and that it radiates most of its energy in the infrared, visible and ultraviolet regions of the electromagnetic spectrum] [SLO: P-10-F-23] Describe that it is hypothesized that most of the matter in the universe is made up of dark matter	N/A	[SLO: P-12-F-43] Explain the term luminosity [as the total power of radiation emitted by a star] [SLO: P-12-F-44] Apply the inverse square law for radiant flux intensity [F in terms of the luminosity L of the source $F = \frac{L}{4\pi d^2}$] [SLO: P-12-F-45] Define and apply standard candles [Explain the use of standard candles to determine distances to galaxies] [SLO: P-12-F-46] Explain blackbody radiation and apply Wien's displacement law to solve problems [$\lambda_{max} T = constant$ to estimate the peak surface temperature of a star]

			[SLO: P-12-F-47] Apply the Stefan–Boltzmann law to solve problems [L = $4\pi r^2 \times \sigma T^4$ to solve problems] [SLO: P-12-F-48] estimate the radius of a star [applying Wien's displacement law and the Stefan–Boltzmann law] [SLO: P-12-F-49] Explain that the lines in the emission and absorption spectra from distant objects show an increase in wavelength from their known values [SLO: P-12-F-50] explain why redshift leads to the idea that the Universe is expanding [include using $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$ for the redshift of electromagnetic radiation from a source moving relative to an observer to solve problems relating to the expanding universe] [SLO: P-12-F-51] State and explain Hubble's law and how it leads to the Big Bang theory
N/A	[SLO: P-10-F-23]	N/A	Conceptual:

	Use ideas of convection to explain how cyclones are formed [SLO: P-10-F-24] Explain how global warming contributes to extreme weather events [specifically in the case of hurricanes, heat waves, flooding, rainfall, wildfires, droughts, winter storms] [SLO: P-10-F-25] Explain the phenomena of geothermal activity on the basis of conduction, convection and radiation [how magma flows beneath the Earth, why it causes tectonic plate movement, volcanic eruptions and how the center of the Earth remains hot since being formed over 4 billion years ago]		[SLO: P-12-F-52] Describe Earth's climate system as a complex system having five interacting components [the atmosphere (air), the hydrosphere (water), the cryosphere (ice and permafrost), the lithosphere (earth's upper rocky layer) and the biosphere (living things).] [SLO: P-12-F-53] Relate ocean currents and wind patterns to the climate system [as the statistical characterization of the climate system, representing the average weather, typically over a period of 30 years, and is determined by a combination of processes in the climate system, such as ocean currents and wind patterns.] [SLO: P-12-F-54] Explain climate inertia [as the phenomenon by which climate systems show resistance or slowness to changes in significant factors e.g. stabilization of greenhouse emissions might show a slow response due to the action of complex feedback systems] [SLO: P-12-F-55]

			Explain that climate change can be categorized into internal variations and external forcings: [SLO: P-12-F-56] Explain how global climate is determined by energy transfer from the Sun [with specific reference to the below factors and terms: - state and use the term Earth energy budget - Explain how the energy imbalance between the poles and the equator can affect atmospheric circulation] [SLO: P-12-F-57] Explain that due to the conservation of angular momentum, the Earth's rotation diverts the air to the right in the Northern Hemisphere and to the left in the Southern hemisphere, thus forming distinct atmospheric cells. [SLO: P-12-F-58] Explain that ocean water that has more salt has a higher density and differences in density play an important role in ocean circulation.

			[SLO: P-12-F-59] Explain how the thermohaline circulation transports heat from the tropics to the polar regions. [SLO: P-12-F-60] Explain how climate science is a an example of a chaotic system, [using the metaphor of a butterfly's wing flaps may cause hurricanes in another part of the world, mathematics of chaos theory are not required; just the idea that with very complex systems it is very difficult to predict outcomes and they are very sensitive to initial conditions]
N/A		N/A	[SLO: P-12-F-61] Explain that piezo-electric effect and its application in medical science [ultrasound waves are generated and detected by a piezoelectric transducer] [SLO: P-12-F-62] Explain how ultrasound can be used to obtain diagnostic information about internal body structures

			[SLO: P-12-F-63] Explain that X-rays are produced by electron bombardment of a metal target and calculate the minimum wavelength of X-rays produced from the accelerating p.d. [SLO: P-12-F-64] Explain the use of X-rays in imaging internal body structures [including an describing of the term contrast in X-ray imaging] [SLO: P-12-F-65] Explain how computed tomography (CT) scanning works [it produces a 3D image of an internal structure by first combining multiple X-ray images taken in the same section from different angles to obtain a 2D image of the section, then repeating this process along an axis and combining 2D images of multiple sections]

Domain G: Nature of Science

This field studies science's underlying assumptions, and its methodologies. This involves some integrated study of the history, philosophy and sociology of science.

Note: In the Nature of Science domain SLOs, unless explicitly stated, where the SLO begins with the phrase 'explain with examples' it is enough that students study 2-3 examples and can use them in their answers for examination questions. There is no need to extensively or comprehensively study the history of science or its applications in other fields. The purpose here is that students are able to develop an appreciation of these aspects of the field of physics with some rigor (hence these SLOs are expected to be assessed), but not to become so extensive that it take a lot of time out from building competence in rest of the domains on physics skills and knowledge. Assessment of Nature of Science in standardized board exams will be kept to objective knowledge; students will not be expected to write argumentative essays or express subjective perspectives. Rather assessment in the standardized exams will occur through multiple choice questions and/or through short answer questions that require two-three sentence responses. Sample questions are provided in the Curriculum Guidelines. In their regular classroom study, teachers *are* encouraged to teach these topics through learner-centered activities that promote curiosity, inquiry, creativity, critical discussion and collaboration.

Standard: Students should be able explain with examples that science operates in a historical context that affects its current practices and paradigms			
Benchmark I: Critically analyze claims made about the relationship of physics with society		N/A	
[SLO: P-09-G-01] Describe physics as the study of matter, energy, space, time and their mutual connections and interactions [SLO: P-09-G-02] Explain with examples that physics has many sub-fields, and in today's world involves interdisciplinary fields. (Students should be able to distinguish in terms of the broad subject matter that is studied between the fields: Biophysics Astronomy Astrophysics Cosmology Thermal Physics			N/A

Optics Classical Mechanics Quantum Mechanics Relativistic Mechanics Nuclear Physics Particle Physics, Electromagnetism Acoustics Computational Physics Geophysics Climate Physics [SLO: P-09-G-03] Explain with examples how Physics is a subset of the Physical Sciences and of the natural sciences [SLO: P-09-G-04] State that scientists who specialize in the research of physics are called Physicists [SLO: P-09-G-05] Brief with examples that science is a collaborative field that requires interdisciplinary researchers working together to share knowledge and critique ideas [SLO: P-09-G-06] Understand the terms 'hypothesis', 'theory' and 'law' in the context of research in the physics SLO: P-09-G-07] Explain, with examples in Physics,			

falsifiability as the idea that a theory is scientific only if it makes assertions that can be disproven [SLO: P-09-G-08] Differentiate the terms 'science', 'technology' and 'engineering' with suitable examples			
Standard: Students should be able to explain, with examples, what philosophical assumptions underpin the practice of science			
Benchmark I: Students should able to: - identify common sources of argumentative fallacies - explain the broad schools of thought about the relationship between physics and metaphysics - give examples of ethical dilemmas that emerge from research and practice of science - explain the broad schools of thought about how science is distinguished from other fields of inquiry		Benchmark I: Students should be able to: - explain the broad schools of thought in debates about the role of beauty in science - explain how paradoxes and thought experiments help physicists in scientific inquiry - explain the broad debates about whether it is ethical to continue research in outer space and of subatomic particles	
	Theory of Knowledge in Physics: [SLO: P-10-G-01] Explain, with examples in Physics, falsifiability as the idea that a theory is scientific only if it makes assertions that can be disproven		Debates about Beauty in Physics: [SLO: P-12-G-01] Explain, with examples, what do thinkers who hold the view that there is inherent mathematical beauty in the natural world mean by: (i) elegance of simplicity (ii) symmetry [SLO: P-12-G-02] Explain, with an example, a counterargument to the claim that physical truths must be inherently

			mathematically elegant or display symmetry Debates: [SLO: P-12-G-03] Describe the main pros and cons in the debate about: (i) whether humans should research whether there are aliens somewhere in the universe (ii) whether research should continue on uncovering the secrets of subatomic particles, given the advent of nuclear weapons **Thought experiments** [SLO: P-11-G-04] Explain how the below thought experiments helped convey important physics concepts that would have been impractical to investigate empirically: (i) Newton's cannonball

Experimentation Skills Progression Grid

Guidance for the Reader

Guidance on Practical Work Expectations: For the sciences, there is no compulsory list of practical experiments that students have to conduct during their studies. Students *are* still expected to do extensive practical work (ideally two lessons in the lab per week), but the purpose of the lab work is to build their critical thinking, experiment designing, data collection and analysis skills. In their board exams, they will *not* be expected to reproduce a memorized practical that they have already studied in their classes. In Grade 10 board exams they are expected to conduct experiments (with apparatus and on broad topics that they have studied) as per the instructions they will be provided, and then analyze the data collected and then critique the experimental methodology followed. A more advanced version of this practical exam is also expected to be conducted in Grade 11 board exams. In Grade 12 they are expected to be able to rigorously design experiments of their own to test provided hypotheses (on broad topics that they have studied).

Grade-Wise Progression of Skills: This progression grid is about building skills. Grades 9-10 have the same skills listed, because the idea is to reinforce them through the practical work they will do associated with the topics they are studying. For example, in Grade 9 students may learn about kinematics and conduct practical work to investigate the acceleration of a ball down an inclined plane. In this experiment they would learn experimental design, data collection and analysis skills. Similarly in Grade 10 they may learn about thermodynamics and investigate the heat capacity of materials. Here again they would be building experimental design, data collection and analysis skills; just with a different topic. In contrast, Grade 11 and 12 have their skills learning outcomes separately listed. This is because in Grade 11, compared with Grade 10, the empirical research skills expected are more advanced. In Grade 12, there is a much stronger emphasis on learning how to design experiments to investigate given hypotheses, and these skills are hence listed in more detail at this level. Further guidance for educators on how to conduct lab classes keeping in mind this vision is provided in the Curriculum Guidelines.

Organization of the SLOs in the Progression Grid: Inside a grade, teachers are free to teach the content in any order of preference. Textbook publishers are also free to organize the contents of their books in any manner that they consider most effective, as long as all the SLOs in the Progression Grid and Cross-Cutting themes are covered. The SLOs inside a grade do not need to be taught in the order presented in a grade in this PG.

Grades 9-10	Grade 11	Grade 12
Domain H: Experimentation Skills These cover the skills that are necessary for describing how to design and practically conduct physics experiments. These skills are not meant to be applied not only in the science lab, but as skills of critical analysis for describing empirical data as well.		
Standard: Students should be able to demonstrate knowledge of how to select and safely use techniques, apparatus and materials		
Benchmark I: Students should be able to follow provided safety instructions and take general precautions in a lab setting	Benchmark I: Students should be able to identify and take the safety measures required to conduct experiments	Benchmark I: Students should be able to design safe experiments
[SLO: P-09-10-N-01] - explain, with examples, how hazards in a science lab can be classified into: ((i) physical hazards, (ii) chemical hazards, (iii) biological hazards, (v) safety hazards) [SLO: P-09-10-N-02] - identify for a given experimental procedure what would be the most appropriate personal protective equipment to wear before setting up the apparatus [SLO:P-09-10-N-03] - Identify the meaning of common hazard signs in the laboratory [SLO: P-09-10-N-04] - call emergency services in case of an accident in the lab	[SLO: P-11-N-01] - test that the lab equipment is functioning properly, without any potential risk of injury, before conducting an experiment [SLO: P-11-N-02] - ensure that work space for conducting the experiment is not too crowded with apparatus as to be hazardous [SLO: P-11-N-03] - ensure that safe distance is kept at all times from other investigators who may be handling lab apparatus [SLO: P-11-N-04] - suggest broadly what potential bodily harm could occur from physical, chemical, biological and safety hazards in the context of the experiment being conducted [SLO: P-11-N-05] - State that it is always better to ask for help	[SLO: P-12-N-01] - develop and justify safety guidelines for a proposed procedure, that also outline the overall risks of the experiment, keeping in mind: ((i) the apparatus, (ii) the surrounding environment, (iii) need for personal protective equipment)

	from the lab instructor when unsure of how to use new apparatus	
Standard: Students should be able to plan experiments and investigations		
Benchmark I: Create an outline of how to conduct an experiment to compare a given dependent variable and independent variable	N/A	Benchmark I: Create an outline of a complete experimental design for a formulated hypothesis

[SLO: P-09-10-N-05] Define and use the below terms: - True value: the value that would be obtained in an ideal measurement - Measurement error: the difference between a measured value and the true value of a quantity - Accuracy: a measurement result is described as accurate if it is close to the true value - Precision: how close the measured values of a quantity are to each other - Repeatability: a measurement is repeatable if the same or similar result is obtained when the measurement is repeated under the same conditions, using the same method, within the same experiment - Reproducibility: a measurement is reproducible if the same or similar result is obtained when the measurement is made under either different conditions or by a different method or in a different experiment - Validity of experimental design: an experiment is valid if the experiment tests what it says it will test. The experiment must be a fair test where only the independent variable and dependent variable may change, and controlled variables are kept constant - Range: the maximum and minimum value of the independent or dependent variables - Anomaly: an anomaly is a value in a set of results that appears to be outside the general pattern of the results, i.e. an extreme value that is either very high or very low in comparison to others	N/A	[SLO: P-12-N-02] Formulate a testable hypothesis by: • identifying the independent variable in the experiment • identifying the dependent variable in the experiment • identifying the variables that are to be kept constant. [SLO: P-12-N-03] Explain the methods of data collection by: a• describing the method to be used to vary the independent variable b• describing how the independent and dependent variables are to be measured c• describing how other variables are to be kept constant d• describing, with the aid of a clear labeled diagram, the arrangement of apparatus for the experiment and the procedures to be followed. [SLO: P-12-N-04] Explain the methods of data analysis by: a• describing how the data should be used in order to reach a conclusion, including details of derived quantities to be calculated from graphs. [SLO: P-12-N-05] Suggest how technology can be used to digitize data collection by describing as appropriate: a• the use of an oscilloscope (or storage oscilloscope) to measure voltage, current, time and frequency b• how to use light gates connected to a data logger to determine time, velocity and

- Independent variables: independent variables are the variables that are changed in a scientific experiment by the scientist. Changing an independent variable may cause a change in the dependent variable - Dependent variables: dependent variables are the variables that are observed or measured in a scientific experiment. Dependent variables may change based on changes made to the independent variables [SLO: P-09-10-N-06] identify appropriate apparatus for collecting the data [SLO: P-09-10-N-07] visualize how the collected data would be tabulated or graphed [SLO: P-09-10-N-08] - explain step by step the methodology for analyzing the data (e.g. gradient of line of best fit, plugging average value of dependent variable into a formula etc.) [SLO: P-09-10-N-09] suggest how sources of human and systematic error could be mitigated		acceleration c• how other sensors can be used with a data logger, e.g. motion sensor.
Standard: Students should be able to make and record observations, measurements and estimates		
Benchmark I: Collect data under instructor supervision while minimizing sources of random and systematic error	Benchmark I: Collect data without supervision while minimizing sources of random and systematic error	N/A

[SLO: P-09-10-N-10] - set up experimental apparatus under supervision from an instructor [SLO: P-09-10-N-11] take steps to avoid parallax error [SLO: P-09-10-N-12] identify and correct for potential zero error [SLO: P-09-10-N-13] take an appropriate number of readings to average out errors [SLO: P-09-10-N-14] take correct meniscus readings [SLO: P-09-10-N-15] record sources of potential error (e.g. lack of lighting due to power outage) [SLO: P-09-10-N-16] take steps to avoid systematic error in specific context of the experiment e.g. ensuring that the table the set-up in on is level [SLO: P-09-10-N-17] make measurements using common laboratory apparatus, such as millimetre scales, protractors, top-pan balances, newton meters, analogue or digital electrical meters, measuring cylinders, vernier calipers, micrometer screw gauges and thermometers [SLO: P-09-10-N-18] use a stop-watch to measure intervals of time, including the period of an oscillating system by timing an appropriate number of consecutive oscillations [SLO: P-09-10-N-19] use both analogue scales and digital displays.	[SLO: P-11-N-06] set up apparatus correctly without assistance from a supervisor [SLO: P-11-N-07] follow instructions given in the form of written instructions and diagrams (including circuit diagrams) [SLO: P-11-N-08] use apparatus to collect an appropriate quantity of data [SLO: P-11-N-09] repeat readings where appropriate [SLO: P-11-N-10] make measurements that span the largest possible range of values within the limits either of the equipment provided or of the instructions given.	N/A

Be familiar with the following experimental contexts: [SLO: P-09-10-N-20] measurement of physical quantities such as length, volume or force [SLO: P-09-10-N-21] measurement of small distances or short intervals of time [SLO: P-09-10-N-22] determining a derived quantity such as the extension per unit load for a spring, the value of a known resistance or the acceleration of an object [SLO: P-09-10-N-23] testing and identifying the relationship between two variables such as between the potential difference across a wire and its length [SLO: P-09-10-N-24] comparing measured quantities such as angles of reflection [SLO: P-09-10-N-25] comparing derived quantities such as density [SLO: P-09-10-N-26] cooling and heating, including measurement of temperature [SLO: P-09-10-N-27] experiments using springs and balances [SLO: P-09-10-N-28] timing motion or oscillations [SLO: P-09-10-N-29] electric circuits, including the connection and reconnection of these circuits, and the measurement of current and potential difference [SLO: P-09-10-N-30]		

optics experiments using equipment such as optics pins, mirrors, prisms, lenses, glass or Perspex blocks (both rectangular and semi-circular), including the use of transparent, translucent and opaque substances to investigate the transmission of light [SLO:P-09-10-N-31] procedures using simple apparatus, in situations where the method may not be familiar to the candidate.		
Benchmark II: Tabulate and graph data appropriately	Benchmark II: Tabulate and graph data appropriately, including use of false origins	Benchmark II: Tabulate and graph data appropriately, including use of false origins and tabulating uncertainty estimates
Use the below good practices in tabulating data: [SLO: P-09-10-N-32] Record measured and calculated quantities with correct units accompanying them [SLO: P-09-10-N-33] Organise tabulated results with the following elements present: the heading of each column, the name or symbol of the measured or calculated quantity, together with the appropriate unit. Use the below good practices in drawing graphs: [SLO: P-09-10-N-34] Label axes with quantities and units [SLO: P-09-10-N-35] Use scales for the axes that allow the majority of the graph paper to be used in both directions, and be based on sensible ratios, e.g. 2cm on the graph paper representing 1, 2 or 5 units of the variable (or 10, 20 or 50, etc.).	[SLO: P-11-N-11] use a false origin where appropriate while plotting graphs	[SLO: P-12-N-06] show uncertainty estimates, in absolute terms, beside every value in a table of results

[SLO: P-09-10-N-36] Plot data points to an accuracy of better than one half of one of the smallest squares on the grid. [SLO: P-09-10-N-37] Plot data points using small crosses or fine dots with a circles drawn around them.		
Benchmark III: Estimate data collected to an appropriate number of significant figures and decimal points	Benchmark III: Estimate data collected to an appropriate number of significant figures and with the uncertainty quoted	Benchmark III: Estimate data collected to an appropriate number of significant figures, with the uncertainty quoted and express graphically with error bars and lines of best and worst fit
[SLO: P-09-10-N-38] Use measuring instruments to their full precision [SLO: P-09-10-N-39] Estimate the number of significant figures for calculated quantities as being the same as the least number of significant figures in the raw data used.	[SLO: P-11-N-12] estimate the absolute uncertainty in measurements [SLO: P-11-N-13] express the uncertainty in a measurement as an absolute or percentage uncertainty, and translate between these forms [SLO: P-11-N-14] express the absolute uncertainty in a repeated measurement as half the range of the repeated readings, where this is appropriate.	[SLO: P-12-N-07] show error bars, in both directions where appropriate, for each point on the graph [SLO: P-12-N-08] draw a straight line of best fit and a worst acceptable straight line through the points on the graph.
Standard: Students should be able to interpret and evaluate experimental observations and data		
Benchmark I: Analyse plotted linear graphs and tables	Benchmark I: Analyze tabular data, plotted linear and polynomial graphs for how well they fit with the hypothesized theoretical relationship the studied variables by considering the calculated values obtained and their corresponding percentage uncertainty	Benchmark I: Analyse tabular data, plotted linear, polynomial, exponential and logarithmic graphs for how well they fit with the hypothesized theoretical relationship the studied variables by considering the calculated values obtained and their corresponding percentage and absolute uncertainty
[SLO: P-09-10-N-40] Show clear working in calculations, and key steps in reasoning	[SLO: P-11-N-15] draw straight lines of best fit or curves to show the trend of a graph	[SLO: P-12-N-09] rearrange expressions into the forms y = mx + c, y = axn and y = aekx

[SLO: P-09-10-N-41] Express calculated ratios as decimal numbers, of two or three significant figures. [SLO: P-09-10-N-42] Sketch lines of best fit with an equal number of points on either side of the line over its entire length (the points should not be seen to lie all above the line at one end, and all below the line at the other end) [SLO: P-09-10-N-43] Convey the calculations for the gradient of a straight line by using a triangle whose hypotenuse extends over at least half the length of the plotted graph line. [SLO: P-09-10-N-44] Determine the intercept of a straight line graph [SLO: P-09-10-N-45] Take readings from graphs by extrapolation or interpolation	[SLO: P-11-N-16] draw tangents to curved trend lines and determine the gradient of a straight-line graph or of a tangent to a curve [SLO: P-11-N-17] relate straight-line graphs to equations of the form y = mx + c, and derive expressions that equate to the gradient and/or the y-intercept of their graphs [SLO: P-110-N-18] read the coordinates of points on the trend line of a graph [SLO: P-11-N-19] [SLO: P-11-N-20] determine the y-intercept of a straight-line graph or of a tangent to a curve, including where these are on graphs with a false origin. [SLO: P-11-N-21] draw conclusions from an experiment, including determining the values of constants [SLO: P-11-N-22] explain whether experimental data supports a given hypothesis and make predictions based on the data [SLO: P-11-N-23] determine whether a relationship containing a constant is supported by experimental data [SLO: P-11-N-24] for results of an experiment: (i) calculate the percentage difference between values of the constant (ii) compare this percentage difference with a pre-given percentage uncertainty	[SLO: P-12-N-10] describe how a graph of y against x is used to find the constants m and c in an equation of the form y = mx + c [SLO: P-12-N-11] describe how a graph of log y against log x is used to find the constants a and n in an equation of the form $y = ax^n$ [SLO: P-12-N-12] describe how a graph of ln y against x is used to find the constants a and k in an equation of the form $y = ae^{kx}$ [SLO: P-12-N-13] decide what derived quantities to calculate from raw data in order to enable an appropriate graph to be plotted. [SLO: P-12-N-14] convert absolute uncertainty estimates into fractional or percentage uncertainty estimates and vice versa [SLO: P-12-N-15] calculate uncertainty estimates in derived quantities [SLO: P-12-N-16] estimate the absolute uncertainty in the gradient of a graph by stating that absolute uncertainty = gradient of line of best fit – gradient of worst acceptable line [SLO: P-12-N-17] estimate the absolute uncertainty in the y-intercept of a graph by stating that absolute uncertainty = y-intercept of line of best fit – y-intercept of worst acceptable line

	(iii) give a conclusion based on this comparison.	[SLO: P-12-N-18] express a quantity as a value, an uncertainty estimate and a unit.
Standard: Students should be able to evaluate methods and suggest possible improvements		
Benchmark I: Evaluate and suggest improvements regarding whether an experimental design: - is valid and reliable - has sources of error that could be better mitigated - is safe to conduct	Benchmark I: Evaluate and suggest improvements regarding whether an experimental design could improve on the uncertainty in its conclusions	N/A
[SLO: P-09-10-N-46] Identify whether an experimental procedure has validity (whether the results really do represent what they are supposed to measure) regarding the hypothesis being tested, and suggest changes to ensure validity as appropriate [SLO: P-09-10-N-47] identify whether an experimental procedure is reliable (whether the results can be reproduced under the same conditions), and suggest changes to ensure reliability as appropriate [SLO: P-09-10-N-48] recommend how to mitigate sources of random and systematic error inherent in the given experimental design [SLO: P-09-10-N-49] identify unsafe procedure in an experimental design and suggest ways to mitigate any hazards	[SLO: P-11-N-25] •identify and describe the limitations in an experimental procedure [SLO: P-11-N-26] identify the most significant sources of uncertainty in an experiment. suggest modifications: [SLO: P-11-N-27] - an experimental arrangement that will improve the accuracy of the experiment or to extend the investigation to answer a new question [SLO: P-11-N-28] describe these modifications clearly in words or diagrams.	N/A

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