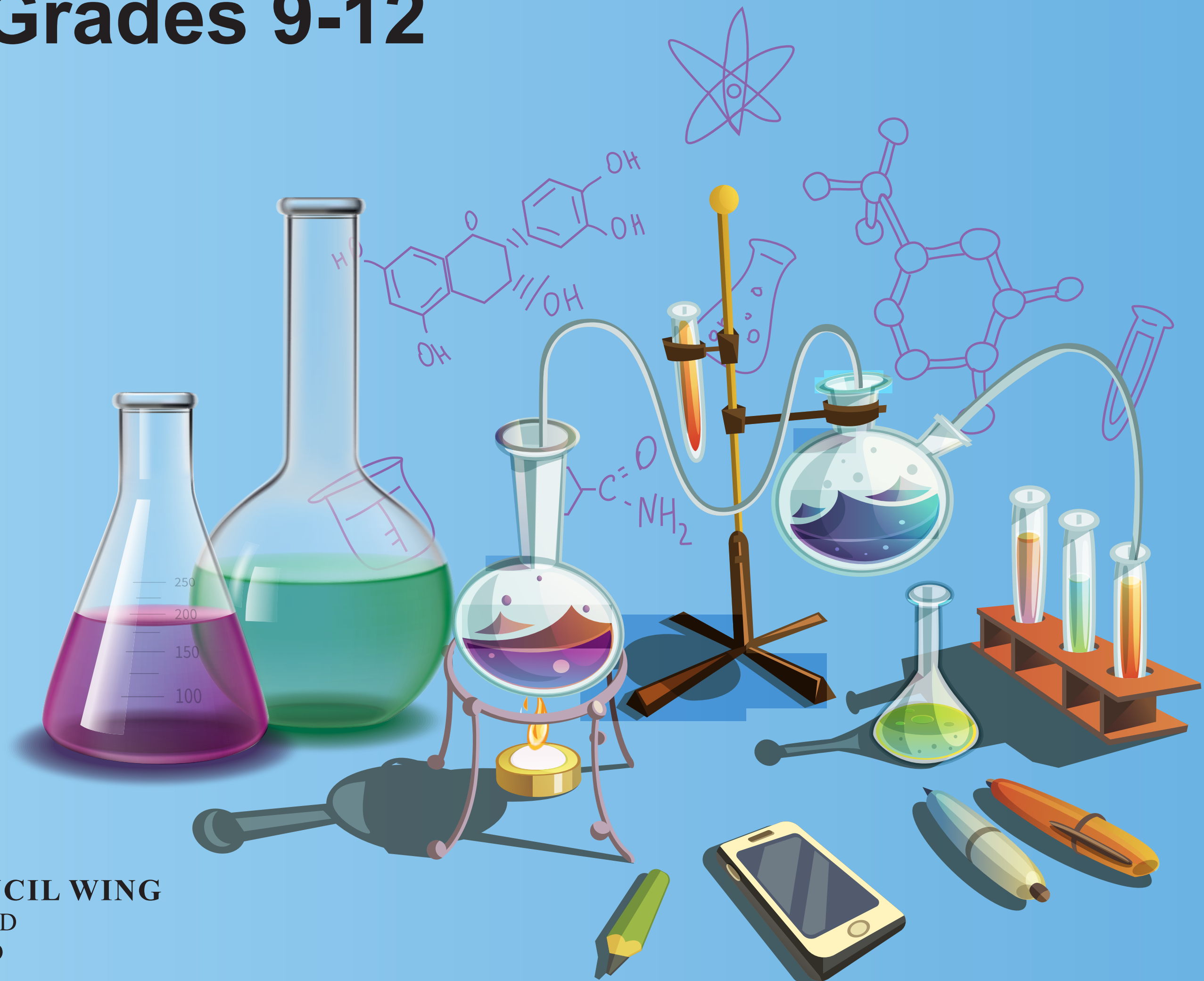
National Curriculum of Pakistan 2026

CHEMISTRY

Grades 9-12



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

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Acknowledgement

It is with great pride that the National Curriculum Council Wing, Ministry of Federal Education and Professional Training, presents the Rationalised National Curriculum 2026 for Chemistry (Grades IX–XII). Building on the National Curriculum 2022–23, this revision streamlines content to improve coherence, reduce unnecessary overlap, and strengthen conceptual understanding while aligning with national priorities and international standards.

Developed through a consultative, evidence-based process involving subject experts, universities, provincial education departments, textbook boards, assessment bodies, teacher education institutions, and practitioners, the curriculum promotes inquiry-based learning, scientific reasoning, practical application, and meaningful assessment.

The National Curriculum Council Wing sincerely acknowledges the invaluable contributions of all stakeholders whose expertise and commitment have made this rationalisation process possible. Their collective efforts have ensured a curriculum that is relevant, manageable, competency-based, and future-ready for the learners of Pakistan.

Dr. Tabassum Naz
Director
National Curriculum Council Wing
Ministry of Federal Education and Professional Training

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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 Chemistry 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. Put Scientific Method in cross cutting themes

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.	**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

	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. 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	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 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.

	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. **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.	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 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.

	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. 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., self generated, 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 trade off 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 & Engineering	**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 trade off 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 problem based 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 trade off 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**	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

	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. 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.	

Cross Cutting Theme

Grade 9	**Grade 10**	**Grade 11**	**Grade 12**
1. State that people who study chemistry are called chemists. 2. Justify, with examples, that civilizations throughout history have systematically studied living things (Some examples include: ● The ancient Egyptians experimented with metals, dyes, and medicines, while the ancient Greeks studied the properties of matter and proposed theories about composition. ● The Indus Valley Civilization developed advanced metallurgy and pottery techniques, and Ayurvedic medicine utilized chemical compounds. ● In China, alchemists experimented with chemical processes to create materials	1. Suggest, with examples, the impact of social and political factors on the recognition of scientific contributions, using historical examples. (for example: - historically the contributions of women to scientific research have not been highlighted) - the effects of racism, colonialism and elitism on who gets credit for work - the influence (private, public, national, international) of funding sources and lobbying)		

like porcelain, gunpowder, and paper, and discovered the principles of distillation and fermentation. ● During the Islamic Golden Age, scholars like Jabir ibn Hayyan conducted experiments with metals and acids, paving the way for the discovery of many chemical reactions and compounds.) 3. Illustrate, with examples from the physical sciences, that scientists often work in areas, or produce findings, that have significant ethical and political implications. (Some examples include: - These areas include development of chemical weapons, drug research, disposal of chemical waste practices, mining of rare earth metals, development of chemical products that may have unforeseen side effects like causing cancer - There are also questions involving intellectual property rights and the free exchange of information that			

may impact significantly on a society. - Science is undertaken in universities, commercial companies, government organizations, defense agencies and international organizations. Questions of patents and intellectual property rights arise when work is done in a protected environment. - Science has been used to solve many problems and improve humankind’s lot, but it has also been used in morally questionable ways and in ways that inadvertently caused problems. Advances in sanitation, clean water supplies and hygiene led to significant decreases in death rates but without compensating decreases in birth rates, this led to huge population increases with all the problems of resources, energy and food supplies that entails. - Ethical discussions, risk–benefit analyses, risk assessment and the precautionary principle are all parts of the scientific way of addressing the common good.)			

Theoretical Concepts Progression 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 A Guidance for the Reader: Nature of Science learning objectives have been added to the Progression Grids of Physics, Biology, Chemistry and Math. 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 student's 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 chemistry with some rigor (hence these SLOs are expected to be assessed), but not to become so extensive that it takes a lot of time out from building competence in rest of the domains on chemistry skills and knowledge.

Assessment Criterion for Domain A

Assessment of Nature of Science Domain A 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.

Grade 9	Grade 10	Grade 11		Grade 12
Domain A: Nature of Science in Chemistry				
Standard: Students will demonstrate an understanding, skill and attitude to deal in the areas of chemistry as an introduction to chemistry.				
Benchmark 1: Students will be able to explain and analyse major branches of Chemistry and their role in real life.			**N/A**	
Students will be able to **[SLO: C-09-A-01]** Define chemistry as the study of matter, its properties, composition, and interactions with other matter and energy. **(Knowledge)** **[SLO: C-09-A-02]** Explain with examples that chemistry has many sub-fields and interdisciplinary fields. (Some examples include: • Biochemistry • Medicinal Chemistry • Polymer Chemistry • Geochemistry • Environmental Chemistry • Analytical Chemistry • Physical Chemistry • Organic Chemistry • Inorganic Chemistry • Nuclear Chemistry **(Understanding)**			**N/A**	

[SLO: C-09-A-03] Compare different branches of Chemistry in terms of focus and key differences by providing two real life examples for each branch. **(Application)**				
Domain B: Physical Chemistry				
Standard: States of matter **Students should be able to: Investigate and explain the physical and chemical properties of matter, analyze how temperature and pressure influence changes of state, and apply gas laws to interpret and solve real-world phenomena and problems.**				
Benchmark 1: Students will explain the nature of matter, its composition including atoms, elements, and molecules.			**N/A**	
[SLO: C-09-B-01] Define matter. **(Knowledge)** **[SLO: C-09-B-02]** Differentiate macroscopic properties of commonly observed states of solids, liquids and gasses with reference to density, compressibility, and fluidity. **(Knowledge)** **[SLO: C-09-B-03]** Identify states of matter as distinct forms of matter, including common, intermediate, and exotic states such as plasma, liquid crystals, **(Knowledge)**				N/A

[SLO: C-09-B-04] Explain allotropic forms of elements (Diamond, Graphite, and Fullerenes) **(Understanding)** **[SLO: C-09-B-05]** Explain the differences between elements, compounds and mixtures **(Understanding)** **[SLO: C-09-B-06]** Identify solutions, colloids, and suspensions as types of mixtures and distinguish them by giving a clear example of each. **(Knowledge)** **[SLO: C-09-B-07]** Explain the effect of temperature on solubility and formation of unsaturated and saturated solutions **(Understanding)**				
Benchmark 2: Students will be able to understand states of matter and phase changes, and explain how temperature and pressure affect the behavior of matter.			**N/A**	
N/A	**[SLO: C-10-B-01]** State the assumptions of the kinetic molecular theory and explain phase changes melting, boiling, freezing, condensation, sublimation, and deposition in terms of particle behavior and energy changes. **(Understanding)**		N/A	N/A

	[SLO: C-10-B-02] Distinguish between evaporation and boiling. **(Understanding)** **[SLO: C-10-B-03]** Interpret heating and cooling curves in terms of kinetic theory **(Understanding)** **[SLO: C-10-B-04]** State Boyle's law, Charles' Law, and Avogadro's Law. **(Knowledge)** **[SLO: C-10-B-05]** Explain qualitative effect of external pressure on rate of boiling and evaporation **(Understanding)** **[SLO: C-10-B-06]** Explain diffusion of gases in terms of kinetic particle theory. **(Understanding)** **[SLO: C-10-B-07]** Examine qualitative the effect of molecular mass and temperature on the rate of diffusion **(Understanding)** **[SLO: C-10-B-08]** Explain, with the help of kinetic particle theory, the importance of rates of diffusion of medicines in the body **(Application)**			

Standard: Students will be able to describe atomic structure, atomic number, electronic arrangement, isotopes, and ion formation, and explain how these determine chemical properties.				
Benchmark 1: Students will be able to describe the structure of atoms, including the protons, neutrons, and electrons and using these concepts to discuss Isotopes.			**Benchmark 1: Students will be able to explain the arrangement of electrons in energy levels and orbitals, and relate atomic structure to the periodic properties of elements.**	
[SLO: C-09-B-08] Explain the structure of an atom as a central nucleus containing neutrons and protons surrounded by electrons. **(Understanding)** **[SLO: C-09-B-09]** State that electron shells (orbits) are discrete energy levels, where higher shells have greater energy and the electrons are, on average, farther from the nucleus. **(Knowledge)** **[SLO: C-09-B-10]** Explain that a nucleus is made up of protons and neutrons, held together by strong nuclear force **(Understanding)**	N/A		**[SLO: C-11-B-01]** Describe that each atomic shell and subshell is divided into degenerate orbitals, which have the same energy within a given subshell. **(Understanding)** **[SLO: C-11-B-02]** Describe protons, neutrons and electrons in terms of their relative charges and relative masses **(Understanding)** **[SLO: C-11-B-03]** Describe the behavior of beams of protons, neutrons and electrons moving at the same velocity in an electric field. **(Understanding)** **[SLO: C-11-B-04]** Determine the number of protons, neutrons, and electrons in atoms and ions using atomic (proton) number, mass (nucleon) number, and charge **(Understanding)**	N/A

[SLO: C-09-B-11] State the relative charge and relative masses of a subatomic particles (an electron, proton and neutron) **(Knowledge)** **[SLO: C-09-B-12]** Interpret the relationship between two subatomic particles and their mass and charge. **(Understanding)** **[SLO: C-09-B-13]** Illustrate the trajectories of positively and negatively charged particles when subjected to a uniform electric field. **(Understanding)** **[SLO: C-09-B-14]** Define proton number/atomic number as the number of protons in the nucleus of an atom. **(Knowledge)** **[SLO: C-09-B-15]** Explain that proton number is unique to each element and serves as the basis for arranging elements in periodic table **(Understanding)**			**[SLO: C-11-B-05]** Determine and write the electronic configurations of elements and their ions in both shell arrangement (e.g., 2,8,1) and subshell notation (e.g., $1s^2\ 2s^2\ 2p^6\ 3s^1$) using their proton numbers and positions in the periodic table. Students should be able to derive electronic configurations from the periodic table and explain that the chemical properties of elements are primarily governed by their valence electrons. **(Knowledge/(Understanding)**	

[SLO: C-09-B-16] State that radioactive decay can change the proton number of a nucleus, thereby changing the identity of the atom. **(Understanding)** **[SLO: C-09-B-17]** Define nucleon (mass) number as the total number of protons and neutrons in the nucleus of an atom. **(Knowledge)** **[SLO: C-09-B-18]** Define isotopes **(Knowledge)** **[SLO: C-09-B-19]** State that isotopes affect the atomic mass but do not significantly change the chemical properties of an element. **(Understanding)**				

[SLO: C-09-B-20] Calculate the number of protons and neutrons in different isotopes using atomic number and mass number **(Application)** **[SLO: C-09-B-21]** Define relative atomic mass as the average mass of isotopes of an element compared to $\frac{1}{12}^{th}$ of mass of an atom of carbon-12. **(Knowledge)** **[SLO: C-09-B-22]** State that some isotopes of same element exhibit radioactivity **(Understanding)** **[SLO: C-09-B-23]** Discuss the importance and uses of isotopes, including Carbon-14 for radiocarbon dating and Technetium-99 for medical imaging and diagnostic procedures. **(Understanding)**				

[SLO: C-09-B-24] Describe the formation of positive (cation) and negative (anion) ions from atoms. **(Understanding)** **[SLO: C-09-B-25]** Interpret and use standard chemical symbols to represent atoms and ions, including atomic number, mass number, and charge notation. **(Understanding)** **[SLO: C-09-B-26]** Calculate relative atomic mass of an element from relative masses and abundance of isotopes **(Application)** **[SLO: C-09-B-27]** Determine the electronic configuration of elements and their ions with proton numbers. (From Proton number 1 to 20) simple configuration include K, L and M. (s, p and d configurations are not required) **(Application)**				

N/A			**Benchmark 2:** **Students will be able to explain and apply the principles of electronic configuration to describe the arrangement of electrons in atoms and ions in terms of shells, subshells, and orbitals, using quantum numbers, energy ordering, and fundamental electron-filling rules.**	
N/A	N/A		**[SLO: C-11-B-06]** Define and explain terms related to electronic structure, including shells, subshells, orbitals, principal quantum number (n)(n)(n), and ground state. ***(Knowledge)*** **[SLO: C-11-B-07]** Relate quantum numbers to the arrangement and distribution of electrons in atoms. ***(Understanding)*** **[SLO: C-11-B-08]** Describe the number of orbitals present in s, p, d, and f subshells and state the maximum number of electrons that each subshell can accommodate. ***(Understanding)*** **[SLO: C-11-B-09]** Describe the shapes and orientations of s, p, and d orbitals. ***(Understanding)***	N/A

<table>
<tr><td></td><td></td><td></td><td>SLO: C-11-B-10]
Apply the Aufbau principle, Pauli exclusion principle, and Hund's rule to explain the filling of electrons in atomic orbitals.
(Application)

[SLO: C-11-B-11]
Explain the relative energies and order of filling of s, p, d, and f subshells.
(Understanding)

[SLO: C-11-B-12]
Interpret electronic configurations in terms of electron energy levels, stability, and inter-electronic repulsions.
(Understanding)

[SLO: C-11-B-13]
Define free radicals as species containing one or more unpaired electrons.
(Understanding)</td><td></td></tr>
<tr><td colspan="5">Standard: (Chemical Bonding) Students will be able to explain ionic, covalent, and metallic bonding, describe factors affecting bond strength (bond length and bond energy), and relate bonding types to the physical properties of materials and molecular compounds.</td></tr>
<tr><td colspan="2">Benchmark 1: Students will be able to describe the types of chemical bonds, including ionic, covalent, coordinate covalent, and metallic bonds.</td><td></td><td colspan="2">Benchmark 1: Students will be able to apply the concepts of chemical bonding to predict the structure and properties of molecules, including molecular geometry and polarity.</td></tr>
</table>

[SLO: C-09-B-28] Explain how noble gas electronic configuration, the octet rule, and the duplet rule help predict the chemical properties and stability of main group elements. **(Understanding)** **[SLO: C-09-B-29]** Compare the formation of cations and anions in terms of electron loss and gain. **(Understanding)** **[SLO: C-09-B-30]** Explain the electropositive nature of metals and the electronegative nature of nonmetals based on their tendency to lose or gain electrons. **(Understanding)**	N/A		**[SLO: C-11-B-14]** Describe covalent bonding in molecules using the concept of hybridization, including sp, sp^2, and sp^3 orbitals. ***(Understanding)*** **[SLO: C-11-B-15]** Compare the reactivity of covalent molecules using bond energy values and bond length. ***(Application)*** **[SLO: C-11-B-16]** Describe molecular shapes and bond angles using VSEPR theory, including representation through sketches. ***(Understanding)*** **[SLO: C-11-B-17]** Predict the shapes and bond angles of molecules and ions using VSEPR theory. ***(Understanding)***	N/A	

[SLO: C-09-B-31] Define ionic, covalent, coordinate covalent, and metallic bonds. **(Knowledge)** **[SLO: C-09-B-32]** Differentiate between ionic and covalent compounds on the basis of bond formation, structure, and properties, including the nature of ionic, covalent, and metallic bonding as electrostatic attractions. **(Understanding)** **[SLO: C-09-B-33]** Explain the physical properties of compounds in terms of their bonding and structure. **(Understanding)** **[SLO: C-09-B-34]** Compare the properties and uses of materials, such as strength and electrical conductivity, in relation to the type of chemical bonding present between their atoms. **(Understanding)**			**[SLO: C-11-B-18]** Explain hybridization and its types in covalent bonding. ***(Understanding)*** **[SLO: C-11-B-19]** Explain the valence bond theory of chemical bonding. ***(Understanding)*** **[SLO: C-11-B-20]** Explain the salient features of molecular orbital theory. ***(Understanding)*** **[SLO: C-11-B-21]** Explain the paramagnetic nature of the oxygen molecule in terms of molecular orbital theory. ***(Understanding)*** **[SLO: C-11-B-22]** Calculate the bond order of simple diatomic molecules such as N_2, O_2, F_2, and He_2. ***(Understanding)*** **[SLO: C-11-B-23]** Use the concept of electronegativity to explain bond polarity and molecular dipole moments. ***(Understanding)*** **[SLO: C-11-B-24]** State that ionic, covalent, and metallic bonds are generally stronger than intermolecular forces. ***(Understanding)***	

[SLO: C-09-B-35] Interpret the effect of the strength of intermolecular and electrostatic forces on the melting and boiling points of ionic and covalent compounds. ***(Understanding)*** **[SLO: C-09-B-36]** Explain the availability of free charged particles (ions or electrons) responsible for electrical conductivity in ionic, covalent, and metallic substances. ***(Understanding)*** **[SLO: C-09-B-37]** Recognize that some substances ionize in water and conduct electricity. ***(Understanding)*** **[SLO: C-09-B-38]** Justify the industrial uses of graphite, diamond, and metals based on their bonding, structure, and physical properties. ***(Understanding)*** **[SLO: C-09-B-39]** Draw and explain the formation of ionic and covalent			**[SLO: C-11-B-25]** Recognize that polyatomic ions may contain expanded octets, such as sulfate and nitrate ions. ***(Understanding)*** **[SLO: C-11-B-26]** Explain the formation of dative (coordinate) bonds in species such as CO, ozone, and the hydronium ion (H_3O^+), without involving resonance structures. ***(Understanding)***	

compounds (NaCl, NaF, $CaCl_2$, H_2, Cl_2, O_2, N_2, H_2O, NH_3, CH_4, CO_2, C_2H_4 and HCN) using dot-and-cross diagrams and Lewis dot structures. ***(Application)***				
Standard: Stoichiometry **Students will be able to explain the mole concept and apply it in chemical calculations involving stoichiometry. They will use the law of conservation of mass to construct and balance chemical equations and to predict quantities of reactants and products in chemical reactions. Students will also relate moles, mass, and volume to perform stoichiometric calculations accurately.**				
Benchmark 1: **Students will be able to balance chemical equations and perform stoichiometric calculations using the mole concept**			**Benchmark 1:** **Students will be able to use stoichiometry to predict the quantities of reactants and products in chemical reactions, identify the limiting reactant, and write balanced chemical equations.**	
[SLO: C-09-B-40] State and write the chemical formulae of common elements and compounds Including O_2, H_2, N_2, H_2O, CO_2, NaCl, and HCl. **(Knowledge)** **[SLO: C-09-B-41]** Define molecular formula of a compound as the number and type of different atoms in one molecule **(Knowledge)**	**[SLO: C-10-B-9]** Use the molar gas volume of 24 dm^3 at room temperature and pressure (r.t.p.) to calculate the volume and Use the molar gas volume of 24 dm^3 at room temperature and pressure to calculate the volume and number of moles of a gas in a given reaction. **(Application)**		**[SLO: C-11-B-27]** Interpret a balanced chemical equation in terms of moles, representative particles, masses of reactants and products, and volumes of gases (at STP). **(Application)** **[SLO: C-11-B-28]** Explain what a limiting reagent is and identify it in a given chemical reaction by comparing the mole ratios of reactants **(Understanding)**	N/A

[SLO: C-09-B-42] Define empirical formula as the simplest whole number ratio of atoms of each element present in a compound. **(Knowledge)** **[SLO: C-09-B-43]** Deduce the formula and name of binary ionic compounds from charges of their constituent ions. **(Application)** **[SLO: C-09-B-44]** Deduce the formula of a molecular substance from the given structure of molecules. **(Application)** **[SLO: C-09-B-45]** Define the mole as the SI unit of amount of substance equal to Avogadro's number ($6.02 x 10^{23}$) representing particles (atoms, molecules or ions) **(Knowledge)** **[SLO: C-09-B-46]** Use the relationship n = m/M to calculate the amount of substance (moles), mass and molar mass to calculate number of moles, and use n=N/Na to calculate the number of particles, given relevant data. **(Application)**	**[SLO: C-10-B-10]** Define concentration of a solution as the amount of solute dissolved per unit volume of solution, expressed in g/dm^3 or mol/dm^3. **(Knowledge)** **[SLO: C-10-B-11]** Calculate the concentration of a solution in g/dm^3 and mol/dm^3, and convert between the two units using molar mass. **(Application)** **[SLO: C-10-B-12]** Calculate stoichiometric relationships between reactants and products specifically: ● reacting masses using mole ratios from a balanced chemical equation. ● limiting reactant in a chemical reaction ● volume of a gas produced or consumed in a reaction at r.t.p. ● volume or concentration of a solution involved in a reaction, expressing concentration in g/dm^3 or mol/dm^3. **(Application)**		**[SLO: C-11-B-29]** Calculate the maximum amount of product formed and the amount of any unreacted excess reagent remaining, using the limiting reagent and stoichiometric mole ratios from a balanced chemical equation. **(Application)** **[SLO: C-11-B-30]** Calculate the percentage yield of a chemical reaction using the relationship: percentage yield = (actual yield ÷ theoretical yield) × 100, given experimental and stoichiometric data. **(Application)** **[SLO: C-11-B-31]** State the volume of one mole of a gas at STP **(Knowledge)** **[SLO: C-11-B-32]** Use the molar volume of a gas at STP to calculate the volume or number of moles of a gas in a given reaction. **(Application)** **[SLO: C-11-B-33]** Calculate the gram molecular mass of a gas from density measurements at STP. **(Application)**	

[SLO: C-09-B-47] Explain the relationship between a mole and Avogadro's constant **(Understanding)** **[SLO: C-09-B-48]** Construct balanced chemical equations including state symbols to represent chemical reactions **(Application)** **[SLO: C-09-B-49]** Construct balanced ionic equations, including state symbols, to show the reaction between ions in aqueous solutions. **(Application)** **[SLO: C-09-B-50]** Deduce and write a balanced symbol equation with state symbols for a chemical reaction Deduce and write a balanced symbol equation with state symbols for a chemical reaction when given a written description of the reaction. **(Application)**	**[SLO: C-10-B-13]** Calculate empirical formula of a compound from its percentage composition by mass and molecular formula from its empirical formula and relative molecular mass (Mr). **(Application)** **[SLO: C-10-B-14]** Calculate • percentage yield of a product in a chemical reaction using actual yield and theoretical yield. • percentage composition by mass of each element in a compound • percentage purity of a substance given the mass of pure substance and the total mass of the impure sample. **(Application)**		**[SLO: C-11-B-34]** Calculate the mass, volume at STP, and number of representative particles of a substance when given the amount in moles, and vice versa. **(Application)** **[SLO: C-11-B-35]** Apply stoichiometric principles to solve multi-step problems involving reacting masses, gas volumes at STP, solution concentrations, limiting reagents, and percentage yield using data from balanced chemical equations. **(Application)**	

Standard: Electrochemistry

Students will be able to explain the principles of electrochemistry in terms of oxidation–reduction reactions and the transfer of electrons. They will describe the processes of oxidation, reduction, and electrolysis, and explain the role of electrodes and electrolytes in chemical reactions involving electricity. Students will also apply electrochemical principles to interpret the working and applications of batteries, fuel cells, and other electrochemical devices.

Benchmark 1:

Students will be able to describe the principles of electrochemistry, including redox reactions, oxidation and reduction processes, and the behavior of electrolytes.

	[SLO: C-10-B-15] Define redox reactions as simultaneous oxidation and reduction in terms of oxygen, hydrogen, electrons and changes in oxidation state **(Understanding)** **[SLO: C-10-B-16]** Apply the rules of oxidation states to assign oxidation numbers to elements in compounds and ions, and use Roman numerals in parentheses to indicate the oxidation state of variable-valency metals in their IUPAC names. **(Application)** **[SLO: C-10-B-17]** Identify oxidizing and reducing agents in a given redox reaction **(Understanding)**		N/A	**[SLO: C-12-B-01]** Apply the concept of oxidation numbers in identifying oxidation and reduction reactions **(Application)** **[SLO: C-12-B-02]** Apply the concept of changes in oxidation numbers to balance chemical equations **(Application)** **[SLO: C-12-B-03]** Define the terms redox, oxidation, reduction, and disproportionation (in terms of electron transfer and changes in oxidation number) **(Knowledge)** **[SLO: C-12-B-04]** Identify the oxidizing and reducing agents in a redox reaction. **(Understanding)**

	[SLO: C-10-B-18] State that the oxidation number of any uncombined element in its free state is zero, including diatomic molecules such as O_2, H_2, and Cl_2, and polyatomic molecules such as P_4 and S_8. ***(Knowledge)*** **[SLO: C-10-B-19]** Deduce the chemical formula of ionic compounds, including binary ionic compounds and those containing polyatomic ions, by balancing the charges of the constituent ions so that the overall charge of the compound is zero. ***(Application)*** **[SLO: C-10-B-20]** Identify that the oxidation number of a monatomic ion is the same as the charge on the ion **(Knowledge)** **[SLO: C-10-B-21]** Explain that the sum of the oxidation numbers in a neutral compound is zero **(Understanding)**			**[SLO: C-12-B-05]** Describe the role of oxidizing and reducing agents in the redox reaction **(Understanding)** **[SLO: C-12-B-06]** Explain the concept of activity series of metals and its relation with ease of oxidation **(Understanding)** **[SLO: C-12-B-07]** Deduce the feasibility of redox reactions from activity series. **(Application)** **[SLO: C-12-B-08]** Explain the concept of electrolytic cells in converting electrical energy into chemical energy, including the processes of oxidation at the anode and reduction at the cathode. **(Understanding)** **[SLO: C-12-B-09]** predict the substances liberated at the electrodes during electrolysis by applying knowledge of the state and concentration of the electrolyte and the relative positions of ions in the electrochemical (redox) series. **(Application)**

	[SLO: C-10-B-22] Explain that the sum of the oxidation numbers in an ion is equal to the charge on the ion **(Understanding)** **[SLO: C-10-B-23]** Determine whether a substance is an oxidising agent or a reducing agent by interpreting the colour changes observed when tested with acidified aqueous potassium manganate(VII) (purple to colourless) or aqueous potassium iodide (colourless to brown due to liberation of iodine). **[SLO: C-10-B-24]** Define electrolysis as decomposition of ionic compound, in molten or aqueous solution, by passage of electric current **(Knowledge)** **[SLO: C-10-B-25]** Identify and label the components of a simple electrolytic cells, including the anode (+), cathode (-), electrolyte and indicate the direction of electron flow in external circuit, movement of ions towards each electrode. **(Application)** **[SLO: C-10-B-26]** Describe the movement of electrons through the external circuit, movement of ions in the			**[SLO: C-12-B-10]** Apply the relationship between the Faraday constant, Avogadro constant, and the charge on the electron to solve problems **(Application)** **[SLO: C-12-B-11]** Calculate the quantity of charge passed during electrolysis and mass or volume of the substances liberated during electrolysis. **(Application)** **[SLO: C-12-B-12]** Deduce the Avogadro constant by an electrolytic method. **(Application)** **[SLO: C-12-B-13]** Define the terms standard electrode potential and standard cell potential **(Knowledge)** **[SLO: C-12-B-14]** Describe the structure and function of the standard hydrogen electrode and explain how it is used to determine standard electrode potentials. **(Understanding)**

	electrolyte and transfer of electrons at electrodes during electrolysis. **(Understanding)** **[SLO: C-10-B-27]** Identify the products formed at electrodes and describe the observations made during the electrolysis of the following substances using inert electrodes (platinum or carbon/graphite): • Molten lead(II) chloride • Concentrated and dilute aqueous sodium chloride • Dilute sulfuric acid **(Application)** **[SLO: C-10-B-28]** State that a hydrogen-oxygen fuel cell uses hydrogen and oxygen to produce electricity with water as the only chemical product **(Knowledge)** **[SLO: C-10-B-29]** Describe the advantages and disadvantages of using hydrogen–oxygen fuel cells in comparison with gasoline/petrol engines in vehicles **(Understanding)**			**[SLO: C-12-B-15]** Calculate standard cell potentials from the standard electrode potentials of two half-cells and use these values to predict the feasibility of redox reactions and the direction of electron flow in electrochemical cells. **(Application).** **[SLO: C-12-B-16]** Deduce the relative reactivity of elements, compounds, and ions as oxidizing agents or reducing agents from their electrode potential values. **(Application)** **[SLO: C-12-B-17]** Construct redox equations using relevant half-equations. **(Application)** **[SLO: C-12-B-18]** Explain how electrode potentials vary with the concentrations of aqueous ions and use the Nernst equation to predict this quantitatively. **(Application)**

	[SLO: C-10-B-30] Define corrosion as the gradual deterioration of a metal due to chemical reaction with its environment, and describe methods of preventing corrosion including barrier methods such as painting, galvanizing, and electroplating, and sacrificial protection such as the use of magnesium blocks in ships. ***(Knowledge/Understanding)***			
Benchmark 2: Students will be able to apply the principles of electrochemistry to explain and predict the behavior of galvanic and electrolytic cells, determine the direction of electron flow and feasibility of redox reactions, and explain the applications of electrochemical processes in batteries, corrosion, corrosion prevention, and electroplating.			**Benchmark 2: Students should be able to explain how voltaic (galvanic) cells convert chemical energy into electrical energy through redox reactions and the flow of electrons.**	
	[SLO: C-10-B-31] Identify the products formed at electrodes and describe the observations made during the electrolysis of dilute copper(II) sulfate using inert electrode or copper electrode **(Understanding)** **[SLO: C-10-B-32]** Construct half ionic equations for reaction at either electrode. **(Application)**			**[SLO: C-12-B-19]** Explain how voltaic (galvanic) cells convert energy from spontaneous, exothermic chemical processes to electrical energy, with oxidation at the anode and reduction at the cathode **(Understanding)** **[SLO: C-12-B-20]** Explain how voltaic cells convert chemical energy from redox reactions to electrical energy using Cu-Zn galvanic cell

	[SLO: C-10-B-33] Describe electroplating and its applications. **(Understanding/(Application)** **[SLO: C-10-B-34]** Sketch a schematic diagram for a voltaic cell e.g. Daniel cell **(Application)**			as an example. **(Understanding)**

Standard: (States and Phases of Matter) **Students will be able to explain the physical properties of solids, liquids, and gases in terms of particle arrangement and intermolecular forces, including hydrogen bonding; interpret basic thermal properties such as heat of fusion, heat of vaporization, and molar heat capacity; describe the properties of liquid crystals; and classify solids based on their structure and bonding.**				
N/A			**Benchmark 1: Students should be able to explain and apply the kinetic molecular theory to predict the properties of liquids in terms of molecular motion and intermolecular forces.**	
N/A	N/A		**[SLO: C-11-B-36]** Describe different types of intermolecular forces, including instantaneous dipole–induced dipole (London dispersion forces), permanent dipole–permanent dipole interactions, and hydrogen bonding as a special case of dipole–dipole interaction occurring when hydrogen is bonded to highly electronegative atoms. **[SLO: C-11-B-37]** Describe hydrogen bonding, limited to molecules containing N–H, O–H and H–F groups, (including ammonia, water and H–F as simple examples) **(Understanding)**	N/A

			[SLO: C-11-B-38] Use the concept of hydrogen bonding to explain the anomalous properties of H_2O (ice floats on water) **(Understanding)** **[SLO: C-11-B-39]** Explain the strength and applications of dipole-dipole forces, hydrogen bonding and London forces. **(Understanding/Application)** **[SLO: C-11-B-40]** Describe physical properties of liquids such as evaporation, vapor pressure, boiling point, viscosity and surface tension. **(Understanding)** **[SLO: C-11-B-41]** Apply the concept of hydrogen bonding to explain the properties of water (specifically high surface tension, high specific heat, low vapor pressure, high heat of vaporization, and high boiling point) **(Application)** **[SLO: C-11-B-42]** Define molar heat of fusion and molar heat of vaporization. **(Knowledge)** **[SLO: C-11-B-43]** Describe how heat of fusion and heat of vaporization relate to changes in the arrangement and energy of particles during phase changes of matter. **(Understanding)**	

			[SLO: C-11-B-44] State assumption of kinetic molecular theory of gases. **(Knowledge)** **[SLO: C-11-B-45]** State Boyle's, Charle's and Avogadro's law and interpret them graphically. **(Understanding)** **[SLO: C-11-B-46]** Using PV=nRT in calculations including density and Mr. **(Application)**	
N/A			**Benchmark 2: Explain the properties of solids depending on the type of solid in context.**	
N/A	N/A		**[SLO: C-11-B-47]** Differentiate between amorphous and crystalline solids based on their structural arrangement and physical properties. **(Knowledge)** **[SLO: C-11-B-48]** Describe properties of crystalline solids like geometrical shape, melting point and cleavage planes. **(Understanding)**	N/A

Standard: Energetics **Students will be able to describe the nature of energy using energy profile diagrams and explain its relationship with chemical reactions, including exothermic and endothermic processes; apply thermochemical principles to calculate heat transfer and enthalpy changes; explain the laws of thermodynamics and their application in chemical systems; and describe the relationship between energy and work in thermodynamic processes.**				
Benchmark 1: Students should be able to define and apply energy concepts, including internal energy, enthalpy, and heat changes, to explain thermochemical processes in chemical reactions.			**Benchmark 1: Students should be able to apply the laws of thermodynamics to analyze and predict energy changes in chemical systems, including exothermic and endothermic reactions, enthalpy changes, and entropy changes.**	
[SLO: C-09-B-51] Explain the concept of a chemical system and its surroundings, and how their interaction influences energy transfer during a chemical reaction. **(Understanding)** **[SLO: C-09-B-52]** Differentiate between exothermic and endothermic reactions by giving examples. **(Understanding)** **[SLO: C-09-B-53]** State that heat energy at constant pressure is known as enthalpy change and identify that it is negative for exothermic reactions and positive for endothermic reactions. **(Knowledge)**	N/A		**[SLO: C-11-B-49]** Describe that chemical reactions are accompanied by enthalpy changes and these changes can be exothermic (ΔH is negative) or endothermic (ΔH is positive) **(Understanding)** **[SLO: C-11-B-50]** interpret a reaction pathway diagram, in terms of the enthalpy change of reaction and activation energy **(Application)** **[SLO: C-11-B-51]** Define standard conditions, enthalpy change, enthalpy of reaction, enthalpy of formation, enthalpy of combustion, and enthalpy of neutralization. **(Knowledge)**	N/A

[SLO: C-09-B-54] Define activation energy as the minimum energy that colliding particles must possess for a successful (effective) collision to occur. **(Knowledge)** [**SLO: C-09-B-55**] Explain that activation energy depends on reaction pathway, which can be changed using catalysts or enzyme (detailed pathways not required) **(Understanding)** **[SLO: C-09-B-56]** Draw, label, and interpret reaction pathway diagram for exothermic and endothermic reactions including enthalpy change, activation energy (uncatalyzed and catalyzed), reactants and products **(Application)** **[SLO: C-09-B-57]** Recognize that bond breaking is endothermic process and bond making is an exothermic processes. **(Understanding)** **[SLO: C-09-B-58]** Explain that enthalpy change is the sum of energies absorbed in bond breaking and released in bond forming **(Understanding)**			**[SLO: C-11-B-52]** Explain in terms of bond breaking and bond making whether the reaction is endothermic or exothermic. **(Understanding)** **[SLO: C-11-B-53]** Calculate the enthalpy change of a reaction (ΔH) using bond energies. **(Application)** **[SLO: C-11-B-54]** Describe that some bond energies are exact values while others are average (approximate) values. **(Understanding)** **[SLO: C-11-B-55]** Calculate enthalpy changes from experimental data using the relationships $q = mc\Delta T$ and $\Delta H = -mc\Delta T/n$ **(Application)** **[SLO: C-11-B-56]** Define enthalpy change of atomization(ΔH_{atm}) and lattice energy ($\Delta H_{lattice}$) **(Knowledge)** **[SLO: C-11-B-57]** Construct Born–Haber cycles for ionic solids to determine lattice energy. **(Application)**	

[SLO: C-09-B-59] Calculate the enthalpy change of a reaction using bond energy data **(Application)**			**[SLO: C-11-B-58]** Perform calculations involving Born–Haber cycles **(Application)** **[SLO: C-11-B-59]** Explain the effect of ionic charge and ionic radius on the magnitude of lattice energy **(Understanding)** **[SLO: C-11-B-60]** Apply enthalpy change with reference to hydration and enthalpy of solution **(Application)** **[SLO: C-11-B-61]** Construct an energy cycle involving enthalpy of solution, lattice energy and enthalpy of hydration **(Application)** **[SLO: C-11-B-62]** Perform calculations involving energy cycles **(Application)** **[SLO: C-11-B-63]** Explain the effect of ionic charge and ionic radius on the magnitude of enthalpy of hydration **(Understanding)**		

			[SLO: C-11-B-64] Define entropy, S, as the measure of the number of possible arrangements of the particles and their energy in a given system **(Knowledge)** **[SLO: C-11-B-65]** explain the sign of the entropy change during changes of state, temperature changes and reactions involving changes in the number of gaseous molecules **(Understanding)**	
			[SLO: C-11-B-66] Calculate the entropy change of a reaction, ΔS, using standard entropies, S, of reactants and products **(Application)** **[SLO: C-11-B-67]** Explain the concept of heat as a form of energy transfer **(Understanding)** **[SLO: C-11-B-68]** Explain the concept of standard conditions and standard states in measuring energy changes. **(Understanding)** **[SLO: C-11-B-69]** Explain Hess's Law **(Understanding)**	

			[SLO: C-11-B-70] Apply Hess's Law to calculate enthalpy changes of a reactions carried out in multiple steps. **(Application)** **[SLO: C-11-B-71]** Define Gibbs free energy **(Knowledge)** **[SLO: C-11-B-72]** Apply the concept of Gibbs free energy to solve problems by using $\Delta G = \Delta H - T\Delta S$ **(Application)** **[SLO: C-11-B-73]** Explain the relationship between Gibbs free energy change, ΔG, and the feasibility of a reaction **(Understanding)**	
Standard: (Reaction Kinetics) Students will be able to describe the nature of chemical reactions in terms of activation energy and rate of reaction; explain the factors affecting reaction rate, including temperature, concentration, surface area, and catalysts; and apply kinetic models such as rate laws and rate constants to describe reaction behavior.				
			Benchmark 1: The student be able to calculate the rate of reaction and the rate constant using rate law equation and interpret the significance of the rate constant in relation of reaction rate.	

N/A			**[SLO: C-11-B-74]** Explain the concept of rate of reaction and rate constant. **(Understanding)** **[SLO: C-11-B-75]** Use experimental data to calculate the rate of a reaction **(Application)** **[SLO: C-11-B-76]** Explain the concept of activation energy and its role in chemical reactions **(Understanding)** **[SLO: C-11-B-77]** Use the Boltzmann distribution curve to explain the effect of temperature on the rate of a reaction **(Understanding)** **[SLO: C-11-B-78]** Explain the concept of catalyst and how catalysts increase the rate of a reaction by lowering activation energy **(Understanding)** **[SLO: C-11-B-79]** Interpret reaction pathway diagrams, including those with and without catalysts **(Application)** **[SLO: C-11-B-80]** Use rate equations to determine orders of reaction and rate constants **(Application)**	N/A

			[SLO: C-11-B-81] Calculate the numerical value of a rate constant using initial rates and half-life method. **(Application)** **[SLO: C-11-B-82]** Deduce the units of rate constant for Zero, 1^{st} and 2nd order reactions. **(Application)** **[SLO: C-11-B-83]** Suggest a reaction mechanism that is consistent with a given rate equation and rate-determining step **(Application)** **[SLO: C-11-B-84]** Describe the effect of temperature change on rate constant and rate of reaction. **(Understanding)**	

			N/A	
N/A			N/A	N/A
Standard: (Equilibria) Students will be able to describe the concept of chemical equilibrium and its dynamic nature; explain the relationship between concentrations of reactants and products and the position of equilibrium; apply the law of mass action to predict equilibrium position; and analyze the effects of temperature and pressure on chemical equilibrium using Le Chatelier's principle.				
Benchmark 1: Students should be able to describe chemical equilibrium and explain how reversible reactions are affected by changes in physical conditions such as temperature, pressure, and concentration.			**Benchmark 1: Students should be able to apply the principles of chemical equilibrium to predict the position and extent of equilibrium, including the degree of dissociation of solutes under different physical conditions.**	
[SLO: C-09-B-60] Recognize that reversible reaction are shown by symbol $\rightleftharpoons$ and may not go to completion **(Knowledge)** **[SLO: C-09-B-61]** Describe how changing the physical conditions of a chemical equilibrium system can redirect reversible reactions (Some examples can include:	N/A		**[SLO: C-11-B-85]** Describe reversible reactions and dynamic equilibrium in terms of equal rate of forward and reverse reactions and constant concentrations of reactants and products. **(Understanding)**	

a. effect of heat on hydrated compounds b. addition of water to anhydrous substances in particular copper(II) sulfate and cobalt (II) chloride **(Understanding)** **[SLO: C-09-B-62]** State that reversible reactions can achieve equilibrium in a closed system when rate of forward and backward reactions are equal. **(Understanding)**			**[SLO: C-11-B-86]** Define dynamic equilibrium between two physical states. **(Knowledge)** **[SLO: C-11-B-87]** State the necessary conditions for equilibrium and how equilibrium can be recognized. **(Knowledge)** **[SLO: C-11-B-88]** Describe with example the microscopic events that occur when a chemical system is in equilibrium **(Understanding)** **[SLO: C-11-B-89]** Deduce the equilibrium constant expression [Kc] from the equation of a homogeneous reaction. **(Application)** **[SLO: C-11-B-90]** Write the equilibrium constant expression for a given chemical reaction in terms of concentration (K_c), partial pressure (Kp), and mole fraction. (**Application)** **[SLO: C-11-B-91]** Use Kp and Kc expressions to perform calculations involving equilibrium concentration and partial pressures of reactants and products. **(Application)**		

			[SLO: C-11-B-92] Determine whether the equilibrium constant will increase or decrease when temperature is changed, given the reaction equation. **(Understanding)** **[SLO: C-11-B-93]** State Le Chatelier's Principle and apply it to systems in equilibrium with changes in concentration, pressure, temperature, or the addition of catalyst Occur. **(Application)** **[SLO: C-11-B-94]** Explain industrial applications of Le Chatelier's Principle using the Haber's process and the Contact Process as example. **(Understanding)** **[SLO: C-11-B-95]** Discuss industrial applications of chemical equilibrium and how it is used to optimize chemical reactions to maximize yields and minimize waste. **(Application)** **[SLO: C-11-B-96]** Explain the common ion effects with suitable examples. **(Understanding)** **[SLO: C-11-B-97]** Demonstrate understanding and application of the concept of solubility product. (K_{sp}) **(Application)**	

			[SLO: C-11-B-98] Construct expression for K_{sp} **(Application)** **[SLO: C-11-B-99]** calculate K_{sp} from concentrations data and vice versa **(Application)** **[SLO: C-11-B-100]** Apply common ion effect to explain changes in solubility when a substance is dissolved in a solution containing a common ion. **(Application)** **[SLO: C-11-B-101]** perform calculations using K_{sp} values and concentration of a common ion. **(Application)** **[SLO: C-11-B-102]** state the meaning of the partition coefficient, K_{pc} **(Knowledge)** **[SLO: C-11-B-103]** calculate the partition coefficient for a system where a solute existd in the same physical state in two immiscible solvents **(Application)** **[SLO: C-11-B-104]** Explain the factors affecting the numerical value of the partition coefficient in terms of the polarities of the solute and the solvent. **(Understanding)**	

Standard: (Acid-Base Chemistry and pH) Students will be able to define acids and bases and describe their properties; explain the concept of pH and its relationship with hydrogen ion concentration; describe acid–base reactions including neutralization and proton transfer; and explain the role of buffers in maintaining pH, including buffer capacity and the concentration of buffer components.				
Benchmark 1: Students should be able to identify and distinguish acids and bases based on their properties, chemical behavior, and Brønsted-Lowry theory.			**Benchmark 1: Students should be able to calculate pH values of acidic and alkaline solutions, including applications in titration experiments.**	
[SLO: C-09-B-63] Define Bronsted-Lowry acids as proton donors and Bronsted-Lowry bases as proton acceptors **(Knowledge)** **[SLO: C-09-B-64]** Recognize that aqueous solutions of acids contain H^+ ions and aqueous solutions of alkalis contain OH ions **(Knowledge)** **[SLO: C-09-B-65]** Define strong acids and bases as substances that completely dissociates in aqueous solution and weak acid and base that partially dissociates in aqueous solution,with examples including hydrochloric acid, sulphuric acid, nitric acid, and ethanoic acid. represent their dissociation using symbolic equations. **(Knowledge)** **[SLO: C-09-B-66]** Formulate dissociation equations for acid or base in aqueous solution. **(Application)**	N/A			Acid-Base Theory **[SLO: C-12-B-21]** Define conjugate acid–base pairs **(Knowledge)** **[SLO: C-12-B-22]** identify conjugate acid-base pairs in reactions **(Understanding)** **[SLO: C-12-B-23]** Apply the concept of conjugate acid and conjugate base on salt hydrolysis **(Application)** **[SLO: C-12-B-24]** Define mathematically the terms pH, K_a, pK_a and K_w and use them in calculations (K_b and the equation $K_w = K_a \times K_b$ will not be tested) **(Application)** **[SLO: C-12-B-25]** calculate $[H^+(aq)]$ and pH values for: (a) strong acids (b) strong alkalis

[SLO: C-09-B-67] Recognize that bases are metal oxides or hydroxides and that alkalis are water-soluble bases **(Understanding)** **[SLO: C-09-B-68]** Describe the characteristic properties of acids in terms of their reactions with metals, bases and carbonates **(Understanding)** **[SLO: C-09-B-69]** Identify the characteristic properties of bases in terms of their reactions with acids and ammonium salts **(Understanding)** **[SLO: C-09-B-70]** Define acid rain. **(Knowledge)** **[SLO: C-09-B-71]** Discuss effects of acid rain and relate them with properties of acids. **(Understanding)**				(c) weak acids (d) weak alkalies **(Application)** **[SLO: C-12-B-26]** Calculate the $[H_30^+]$ given the Ka and molar concentration of weak acid. **(Application)** **[SLO: C-12-B-27]** Distinguish that Lewis acids are electron pair acceptors and Lewis bases are electron pair donors forming coordinate covalent bond. **(Understanding)** **[SLO: C-12-B-28]** Use the extent of ionization and the acid dissociation constant, K_a, to distinguish between strong and weak acids. **(Application)** **[SLO: C-12-B-29]** Use the extent of ionization and the base dissociation constant, K_b, to distinguish between strong and weak bases. **(Application)**

				[SLO: C-12-B-30] Explain what is meant by a chemical buffer and how a buffer system works. (For context this should include: a. defining what is a buffer solution b. explaining how a buffer solution can be made c. explaining how buffer solutions control pH; use chemical equations in these explanations d. describe and explain the uses of buffer solutions, including the role of HCO_3^- in controlling pH in blood) **(Understanding)** **[SLO: C-12-B-31]** calculate the pH of buffer solutions by using appropriate data **(Application)**

				[SLO: C-12-B-32] Sketch the pH titration curves using combinations of strong and weak acids with strong and weak alkalis **(Application)** **[SLO: C-12-B-33]** Use the concept of hydrolysis to explain why aqueous solutions of some salts are acidic or basic. **(Application)**
Standard: (Salts) Students will be able to describe the nature of salts and their formation from acid–base reactions; explain ionic compounds in terms of crystal lattice structure; discuss the properties of salts including solubility, conductivity, and melting point; apply principles of chemical bonding to explain the behavior of salts in different physical states; and describe the role of salts in chemical reactions, including their effect on acid–base equilibria.				
Benchmark 1: Students will be able to differentiate between different types of salts based on their properties and solubility behaviour.			**N/A**	

N/A	**[SLO: C-10-B-35]** Explain that salts are ionic compounds formed by electrostatic attraction between oppositely charged ions where positive ions are derived from bases and negative ions are derived from acids. **(Understanding)** **[SLO: C-10-B-36]** Explain why at STP salts are solids with high melting points. **(Understanding)** **[SLO: C-10-B-37]** Describe that under normal conditions, ionic compounds are usually solids with lattice structures. **(Knowledge)** **[SLO: C-10-B-38]** Explain why the molten and aqueous solutions of salts are good conductors of electricity by making reference to the idea of mobile ions **(Understanding)**		N/A	N/A

	[SLO: C-10-B-39] Describe general trends in the solubility of salts in water, including that all sodium, potassium, ammonium, and nitrate salts are soluble; most chlorides are soluble except those of silver and lead; carbonates are generally insoluble except those of sodium, potassium, and ammonium; and hydroxides are generally insoluble except those of sodium, potassium, ammonium, and calcium (partially soluble). (**Knowledge)** **[SLO: C-10-B-40]** Describe the preparation, separation and purification of soluble salts by reaction of acids with alkali (titration), excess metal, excess insoluble base, and excess insoluble carbonate **(Understanding)**			

Domain C: Inorganic Chemistry

Standard: (Periodic Table and Periodicity)
Students will be able to describe the organization of the periodic table based on atomic number, electron configuration, and chemical properties; explain periodicity as repeating patterns in physical and chemical properties; describe periodic trends such as ionization energy, electron affinity, and electronegativity; apply periodic trends to predict properties and reactivity of elements; and explain the importance of the periodic table in studying and predicting chemical behavior.

Benchmark 1: Students will be able to explain the similarities and differences in properties of elements within the same group (vertical column) and across periods (horizontal row) of the periodic table, including the classification of elements into s- and p-blocks based on their electron configurations.			**Benchmark 1: The student will be able to interpret and explain periodic trends in electron configuration, ionization energy, electron affinity, and atomic radius; predict the properties and reactivity of elements based on their position in the periodic table; and use periodic properties to classify elements and compounds into groups and identify relationships among them.**	
[SLO:C-09-C-01] Define the periodic table as an arrangement of elements into periods and groups in order of increasing proton number (atomic number). **(Knowledge)** **[SLO:C-09-C-02]** Identify the group, period, or block of an element from its electronic configuration (only the concept of subshells related to blocks may be introduced). **(Understanding)** **[SLO:C-09-C-03]** Explain the relationship between the group number and the charge of ions formed by elements of that group in terms of their outermost electron shells. **(Understanding)** **[SLO:C-09-C-04]** Explain the similarities in the chemical properties of elements within the same group in terms of their electronic configurations. **(Understanding)**	N/A		**[SLO:C-11-C-01]** Explain the arrangement of elements in the periodic table. **(Understanding)** **[SLO:C-11-C-02]** Explain that the periodic table is divided into four blocks associated with the four sublevels: s, p, d, and f. **(Understanding)** **[SLO:C-11-C-03]** Recognize that the period number (*n*) corresponds to the outermost principal energy level occupied by electrons. **(Understanding)** **[SLO:C-11-C-04]** State that the principal energy level number and the number of valence electrons in an atom can be deduced from its position in the periodic table. **(Knowledge)**	N/A

[SLO:C-09-C-05] Identify trends across groups and periods using information about elements, including trends in atomic radius, electron affinity, electronegativity, ionization energy, metallic character, reactivity, and density. **(Understanding)** **[SLO:C-09-C-06]** Use the terms *alkali metals, alkaline earth metals, halogens, noble gases, transition metals, lanthanides,* and *actinides* in reference to the periodic table. **(Knowledge)** **[SLO:C-09-C-07]** Predict the characteristic properties of an element in a given group using knowledge of chemical periodicity. **(Application)** **[SLO:C-09-C-08]** Predict the possible position of an unknown element in the periodic table with reference to its electronic configuration. **(Application)**			**[SLO:C-11-C-05]** Identify the positions of metals, non-metals, and metalloids in the periodic table. **(Understanding)** **[SLO:C-11-C-06]** Explain that ionization energy arises from the attraction between the nucleus and the outermost electron. **(Understanding)** **[SLO:C-11-C-07]** Explain the variation in the successive ionization energies of an element. **(Understanding)** **[SLO:C-11-C-08]** Explain the factors that influence the ionization energies of elements, including nuclear charge, atomic and ionic radius, shielding by inner shells and subshells, and spin-pair repulsion. **(Understanding)** **[SLO:C-11-C-09]** Deduce the electronic configuration of an element using successive ionization energy data. **(Application)**		

			[SLO:C-11-C-10] Deduce the position of an element in the periodic table using successive ionization energy data. **(Application)** **[SLO:C-11-C-11]** Define electronegativity as the ability of an atom to attract electrons toward itself. **(Knowledge)** **[SLO:C-11-C-12]** Explain the factors that influence the electronegativity of elements, including nuclear charge, atomic radius, and shielding by inner shells and subshells. **(Understanding)** **[SLO:C-11-C-13]** Use differences in Pauling electronegativity values to predict whether ionic or covalent bonds will form. **(Application)** **[SLO:C-11-C-14]** Define first electron affinity (EA). **(Knowledge)**	

			[SLO:C-11-C-15] Explain the factors that affect the electron affinities of elements. **(Understanding)** **[SLO:C-11-C-16]** Explain the vertical and horizontal trends in the periodic table for atomic radius, ionic radius, ionization energy, electron affinity, and electronegativity. **(Understanding)** **[SLO:C-11-C-17]** Recognize that trends in metallic and non-metallic character are due to trends in the number of valence electrons. **(Understanding)** **[SLO:C-11-C-18]** Deduce the electron configuration of an atom from its position in the periodic table, and vice versa, based on s, p, d, and f subshells. **(Application)** **[SLO:C-11-C-19]** Describe, including writing equations, the reactions (if any) of third-period oxides (acidic and basic) with water, including the likely pH of the resulting solutions. **(Understanding)**	

			[SLO:C-11-C-20] Explain, with the help of equations, the acidic, basic, and amphoteric behavior of the oxides of third-period elements. **(Understanding)** **[SLO:C-11-C-21]** Predict the characteristic properties of an element in a given group using knowledge of chemical periodicity. **(Application)**	

Standard: (Group Properties and Elements) Students will be able to describe group properties of elements including electron configurations and reactivity; explain trends in reactivity, atomic size, and electronegativity within groups; discuss the chemical behavior of elements in different oxidation states; apply electron configuration and electron transfer concepts to explain reactivity; and describe the properties and applications of elements in groups such as alkali metals, alkaline earth metals, halogens, and noble gases.				
Benchmark 1: Students should be able to describe the physical and chemical properties of elements in different groups of the periodic table, including their reactivity and tendency to form compounds.			**N/A**	
Group I Properties **[SLO: C-09-C-09]** Define Group I Alkali metals as soft metals and describe general trends down the group including decreasing melting point, increasing density and increasing reactivity **(Knowledge)** **[SLO: C-09-C-10]** Predict properties of other elements in group I, given information about the elements. **(Application)** **[SLO: C-09-C-11]** Predict properties of elements in group 1 in order of reactivity given relevant information. **(Application)**	Nitrogen and Sulfur **[SLO: C-10-C-01]** Describe the catalytic role of NO and NO_2 in the oxidation of atmospheric sulfur dioxide to sulphur trioxide. **(Understanding)** **[SLO: C-10-C-02]** State the symbol equation for the production of ammonia in the Haber process, $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$ **(Knowledge)** **[SLO: C-10-C-03]** State the sources of the hydrogen (methane) and nitrogen (air) in the Haber process **(Knowledge)** **[SLO: C-10-C-04]** State the typical conditions in the Haber process as 450°C, 200 atm and an iron catalyst **(Knowledge)**			

Group VII Properties **SLO:C-09-C-12]** Define Group VII halogens as diatomic non-metals with general trends limited to increasing density and decreasing reactivity. **(Knowledge)** **[SLO:C-09-C-13]** Identify the appearance of halogens at room temperature and pressure (RTP) as follows: fluorine as a pale yellow gas, chlorine as a yellow-green gas, bromine as a red-brown liquid, and iodine as a grey-black solid. **(Knowledge)** **[SLO:C-09-C-14]** Explain the displacement reactions of halogens with halide ions, and their behavior as reducing agents. **(Understanding)** **[SLO:C-09-C-15]** Predict the properties of elements in Group VII using given information about the elements. **(Application)** **[SLO:C-09-C-16]** Analyze the relative thermal stability of hydrogen halides and explain it in terms of bond strength. **(Understanding)**	**[SLO: C-10-C-05]** State the symbol equation for the conversion of sulfur dioxide to sulfur trioxide in the Contact process, $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$ **(Knowledge)** **[SLO: C-10-C-06]** State the sources of the sulfur dioxide (burning sulfur or roasting sulfide ores) and oxygen (air) in the Contact process **(Knowledge)** **[SLO: C-10-C-07]** State the typical conditions for the conversion of sulfur dioxide to sulfur trioxide in the Contact process as 450°C, 200kPa /atm and a vanadium(V) oxide catalyst **(Knowledge)**			

Transition Elements **[SLO:C-09-C-17]** Describe transition elements as metals that have high densities, high melting points, and variable oxidation states, and that form colored compounds and act as catalysts in industrial processes. Examples of catalytic uses include the Haber process, catalytic converters, the Contact process, and the manufacture of margarine. **(Knowledge)** **Noble Gases** **[SLO:C-09-C-18]** Define Group 18 noble gases as unreactive, monatomic gases. **(Knowledge)** **[SLO:C-09-C-19]** Explain their lack of reactivity in terms of their electronic configuration. **(Understanding)**	**Oxides** **[SLO: C-10-C-08]** Describe amphoteric oxides as oxides that react with acids and bases to produce a salt and water **(Understanding)** **[SLO: C-10-C-09]** Classify oxides as acidic (nonmetal oxides), basic (metal oxides) or amphoteric, limited to Al_2O_3 and ZnO, related to metallic and non-metallic character. **(Understanding)** **Properties of metals** **[SLO: C-10-C-10]** Identify the general chemical properties of metals, limited to their reactions with dilute acids, cold water, steam and oxygen. **(Understanding)** - **[SLO: C-10-C-11]** Arrange metals in order of reactivity given relevant information **(Application)**			

Properties of metals **[SLO:C-09-C-20]** Compare the general physical properties of metals and non-metals, specifically in terms of thermal conductivity, electrical conductivity, malleability and ductility, and melting and boiling points. **(Understanding)**				
Standard: S Block Elements Students will be able to identify and classify Group 2 elements based on their position in the periodic table; explain trends in reactivity based on electron configuration and oxidation state; describe industrial and everyday uses of Group 2 elements such as magnesium, calcium, and barium; explain methods of extraction and purification including thermal reduction and electrolysis; and describe the properties of Group 2 compounds, including trends in solubility and reactivity of oxides, hydroxides, and carbonates.				
N/A			**Benchmark 1: Students should be able to describe trends in atomic properties of Group 2 elements and explain their chemical reactivity with the other elements including trends in reactivity , solubility, and the formation of oxides and carbonates.**	

N/A	N/A		N/A	**[SLO: C-12-C-01]** Describe the properties and trends of Group 1 and 2 elements, including their electron configurations, reactivity, and common compounds such as oxides, hydroxides and carbonates **(Understanding)** **[SLO: C-12-C-02]** Explain the chemical reactivity of Group 1 and 2 elements, including their reactions with oxygen, water, and acids (Be, Mg, Ca). **(Understanding)** **[SLO: C-12-C-03]** Explain the variation in the oxidation number of the oxides and chlorides (NaCl, $MgCl_2$) in terms of their outer shell (valence shell) electrons. **(Understanding)** **[SLO: C-12-C-04]** Explain the reactivity of Group 1 and 2 elements in terms of their electron configuration and valence electrons. **(Understanding)** **[SLO:C-12-C-05]** Describe the industrial and everyday uses of selected Group 2 compounds such as magnesium oxide, calcium oxide, calcium hydroxide, and

				magnesium sulfate, including their roles in medicine and agriculture. **(Application)** **[SLO: C-12-C-06]** Explain the term reactivity series and its application in predicting the outcomes of chemical reactions. **(Understanding)** **[SLO: C-12-C-07]** Use the concept of the reactivity series to predict the outcomes of chemical reactions. **(Application)** **[SLO: C-12-C-08]** Explain the extraction and purification process of Group II elements and their compounds. **(Understanding)** **[SLO: C-12-C-09]** Understand the term thermal decomposition and its application in the analysis of Group 2 compounds especially carbonates and nitrates. **(Understanding)** **[SLO: C-12-C-10]** Explain the trend in solubility of group 2 sulfates and hydroxides using terms enthalpy of hydration and enthalpy of solution **(Application)**

				[SLO: C-12-C-11] Compare the properties and reactivity of Group 2 elements with group 1 in the periodic table. **(Application)** **[SLO: C-12-C-12]** Describe qualitatively the trend in the thermal stability of the nitrates and carbonates of group 1 and 2 including the effect of ionic radius on the polarisation of the large anion **(Application)** **[SLO: C-12-C-13]** describe qualitatively the variation in solubility and enthalpy change of solution, of hydroxides and sulfates in terms of relative magnitudes of enthalpy change of hydration and lattice energy **(Application)**

Standard: P Block Elements Students will be able to describe trends in the properties of Group 17 elements (fluorine, chlorine, bromine, iodine, and astatine), including volatility, reactivity, and electronegativity; explain the industrial and everyday uses of halogens and their compounds such as in refrigerants and disinfectants; identify halide ions (chloride, bromide, and iodide) and explain their reactivity trends; describe reactions of Group 17 elements and their compounds including redox reactions and halide exchange reactions; and discuss the environmental impacts of halogens and their compounds, including ozone depletion and pollution from halogenated organic compounds.

Students will be able to describe the reactivity of nitrogen and sulfur compounds; explain the major chemical reactions and products involving nitrogen and sulfur; discuss the environmental effects of nitrogen and sulfur compounds; distinguish between nitrification and denitrification processes; and describe the industrial production of nitrates and sulfates.

N/A			**Benchmark 1: Students should be able to describe trends in the reactivity of halogens and explain their tendency to form compounds with other elements in the periodic table.**	
N/A	N/A		**[SLO: C-11-C-22]** Describe the colors and trend in volatility of chlorine, bromine and iodine **(Understanding)** **[SLO: C-11-C-23]** Describe the relative reactivity of the halogen elements as oxidizing agents **(Understanding)** **[SLO: C-11-C-24]** Describe the reactions of the halogens with hydrogen and explain their relative reactivity in these reactions **(Understanding)** **[SLO: C-11-C-25]** Describe the relative thermal stabilities of the hydrogen halides and explain these in terms of bond strengths **(Understanding)** **[SLO: C-11-C-26]** Describe the relative reactivity of halide ions as reducing agents **(Understanding)**	N/A

			[SLO: C-11-C-27] Explain the reactions of halide ions with concentrated sulfuric acid **(Understanding)** **[SLO: C-11-C-28]** Interpret the reactions of chlorine with cold and hot aqueous sodium hydroxide as disproportionation reactions **(Application)** **[SLO: C-11-C-29]** Explain the use of chlorine in water purification, including the formation of active species such as HOCl and ClO, which kill bacteria. **(Understanding)**	

N/A			**Benchmark 1: Students should be able to describe the reactivity of Nitrogen and Sulphur, th properties of their compounds, their major chemical reactions and their roles in the environment.**	
N/A	N/A		**Nitrogen** **[SLO: C-11-C-30]** Explain the lack of reactivity of nitrogen due to its triple bond strength and lack of polarity **(Understanding)** **Sulfur** **[SLO: C-11-C-31]** Explain the lack of reactivity of sulfur, with reference to its bonding and stability of its compounds. **(Understanding)** **[SLO: C-11-C-32]** Describe the different oxidation states of sulfur and their relative stability. **(Understanding)** **[SLO: C-11-C-33]** Describe the chemical reactions and processes involving sulfur, such as combustion and oxidation. **(Understanding)** **[SLO: C-11-C-34]** Explain the uses of sulfur compounds in industry and everyday life, such as in fertilizers, gunpowder and rubber, and in the	N/A

			Synthetic organic chemistry, including the synthesis of dyes and drugs. **(Understanding/Application)**	
Standard: Transition Metals **Students will be able to describe the general physical properties of transition elements; and explain the pattern of electronic configuration in d-block elements and its implications for chemical bonding, chemical reactions, and physical properties.**				
N/A			**Benchmark 1: Students should be able to Identify d-block in the periodic table and understand their general physical and chemical properties.**	
N/A	N/A			**[SLO: C-12-C-14]** Identify the general physical and chemical properties of the first row of transition elements, titanium to copper **(Understanding)** **[SLO: C-12-C-15]** define a transition element as a d-block element that forms one or more stable ions with incomplete d orbitals **(Knowledge)** **[SLO: C-12-C-16]** Identify the properties of transition elements (Some examples include: a) they have variable oxidation states

				b) they behave as catalysts c) they form complex ions d) they form coloured compounds) **(Understanding)** **[SLO: C-12-C-17]** Explain why transition elements exhibit variable oxidation states in terms of the similar energies of the 3d and 4s subshells. **(Understanding)** **[SLO: C-12-C-18]** Explain why transition elements act as catalysts in terms of having more than one stable oxidation state and vacant d orbitals that are energetically accessible and capable of forming dative bonds with ligands. **(Understanding)** **[SLO: C-12-C-19]** Explain why transition elements form complex ions in terms of vacant d orbitals that are energetically accessible. **(Understanding)**
N/A				
N/A	N/A			

				[SLO: C-12-C-20] Explain the reactions of transition elements with ligands to form complex ions, including complexes of copper(II) and cobalt(II) ions with water and ammonia molecules, and with hydroxide and chloride ions. **(Application)** **[SLO: C-12-C-21]** Define the term *ligand* as a species that contains a lone pair of electrons which is donated to a central metal atom or ion to form a dative covalent bond. **(Knowledge)** **[SLO: C-12-C-22]** Use the term monodentate ligand and identify examples such as H_2O, NH_3, Cl^- and CN^- **(Knowledge)** **[SLO: C-12-C-23]** Use the term bidentate ligand and polydentate ligand, including examples such as 1,2-diaminoethane, $H_2NCH_2CH_2NH_2$ and ethanedioate ion, $C_2O_4^{2-}$ as bidentate ligand and EDTA as a polydentate ligand. **(Knowledge/Understanding)**

				[SLO: C-12-C-24] Define the term complex as a molecule or ion formed by a central metal atom / ion surrounded by one or more ligands **(Knowledge)** **[SLO: C-12-C-25]** Describe the geometry (shape and bond angles) of transition element complexes which are linear, tetrahedral or octahedral. **(Understanding)** **[SLO: C-12-C-26]** State what is meant by coordination number **(Knowledge)** **[SLO: C-12-C-27]** Predict the formula and charge of a complex ion, given the metal ion, its charge or oxidation state, the ligand and its coordination number or geometry. **(Application)** **[SLO: C-12-C-28]** Explain qualitatively that ligand exchange can occur, including complexes of copper(II) ions and cobalt(II) ions with water and ammonia molecules and hydroxide and chloride ions **(Understanding)**

				Colour of complexes **[SLO: C-12-C-29]** use the terms degenerate and non-degenerate d orbitals **(Knowledge)** **[SLO: C-12-C-30]** Describe the splitting of degenerate d orbitals into two sets of non-degenerate d orbitals of different energies, and use ΔE in: (a) octahedral complexes, where two orbitals are higher in energy and three are lower (b) tetrahedral complexes, where three orbitals are higher in energy and two are lower **(Understanding)** **[SLO: C-12-C-31]** Explain why transition elements form coloured compounds in terms of the frequency of light absorbed when an electron is promoted between non-degenerate d orbitals. **(Understanding)** **[SLO: C-12-C-32]** Describe qualitatively the effect of different ligands on ΔE, the frequency of light absorbed, and the complementary colour observed. **(Application)**

N/A	N/A			**[SLO: C-12-C-33]** Use complexes of copper(II) and cobalt(II) ions with water, ammonia, hydroxide, and chloride ions as examples of ligand exchange affecting observed colour. **(Application)** **Stability Constants, Kstab** **[SLO: C-12-C-34]** Define the stability constant ($K_{sta}b$) of a complex as the equilibrium constant for the formation of a complex ion in solution from its constituent ions or molecules. **(Knowledge)** **[SLO: C-12-C-35]** Write an expression for $K_{sta}b$ of a complex (water molecules should not be included). **(Application)** **[SLO: C-12-C-36]** Use $K_{sta}b$ expressions to perform calculations. **(Application)** **[SLO: C-12-C-37]** Explain ligand exchange in terms of $K_{sta}b$ values and understand that a large $K_{sta}b$ indicates the formation of a more stable complex ion. **(Understanding)**

N/A				
N/A	N/A			

Domain D: Environmental Chemistry				
Standard: (Atmosphere) Students will be able to describe the composition and structure of the Earth's atmosphere, including major and trace gases; explain the role of the atmosphere in Earth's climate, including the greenhouse effect; discuss the sources and effects of atmospheric pollutants, including greenhouse gases and air pollutants; apply principles of chemical reactions to explain the formation and removal of atmospheric pollutants; and describe the role of atmospheric chemistry in environmental chemistry and its impact on air quality and climate.				
Benchmark 1: Students should be able to demonstrate an understanding of the composition, structure and functions of the Earth's atmosphere, including the role of atmospheric gases, pollutants and greenhouse effect.			**Benchmark 1: Students should be able to evaluate the impact of atmospheric pollutants on the environment and living organisms and describe possible solutions to mitigate these effects.**	
	[SLO: C-10-D-01] State that composition of clean, dry air is approximately 78% nitrogen, N_2, 21% oxygen, O_2, and the remainder as a mixture of noble gasses and carbon dioxide, CO_2 **(Knowledge)** **[SLO: C-10-D-02]** state the major sources of air pollutants, including carbon dioxide from complete combustion of carbon-containing fuels; carbon monoxide and particulate matter from incomplete combustion; methane from decomposition of vegetation and waste gases from animal digestion; oxides of nitrogen from car engines; sulfur dioxide from the combustion of		**[SLO: C-11-D-01]** Identify the properties and composition of the atmosphere. (Include the concepts of 4 layers of atmosphere and their composition) **Knowledge)**	N/A

	sulfur-containing fossil fuels; and ground-level ozone formed from reactions between oxides of nitrogen and volatile organic compounds in the presence of sunlight. **(Knowledge)** **[SLO: C-10-D-03]** State the adverse effects of air pollutants, including: **a.** carbon dioxide: increased levels contribute to global warming, leading to climate change **b.** carbon monoxide: a toxic gas c. particulates (dust, smoke, and fine particles): increased risk of respiratory diseases and cancer **d.** methane: increased levels contribute to global warming, leading to climate change **e.** oxides of nitrogen: cause acid rain, photochemical smog (PAN), and respiratory problems **f.** sulfur dioxide: causes acid rain and haze **(Knowledge)**		**[SLO: C-11-D-02]** Describe the sources and effects of air pollution, including both natural and human-caused pollutants such as ozone (O_3), polycyclic aromatic hydrocarbons (PAHs), persistent organic pollutants (POPs), chlorofluorocarbons (CFCs) and other ozone-depleting substances, and heavy metals such as lead, mercury, and cadmium. **(understanding)** **[SLO: C-11-D-03]** Design experiments and collect data to test hypotheses about air quality with respect to the use of an antismog gun. **(Application)**	

	[SLO: C-10-D-04] Explain how the greenhouse gases carbon dioxide and methane cause global warming, including: a. The absorption, reflection and re-emission of thermal energy b. The reduction of heat loss from earth to space) **(Understanding)** **[SLO: C-10-D-05]** Describe the role of sulfur in the formation of acid rain and its impact on the environment. **(Understanding)** **[SLO: C-10-D-06]** Describe strategies to reduce the effects of major environmental issues including: a. climate change: planting trees, reduction in livestock farming, decreasing the use of fossil fuelsand increasing the use of hydrogen and renewable energy such as wind and solar energy b. acid rain: using catalytic converters in vehicles, reducing sulfur dioxide emission by low sulfur fuels and and applying flue gas desulfurization using calcium oxide **(Understanding)**			

	[SLO: C-10-D-07] Describe the role of NO and NO_2 in the formation of acid rain, both directly and through their catalytic role in the oxidation of atmospheric sulfur dioxide. **(Understanding)** **[SLO: C-10-D-08]** Explain how oxides of nitrogen are formed in car engines and describe their removal by catalytic converters, e.g. $CO + 2NO \rightarrow 2CO + N_2$ **(Understanding)** **[SLO: C-10-D-09]** State that water from natural sources may contain useful and harmful substances. including: a. dissolved oxygen b. metal compounds c. plastics d. sewage e. harmful microbes f. nitrates from fertilizers g. phosphates from fertilizers and detergents) **(Knowledge)** **[SLO: C-10-D-10]** Recognize that some naturally occuring substances in water are beneficial including: a. dissolved oxygen for aquatic life			

	b. some metal compounds provide essential minerals for life) **(Understanding)** **[SLO: C-10-D-11]** Recognize that some naturally occuring substances in water are potentially harmful including: a. some metal compounds that are toxic b. some plastics that harm aquatic life c. sewage that contains harmful microbes which cause disease d. nitrates and phosphates that lead to deoxygenation of water and damage to aquatic life Details of the eutrophication process are not required) **(Understanding)** **[SLO: C-10-D-12]** Explain the treatment of the domestic water supply including: (a) sedimentation and filtration to remove solids (b) use of carbon to remove tastes and odors (c) chlorination to kill microbes) **(Understanding)**			

	[SLO: C-10-D-13] Identify the negative effects of water pollutants on life and the ways to avoid them. **(Understanding)** **[SLO: C-10-D-14]** Explain water scarcity as an important issue faced by Pakistan and suggest ways in which it can be resolved. **(Understanding)** **Fertilizers** **[SLO: C-10-D-15]** State that urea, ammonium salts and nitrates are used as fertilizers. **(Knowledge)** **[SLO: C-10-D-16]** Explain the use of NPK fertilizers in providing nitrogen, phosphorus and potassium for improved plant growth. **(Understanding)**			

Standard: Water **Students should be able to describe the composition, properties, sources, distribution, and natural recycling of water on Earth, including the water cycle and groundwater systems. They should also analyze the effects of pollutants such as acid rain, chemical contaminants, and eutrophication on water quality, apply basic chemical principles to explain the formation and removal of these pollutants, and understand the role of water in environmental chemistry and its importance for sustaining water resources and aquatic ecosystems.**				
			Benchmark 1: **Students should be able to demonstrate the ability to identify types of water pollution and common pollutants such as oil, pesticides, and heavy metals. They should also evaluate the impact of human activities, including agriculture and industry, on water resources, and explain strategies for the conservation and sustainable management of water resources.**	
	N/A		**[SLO: C-11-D-04]** Identify different types of water pollution, including point source and nonpoint source pollution. **(Knowledge)** **[SLO: C-11-D-05]** Identify common water pollutants such as oil, pesticides, and heavy metals. **(Knowledge)** **[SLO: C-11-D-06]** Evaluate the impact of human activities, such as agriculture and industrial processes on water resources. **(Application)**	N/A

			[SLO: C-11-D-7] Explain conservation and management strategies for protecting and preserving water resources **(Understanding)**	

Domain E: Organic Chemistry

Standard: (Basics of Organic Chemistry)

(Catenation, isomerism, nomenclature, functional groups, and homologous series)

Students should be able to describe the concept of catenation, including the ability of carbon atoms to bond with each other to form complex structures. They should explain isomerism in organic compounds, including structural and stereoisomers, and understand the systematic nomenclature of organic compounds based on IUPAC rules. They should describe functional groups such as alcohols, carboxylic acids, amines, and aldehydes, and explain the concept of homologous series in terms of similarity in properties and reactivity among its members. They should also apply their knowledge of organic compound properties to predict the outcomes of common reactions, including substitution, elimination, addition, oxidation, and reduction.

Benchmark 1: Students should be able to recognize and classify organic compounds based on their functional groups, nomenclature, isomerism, and homologous series.		**Benchmark 1: Students should be able to analyze the chemical and physical properties of organic compounds based on their functional groups and demonstrate understanding of common organic structures, terminology and reaction mechanisms.**

[SLO: C-09-E-01] Describe organic molecules as straight-chained, branched or cyclic **(Knowledge)** **[SLO: C-09-E-02]** State that a structural formula is an unambiguous representation of how atoms in a molecule are arranged, including examples such as $CH_2=CH_2$, CH_3CH_2OH, CH_3COOCH_3 **(Knowledge)** **[SLO: C-09-E-03]** Identify and draw structural formulae for molecules. **(Knowledge)** **[SLO: C-09-E-04]** Interpret general formulae of compounds in the same homologous series including alkanes, alkenes, alkynes, alcohols and carboxylic acids. **(Understanding)** **[SLO: C-09-E-05]** Define structural isomers as compounds with the same molecular formula, but different structural formulae, including examples such as C_4H_{10} ($CH_3CH_2CH_2CH_3$ and $CH_3CH(CH_3)CH_3$) and C_4H_8 ($CH_3CH_2CH=CH_2$and $CH_3CH=CHCH_3$) **(Knowledge)**	**[SLO: C-10-E-01]** Name and draw the structural and displayed formulae of unbranched alkanes, alkenes, alcohols, and carboxylic acids. (Include but-1-ene and but-2-ene, propan-1-ol, propan-2-ol, butan-1-ol and butan-2-ol) **(Knowledge)** **[SLO: C-10-E-02]** State the type of compound present from its chemical name ending in -ane, -ene, -yne, -ol, or -oic acid or from its molecular, structural or displayed formula **(Knowledge)** **[SLO: C-10-E-03]** Name and draw the displayed formulae of the unbranched esters which can be made from unbranched alcohols and carboxylic acids, each containing up to four carbon atoms **(Knowledge)**		**[SLO: C-11-E-01]** Define catenation and explain its importance in organic chemistry. **(Understanding)** **[SLO: C-11-E-02]** Recognize that hydrocarbons are compounds made up of C and H atoms only **(Knowledge)** **[SLO: C-11-E-03]** Recognize that alkanes are simple hydrocarbons with no functional group **(Knowledge)** **[SLO: C-11-E-04]** Recognize that compounds contain a functional group which dictates their physical and chemical properties **(Understanding)** **[SLO: C-11-E-05]** Interpret the general, structural, displayed and skeletal formulae of the classes of compounds **(Understanding)** **[SLO: C-11-E-06]** Describe the use of systematic nomenclature of simple aliphatic organic molecules (including cyclo alkanes and alkenes) with functional groups **(Understanding)**	**[SLO: C-12-E-01]** Explain stereoisomerism and its division into geometrical (cis/trans) and optical isomerism **(Understanding)** **[SLO: C-12-E-02]** Describe geometrical (cis/trans) isomerism in alkenes, and explain its origin in terms of restricted rotation due to the presence of π bonds **(Understanding)** **[SLO: C-12-E-03]** Explain what is meant by a chiral center and that such a center gives rise to two optical isomers (enantiomers) **(Understanding)** **[SLO: C-12-E-04]** Describe that enantiomers have identical physical and chemical properties except for their ability to rotate plane-polarized light and potential biological activity. **(Understanding)** **[SLO: C-12-E-05]** Apply the terms optically active, racemic mixture and mesocompounds on given structure. **(Application)**

[SLO: C-09-E-06] Identify a functional group as an atom or group of atoms that determine the chemical properties of a homologous series including that for alcohols, aldehydes, ketones, carboxylic acids, **(Knowledge)** **[SLO: C-09-E-07]** Describe the general characteristics of a homologous series including: (a) having the same functional group (b) having the same general formula (c) differing from one member to the next by a $-CH_2-$ unit (d) displaying a trend in physical properties (e) sharing similar chemical properties) **(Understanding)** **[SLO: C-09-E-08]** State that a saturated compound has molecules in which all carbon–carbon bonds are single bonds **(Knowledge)** **[SLO: C-09-E-09]** State that an unsaturated compound is one whose molecules contain one or more carbon–carbon bonds that are not single bonds. **(Knowledge)**			**[SLO: C-11-E-07]** Deduce the molecular or empirical formula of a compound, from its structural, displayed or skeletal formula **(Application)** **[SLO: C-11-E-08]** Describe structural isomerism in organic molecules and its classification into chain, positional, functional group isomerism metamerism and tautomerism. **(Understanding)**	**[SLO: C-12-E-06]** Describe the effect of two optical isomers of a single substance on plane polarized light. **(Understanding)**

Standard: Hydrocarbons **Students should be able to describe the structures and properties of alkanes, alkenes, and alkynes, and classify them as saturated or unsaturated hydrocarbons. They should explain their reactions, including combustion, addition, and substitution, and discuss their uses as fuels and as starting materials for organic synthesis. They should also apply concepts of chemical bonding and reactivity to predict products of hydrocarbon reactions, including aromatic compounds, and describe their importance in organic chemistry, industry, and daily life.**				
Benchmark 1: Students should be able to classify and identify different types of hydrocarbons (alkanes, alkenes, and alkynes) based on their molecular structure, reactivity, and physical properties.			**Benchmark 1: Students should be able to demonstrate understanding of the formation and reactions of hydrocarbons, including aromatic compounds, along with their nomenclature, shapes, and properties.**	
[SLO: C-09-E-10] State that the bonding in alkanes is single covalent and that alkanes are saturated hydrocarbons **(Knowledge)** **[SLO: C-09-E-11]** Describe the reactions of alkane such as combustion and substitution with chlorine as a photochemical reaction, and draw the structural or displayed formulae of the products, limited to monosubstitution **(Understanding)** **[SLO: C-09-E-12]** Describe, using symbol equations, preparation of alkanes from cracking of larger hydrocarbons, hydrogenation of alkenes and alkynes, and reduction of alkyl halides **(Application)**	**Alkenes** **[SLO: C-10-E-04]** State that the bonding in alkenes includes a double carbon–carbon covalent bond and that alkenes are unsaturated hydrocarbons **(Knowledge)** **[SLO: C-10-E-05]** Describe the manufacture of alkenes by the cracking of large alkane molecules using a high temperature and a catalyst **(Understanding)** **[SLO: C-10-E-06]** Describe the reasons for the cracking of large alkane molecules **(Understanding)** **[SLO: C-10-E-07]** Describe the test to distinguish between saturated and unsaturated hydrocarbons by their reaction with aqueous bromine and $KMnO_4$ **(Knowledge)**		**[SLO: C-11-E-09]** Classify hydrocarbons as aliphatic and aromatic. **(Knowledge)** **[SLO: C-11-E-10]** Explain the shapes of alkanes and cycloalkanes exemplified by ethane and cyclopropane. **(Understanding)** **[SLO: C-11-E-11]** Explain unreactive nature of alkanes towards polar reagents. **(Understanding)** **[SLO: C-11-E-12]** Define homolytic and heterolytic fission **(Knowledge)** **[SLO: C-11-E-13]** Describe the mechanism of free radical substitution in alkanes exemplified by methane. **(Understanding)**	**[SLO: C-12-E-07]** Explain the shape of the benzene molecule including sp^2 hybridization, in terms of σ bonds and a delocalised π system (molecular orbital aspect). **(Understanding)** **[SLO: C-12-E-08]** Define resonance, resonance energy and relative stability of benzene. **(Knowledge)** **[SLO: C-12-E-09]** Compare the reactivity of benzene with alkanes and alkenes. **(Application)** **[SLO: C-12-E-10]** Describe the mechanism of electrophilic substitution reactions with chlorine and bromine, including the formation of ortho, para, and meta isomers, and predict the major product(s) of the reaction. **(Application)**

	[SLO: C-10-E-08] Describe the properties of alkenes in terms of addition reactions with: a. bromine or aqueous bromine b. hydrogen in the presence of a nickel catalyst c. steam in the presence of an acid catalyst and draw the structural or displayed formulae of the products **(Understanding)** **[SLO: C-10-E-09]** Describe, using symbol equations, preparation of alkenes by elimination reaction in halogenoalkanes and alcohols **(Application)** **Alkynes** **[SLO: C-10-E-10]** Identify alkynes as hydrocarbons containing triple carbon-carbon covalent bond and that alkynes are unsaturated hydrocarbons **(Knowledge)**		**[SLO: C-11-E-14]** Explain the IUPAC nomenclature of alkenes and alkynes **(Understanding)** **[SLO: C-11-E-15]** Explain shape of ethene and ethyne molecules in terms of structure and bonding. **(Understanding)** **[SLO: C-11-E-16]** Compare the reactivity of alkenes and alkynes in terms of hybridization. **(Application)** **[SLO: C-11-E-17]** Explain dehydration of alcohols and dehydrohalogenation of RX for the preparation of ethene. **(Understanding)** **[SLO: C-11-E-18]** Explain dehydrohalogenation of vicinal dihalide and geminal dihalide for the preparation of alkynes **(Understanding)** **[SLO: C-11-E-19]** Describe the chemistry of alkenes by the following reactions of ethene: hydrogenation, hydrohalogenation, hydration, halogenation, halohydration, oxidation (Baeyer's test), ozonolysis, polymerization. **(Understanding)**	**[SLO: C-12-E-11]** compare the reactivity of halogenoalkane and halogenoarene using chloroethane and chlorobenzene as examples **(Application)** **[SLO: C-12-E-12]** Explain the mechanism of nitration, including the formation of a nitronium ion, and predict the major product(s) of the reaction. **(Application)** **[SLO: C-12-E-13]** Explain the mechanism of Friedel-Crafts alkylation and acylation, respectively, including the role of the Lewis acid catalyst, and predict the major product(s) of the reaction. **(Application)** **[SLO: C-12-E-14]** Explain the side chain oxidation of alkyl benzene, including the formation of a benzoic acid. **(Understanding)** **[SLO: C-12-E-15]** Describe the Orientation of electrophilic substitution reactions in mono substituted benzene., and predict the major product(s) of the reaction based on the directing effects of substituents on the aromatic ring. **(Application)**

	[SLO: C-10-E-11] Describe the use of ethyne as fuel for welding and in artificially ripening fruits **(Knowledge)** **[SLO: C-10-E-12]** Describe separation of petroleum into useful fraction by fractional distillation **(Knowledge)** **[SLO: C-10-E-13]** Describe how the properties of fractions obtained from petroleum change from the bottom to the top of the fractionating column, including decreasing chain length, increasing volatility, lower boiling points, and lower viscosity. **(Understanding)** **[SLO: C-10-E-14]** Name the uses of petroleum fractions, including: a. refinery gas fraction: used as fuel for heating and cooking b. gasoline/petrol fraction: used as fuel for cars c. naphtha fraction: used as a chemical feedstock d. kerosene/paraffin fraction: used as jet fuel e. diesel oil/gas oil fraction: used as fuel for diesel engines f. fuel oil fraction: used as fuel for ships and home heating systems g. lubricating oil fraction: used for lubricants, waxes, and polishes h. bitumen fraction: used for road construction **(Knowledge)**		**[SLO: C-11-E-20]** Describe the chemistry of alkynes by the following reactions of alkynes: hydrogenation, hydrohalogenation, hydration, halogenation, oxidation, **(Understanding)** **[SLO: C-11-E-21]** Explain acidic nature of alkyne by using Ammonical silver nitrate and Ammonical cuprous chloride **(Understanding)** **[SLO: C-11-E-22]** Explain the concept of conjugation in alkenes having alternate double bonds. **(Understanding)** **[SLO: C-11-E-23]** Describe the mechanism of electrophilic addition in alkenes, using bromine with ethene and hydrogen bromide with propene as examples. **(Understanding)** **[SLO: C-11-E-24]** explain the inductive effects of alkyl groups on the stability of primary, secondary and tertiary carbocations formed during electrophilic addition and use this to account for Markovnikov rule. **(Understanding)**		

Standard: Halogenoalkanes **Students will be able to explain the synthesis and classification of halogenoalkanes based on molecular structure. They will describe their common reactions, including substitution (SN_1 and SN_2) and elimination reactions, and predict their reactivity based on structure and reaction conditions. They will also describe simple syntheses of halogenoalkanes and the functional groups involved, and analyze reaction mechanisms and products,**				
N/A			**Benchmark 1: Students should be able to explain the reactions by which halogenoalkanes and halogenoarenes are produced, as well as the chemical reactions of these compounds.**	
N/A	N/A		**[SLO: C-11-E-25]** Classify halogenoalkanes based on the type of halogen atom and its position in the carbon chain, and explain how the molecular structure affects their reactivity. **(Understanding)** **[SLO: C-11-E-26]** Explain the functional groups involved in simple halogenoalkane synthesis, and predict the major product(s) based on the reaction conditions. this includes: • free-radical substitution of alkanes by Cl or Br in the presence of ultraviolet light, (e.g ethane) • electrophilic addition of alkene with a halogen, X_2, or hydrogen halide, HX(g), at room temperature. • substitution of alcohols using HX or KBr with H_2SO_4	.

			or H_3PO_4, or using PCl_3 (with heat), PCl_5, or $SOCl_2$ **(Application)** **[SLO: C-11-E-27]** Describe nucleophilic substitution reactions (specifically: ● the reaction with NaOH(aq) and heat to produce an alcohol ● the reaction with KCN in ethanol and heat to produce a nitrile ● the reaction with NH_3 in ethanol heated under pressure to produce an amine ● the reaction with aqueous silver nitrate in ethanol as a method of identifying the halogen present as exemplified by bromoethane) **(Understanding)**	

			[SLO: C-11-E-28] Describe the elimination reaction with NaOH in ethanol and heat to produce an alkene as exemplified by bromoethane **(Understanding)** **[SLO: C-11-E-29]** Describe the SN_1 and SN_2 mechanisms of nucleophilic substitution in halogenoalkanes including the inductive effects of alkyl groups **(Understanding)** **[SLO: C-11-E-30]** Identify that primary halogenoalkanes tend to react via SN_2 mechanism; tertiary halogenoalkanes via SN_1 mechanism; and secondary halogenoalkanes by a mixture of the two, depending on structure **(Understanding)** **[SLO: C-11-E-31]** Explain the different reactivities of halogenoalkanes with particular reference to the relative strengths of the C–X bonds as exemplified by the reactions of halogenoalkanes with aqueous silver nitrates **(Understanding)**	

N/A				
N/A	N/A		N/A	
Standard: Hydroxy Compounds (Alcohols) **Students should be able to describe the structure and properties of alcohols, including primary, secondary, and tertiary alcohols. They should explain the reactions of alcohols, including oxidation, esterification, and dehydration, and discuss their applications as solvents, fuels, and starting materials in organic synthesis. They should apply concepts of chemical bonding and reactivity to predict the products of alcohol reactions and describe the importance of alcohols in organic chemistry, industry, and daily life.**				
Benchmark 1: Students should be able to identify the processes for manufacturing ethanol, along with its uses and effects.			**Benchmark 1:** **Students should be able to analyze the different reactions through which hydroxy compounds can be produced, as the physical and chemical properties of the corresponding alcohols**	

N/A	**[SLO: C-10-E-15]** Describe the manufacture of ethanol, including: • fermentation of aqueous glucose at 25–35 °C in the presence of yeast under anaerobic conditions (absence of oxygen) • catalytic hydration of ethene using steam at 300 °C and 6000 kPa (6 atm) in the presence of an acid catalyst, including a comparison of the advantages and disadvantages of both methods **(Understanding)** **[SLO: C-10-E-16]** Describe the combustion of alcohols (**Knowledge)** **[SLO: C-10-E-17]** Discuss the applications of alcohols as fuels, including their advantages and disadvantages over fossil fuels. **(Understanding**) **[SLO: C-10-E-18]** Explain the role of alcohols in various industries such as pharmaceuticals, cosmetics, and fuel production. **(Understanding**)			**[SLO: C-12-E-16]** State the reactions (reagents and conditions) by which alcohols can be produced: a) electrophilic addition of steam to an alkene, $H_2O(g)$ and H_3PO_4 catalyst b) reaction of alkenes with cold dilute acidified potassiummanganate (VII) to form a diol c) substitution of a halogenoalkane using NaOH (aq) and heat d) reduction of an aldehyde or ketone using $NaBH_4$ or $LiAlH_4$ e) reduction of a carboxylic acid using $LiAlH_4$ f) hydrolysis of an ester using dilute acid or dilute alkali and heat **(Knowledge)** **[SLO: C-12-E-17]** describe the reaction with oxygen (combustion) of organic hydroxy compounds **(Understanding)** **[SLO: C-12-E-18]** Describe substitution to halogenoalkanes, e.g. by reaction with HX or KBr with H_2SO_4 or H_3PO_4; or with PCl_3 and heat; or with PCl_5; or with $SOCl_2$ **(Understanding)**

	SLO: C-10-E-19] Discuss the impact of alcohols on daily life, including their use as solvents and disinfectants. **(Understanding)**			**[SLO: C-12-E-19]** Describe the reaction of alcohol with Na(s) **(Understanding)** **[SLO: C-12-E-20]** Describe the oxidation with acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ to: carbonyl compounds by distillation, carboxylic acids by refluxing (primary alcohols give aldehydes which can be further oxidized to carboxylic acids, secondary alcohols give ketones, tertiary alcohols cannot be oxidized) **(Understanding)** **[SLO: C-12-E-21]** Describe the dehydration of alcohols to alkenes by using a heated catalyst, e.g. Al_2O_3 or a concentrated acid **(Understanding)** **[SLO: C-12-E-22]** Describe the formation of esters by reaction with carboxylic acids and concentrated H_2SO_4 or H_3PO_4 as catalyst as exemplified by ethanol **(Understanding)**

				[SLO: C-12-E-23] classify alcohols as primary, secondary and tertiary alcohols, to include examples with more than one alcohol group **(Knowledge)** **[SLO: C-12-E-24]** state characteristic distinguishing reactions of primary, secondary and tertiary alcohols e.g. mild oxidation with acidified $K_2Cr_2O_7$, colour change from orange to green **(Knowledge)** **[SLO: C-12-E-25]** deduce the presence of a $CH_3CH(OH)–$ group in an alcohol, $CH_3CH(OH)–R$, from its reaction with alkaline $I_2(aq)$ to form a yellow precipitate of tri-iodomethane and an ion, RCO_2 **(Application)** **[SLO: C-12-E-26]** recall the reactions (reagents and conditions) by which phenol can be produced: reaction of phenylamine with HNO_3 or $NaNO_3$ and dilute acid below 1°C to produce the diazonium salt; further warming of the diazonium salt with H_2O to give phenol **(Knowledge)**

				[SLO: C-12-E-27] recall the chemistry of phenol, as exemplified by the following reactions: ● with Sodium metal and NaOH (aq) to produce sodium phenoxide ● nitration of the aromatic ring with dilute HNO_3(aq) at room temperature to give a mixture of 2- nitrophenol and 4- nitrophenol ● bromination of the aromatic ring with Br_2(aq) to form 2,4,6-tribromophenol **(Knowledge)** **[SLO: C-12-E-28]** explain the acidity of phenol **(Understanding)** **[SLO: C-12-E-29]** describe the relative acidities of water, phenol and ethanol **(Understanding)** **[SLO: C-12-E-30]** explain why the reagents and conditions for the nitration and bromination of phenol are different from those for benzene **(Understanding)**

				[SLO: C-12-E-31] recall that the hydroxyl group of a phenol directs to the 2-, 4- and 6-positions **(Knowledge)**
Standard: Carbonyl Compounds **Students should be able to describe the structure and properties of carbonyl compounds, including their characteristic functional groups. They should explain the reactions of carboxylic acids, including decarboxylation, esterification, and acid–base reactions, and discuss the applications of carboxylic acids and esters as fragrances, flavors, and starting materials in organic synthesis. They should also apply concepts of chemical bonding and reactivity to predict the products of carboxylic acid reactions.**				
Benchmark 1: Students should be able to identify and explain the properties and reactions of carboxylic acids and esters, including their preparation, structure, and uses in industry and daily life. **.**			**Benchmark 1: Students should be able to explain the reactions by which carboxylic acids are produced and describe the nature, reactions, and uses of aldehydes and ketones.**	
N/A	**[SLO: C-10-E-20]** Describe the reactions of carboxylic acids with metals, bases and carbonates including names and formulae of the salts produced. **(Understanding)** **[SLO: C-10-E-21]** Describe the formation of ethanoic acid by the oxidation of ethanol: with acidified aqueous potassium manganate(VII) & by bacterial oxidation during vinegar production **(Understanding)**			**[SLO: C-12-E-32]** state the reactions (reagents and conditions) by which aldehydes and ketones can be produced: a. the oxidation of primary alcohols using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and distillation to produce aldehydes b. the oxidation of secondary alcohols using acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and distillation to produce ketones **(Knowledge)**

	[SLO: C-10-E-22] Describe the reaction of a carboxylic acid with an alcohol using an acid catalyst to form an ester **(Understanding)** **SLO: C-10-E-23]** describe the industrial applications of carboxylic acids and esters, including their use as solvents, flavors, fragrances, and plastics. **(Understanding)** **SLO: C-10-E-24]** explain the role of carboxylic acids and esters in daily life, including their use in food preservation, cosmetics, and pharmaceuticals. **(Understanding)**			**[SLO: C-12-E-33]** Describe: a. the reduction of aldehydes and ketones, using $NaBH_4$ or $LiAlH_4$ to produce alcohols b. the reaction of aldehydes and ketones with HCN, KCN as catalyst, and heat to produce hydroxynitriles exemplified by ethanal and propanone **(Understanding)** **[SLO: C-12-E-34]** Describe the mechanism of the nucleophilic addition reactions of hydrogen cyanide with aldehydes and ketones **(Understanding)** **[SLO: C-12-E-35]** Describe the use of 2,4-dinitrophenylhydrazine (2,4-DNPH reagent) to detect the presence of carbonyl compounds **(Understanding)** **[SLO: C-12-E-36]** Deduce the nature (aldehyde or ketone) of an unknown carbonyl compound from the results of simple tests (Fehling's and Tollens' reagents; ease of oxidation) **(Application)**

				[SLO: C-12-E-37] Deduce the presence of a CH_3CO – group in an aldehyde or ketone, $CH_3CO–R$, from its reaction with alkaline $I_{2(aq)}$ to form a yellow precipitate of tri-iodomethane and an ion, RCO_2^- **(Application)** **[SLO: C-12-E-38]** recall the reactions by which carboxylic acids can be produced: a) oxidation of primary alcohols and aldehydes with acidified $K_2Cr_2O_7$ or acidified $KMnO_4$ and refluxing b) hydrolysis of nitriles with dilute acid or dilute alkali followed by acidification c) hydrolysis of esters with dilute acid or dilute alkali and heat followed by acidification **(Knowledge)** **[SLO: C-12-E-39]** Describe reactions of carboxylic acid: a. the redox reaction with reactive metals to produce a salt and $H_2(g)$ b. the neutralization reaction with alkalis to produce a salt and $H_2O(l)$ c. the acid–base reaction with carbonates to produce a salt and $H_2O(l)$ and $CO_2(g)$

				d. esterification with alcohols with concentrated H_2SO_4 as catalyst e. reduction by $LiAlH_4$ to form a primary alcohol **(Understanding)** **[SLO: C-12-E-40]** Describe the hydrolysis of esters by dilute acid and by dilute alkali and heat **(Understanding)** **[SLO: C-12-E-41]** Describe the reaction of carboxylic acids with PCl_3 and heat, PCl_5, or $SOCl_2$ to form acyl chlorides **(Understanding)** **[SLO: C-12-E-42]** Explain the relative acidities of carboxylic acids, phenols and alcohols **(Understanding)** **[SLO: C-12-E-43]** Explain the relative acidities of chlorine-substituted carboxylic acids **(Understanding)**

				[SLO: C-12-E-44] Recall the reaction by which esters can be produced: reaction of alcohols with acyl chlorides using the formation of ethyl ethanoate and phenyl benzoate as examples **(Knowledge)** **[SLO: C-12-E-45]** Describe the following reactions of acyl chlorides: (check either bullets or add a,b,c,d) a. hydrolysis on addition of water at room temperature to give the carboxylic acid and HCl b. reaction with an alcohol at room temperature to produce an ester and HCl c. reaction with phenol at room temperature to produce an ester and HCl d. reaction with ammonia at room temperature to produce an amide and HCl **(Understanding)** **[SLO: C-12-E-46]** Describe the addition elimination mechanism of acyl chlorides in reactions discuss is SLO E-45. **[SLO: C-12-E-47]** explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and halogenoarenes (aryl chlorides) **(Understanding)**

Standard: Nitrogen Compounds **Students should be able to describe the structure and properties of nitrogen compounds, including their characteristic functional groups. They should explain the reactions of nitrogen-containing compounds and discuss the formation of amide bonds leading to amino acids**				
N/A			**Benchmark 1: Students should be able to explain the classification and reactions of aliphatic and aromatic amines, including their conversion into amides and their role in the formation of amino acids.**	
				Primary and secondary amines **[SLO: C-12-E-48]** Define primary and secondary amines, and explain their basic properties and reactivity. **(Understanding)** **[SLO: C-12-E-49]** Identify the differences between primary and secondary amines in terms of their structure and chemical properties. **(Understanding)** **[SLO: C-12-E-50]** Describe reactions (reagents and conditions) by which primary and secondary amines are produced: (a) reaction of halogenoalkanes with NH_3 in ethanol heated under pressure (b) (c) reaction of halogenoalkanes with primary amines in ethanol, heated in a sealed tube / under pressure

N/A				(C) the reduction of amides with $LiAlH_4$ (E) the reduction of nitriles with $LiAlH_4$ or H2/ Ni **(Understanding)** **[SLO: C-12-E-51]** Describe the reactions by which nitriles can be produced: reaction of a halogenoalkane with KCN in ethanol and heat **(Understanding)** **[SLO: C-12-E-52]** Describe the hydrolysis of nitriles with dilute acid or dilute alkali followed by acidification **(Understanding)** **[SLO: C-12-E-53]** Describe the basicity of aqueous solutions of amines **(Understanding)** **Phenylamine and azo compounds** **[SLO: C-12-E-54]** Describe the reaction of phenylamine with $Br_2(aq)$ at room temperature **(Understanding)** **[SLO: C-12-E-55]** Describe the reaction of phenylamine with HNO_2 or $NaNO_2$ and dilute acid below 1°C to produce the diazonium salt;	

				further warming of the diazonium salt with H_2O to give phenol **(Understanding)** **[SLO: C-12-E-56]** explain the relative basicities of aqueous ammonia, ethylamine and phenylamine **(Understanding)** **[SLO: C-12-E-57]** identify the properties of azo compounds (Some examples include: (a) describe the coupling of benzenediazonium chloride with phenol in NaOH(aq) to form an azo compound (b) identify the azo group (c) state that azo compounds are often used as dyes (d) Recognize that other azo dyes can be formed via a similar route) **(Knowledge)** **Amides** **[SLO: C-12-E-58]** Identify the reactions (reagents and conditions) by which amides are produced (Some examples include: (a) the reaction between ammonia and an acyl chloride at room temperature

				(b) the reaction between a primary amine and an acyl chloride at room temperature) **(Knowledge)** **[SLO: C-12-E-59]** describe the reactions of amides (Some examples include: (a) hydrolysis with aqueous alkali or aqueous acid (b) the reduction of the CO group in amides with $LiAlH_4$ to form an amine) **(Understanding)** **[SLO: C-12-E-60]** explain why amides are much weaker bases than amines **(Understanding)** **[SLO: C-12-E-61]** describe the acid/ base properties of amino acids and the formation of zwitterions, **(Understanding)** **[SLO: C-12-E-62]** describe the formation of amide (peptide) bonds between amino acids to give di- and tripeptides **(Understanding)**	

				[SLO: C-12-E-63] Describe the basic principle of electrophoresis and predict the results of electrophoresis on mixtures of amino acids at varying pHs **(Application)**
Standard: Polymers **Students should be able to describe the structure and properties of polymers, including homopolymers and copolymers. They should explain the formation and synthesis of polymers through addition and condensation polymerization. They should also discuss the applications of polymers in industries such as plastics, textiles, and biomedicine. In addition, students should apply concepts of chemical bonding and reactivity to predict the properties of polymers and describe their importance in materials science, as well as their impact on society and the environment.**				
Benchmark 1: Students should be able to identify and describe the structure, properties, reactions, and applications of various polymers, including both natural and synthetic types.			**Benchmark 1: Students should be able to describe the polymerization process and the factors that affect polymer properties and performance.**	
N/A	**[SLO: C-10-E-25]** Define polymers as large molecules built up from many smaller molecules called monomers (**Knowledge)** **[SLO: C-10-E-26]** Identify the repeating units and/or linkages in addition polymers **(Application**)			**[SLO: C-12-E-64]** Explain the chemical processes and properties of PVC and nylon, and the applications of these polymers in the industry. **(Understanding)**

	[SLO: C-10-E-27] Deduce the structure or repeat unit of an addition polymer from a given alkene and vice versa **(Application)** **[SLO: C-10-E-28]** State that plastics are made from polymers **(Knowledge)** **[SLO: C-10-E-29]** Describe how the properties of plastics have implications for their disposal **(Understanding)** **[SLO: C-10-E-30]** Describe the environmental challenges caused by plastics, limited to: a. disposal in landfill sites b. accumulation in oceans c. formation of toxic gases from burning **(Understanding)**			**[SLO: C-12-E-65]** Describe the chemical processes of addition and condensation polymerization and the differences between them. Examples include a. addition polymers such as poly(ethene) and poly(chloroethene), PVC, b. polyesters (from reactions of diol and dicarboxylic or dioyl acid, and from hydroxycarboxylic acid), c. polyamides (from reactions of a diamine and a dicarboxylic acid or dioyl chloride, of an aminocarboxylic acid, or between amino acids) **(Understanding)** **[SLO: C-12-E-66]** identify the polymer formed, the monomer present in a section of polymer, and classify them as one of the two polymers. **(Application)** **[SLO: C-12-E-67]** Deduce the repeating unit of a polymer obtained from a given monomer or pair of monomers and identify the monomers present in a given section of a polymer molecule. **(Application)**

				[SLO: C-12-E-68] Predict the type of polymerization reaction for a given monomer or pair of monomers. **(Application)** **[SLO: C-12-E-69]** recognise that poly(alkenes) are chemically inert and can therefore be difficult to biodegrade **(Knowledge)** **[SLO: C-12-E-70]** recognise that some polymers can be degraded by the action of light **(Knowledge)** **[SLO: C-12-E-71]** recognise that polyesters (Terylene) and polyamides (protein) are biodegradable by acidic and alkaline hydrolysis **(Knowledge)**

Standard: Organic Synthesis **Students will be able to identify and name common organic functional groups and describe their physical and chemical properties. They will demonstrate understanding of the basic mechanisms of common organic reactions involving functional groups. They will design synthetic routes for simple organic compounds using appropriate reagents and reaction conditions.**				
N/A			**Benchmark 1: Students should be able to understand that functional groups have distinct and varied reactions and explain how one organic compound can be synthesized from another functional group.**	
N/A	N/A			**[SLO: C-12-E-72]** Explain the concept of organic synthesis and functional group interconversions. **(Understanding)** **[SLO: C-12-E-73]** Identify organic functional groups using the reactions in this progression grid. **(Application)** **[SLO: C-12-E-74]** Predict properties and reactions of organic molecules based on functional group presence. **(Application)** **[SLO: C-12-E-75]** Devise multi-step synthetic routes for preparing organic molecules. **(Application)**

				[SLO: C-12-E-76] Analyze a given synthetic route in terms of type of reaction and reagents used for each step of it, and possible by-products. **(Application)** **[SLO: C-12-E-77]** Describe the use of artificial intelligence tools in the design of organic molecules that may have potential as medicines, using Halicin as an example. **(Understanding)**

Benchmark 1: Students should be able to identify the structure of carbohydrates, proteins and fats.			Benchmark 1: Students should be able to explain the structures and roles of different biochemical compounds in living organisms.	
	[SLO: C-10-E-31] Describe proteins as natural polyamides and that they are formed from amino acid monomers with the general structure\\ **(Knowledge)** **[SLO: C-10-E-32]** Draw the general structure of proteins **(Knowledge)** **[SLO: C-10-E-33]** Draw the structure of lipids and carbohydrates **(Knowledge)**			**[SLO: C-12-E-78]** Explain the basis of classification and structure of carbohydrates **(Understanding)** **[SLO: C-12-E-79]** Explain the basis of classification and structure of proteins **(Understanding)** **[SLO: C-12-E-80]** Describe the activity of enzyme as biocatalyst and relate this role to various functions such as digestion of food **(Understanding)** **[SLO: C-12-E-81]** Describe the basis of classification and structure of lipids **(Understanding)** **[SLO: C-12-E-82]** Identify the structural components of DNA and RNA **(Knowledge)** **[SLO: C-12-E-83]** Differentiate between the structures of DNA polymer (double strand) and RNA (single strand). **(Understanding)**

Domain F: Data Collection and Analysis				
Standard: Mass Spectrometry **Students will be able to interpret mass spectra and identify isotopes based on their m/e (mass-to-charge) values and relative abundances. They will determine the atomic mass of an element from its isotopic composition and mass spectrum, and analyze the molecular mass of organic compounds using the molecular ion peak. They will also predict the identity of fragmented ions in a given mass spectrum and determine the number of carbon atoms in a compound using the M+1 peak and the appropriate formula.**				
N/A			**Benchmark 1: Students should be able to understand how mass spectrometers are used to analyze atoms, including isotopes based on their m/e values, and identify molecules based on their masses using mass spectra.**	
				[SLO: C-12-F-01] Analyse mass spectra in terms of m/e values and isotopic abundances (knowledge of the working of the mass spectrometer is not required) **(Application)** **[SLO: C-12-F-02]** calculate the relative atomic mass of an element given the relative abundances of its isotopes, or its mass spectrum **(Application)**

N/A	N/A			**[SLO: C-12-F-03]** Deduce the molecular mass of an organic molecule from the molecular ion peak in a mass spectrum **(Application)** **[SLO: C-12-F-04]** Suggest the identity of molecules formed by simple fragmentation in a given mass spectrum **(Understanding)** **[SLO: C-12-F-05]** Deduce the number of carbon atoms, n, in a compound using the formula $n = \frac{100\ X\ abundance\ of\ [M+1]peak}{1.1\ X\ Abundance\ of\ M^{+}\ peak}$ **(Understanding)** **[SLO: C-12-F-06]** Deduce the presence of bromine and chlorine atoms in a compound using the ratio of M and M+2 peaks. **(Understanding)**

<table>
<tr><td colspan="5">Standard: Spectroscopy

Students will be able to describe the principles of spectroscopy and explain the interaction of electromagnetic radiation with matter. They will analyze spectra to identify chemical species and determine their concentrations. They will compare and contrast different spectroscopic techniques, including infrared (IR), ultraviolet-visible (UV-Vis), and nuclear magnetic resonance (NMR) spectroscopy, and apply these techniques to identify unknown compounds and determine their structures</td></tr>
<tr><td colspan="2">N/A</td><td></td><td colspan="2">Benchmark 1: Students should be able to explain the principles of spectroscopy and use spectral data to identify functional groups and determine molecular structures.</td></tr>
<tr><td>N/A</td><td>N/A</td><td></td><td></td><td>[SLO: C-12-F-07]
Interpret an infrared (IR) spectrum of a simple molecule to identify functional groups
(Application)

[SLO: C-12-F-08]
Deduce possible structures for organic compounds using IR spectrum and molecular formula (Examples: phenol, acetone, ethanol)
(Application)

[SLO: C-12-F-09]
Predict whether a given molecule will absorb in the UV/visible region.
(Application)</td></tr>
</table>

<table>
<tr><td colspan="5">Standard: Nuclear Magnetic Resonance (NMR) Spectroscopy
Students will be able to describe the basic principles of NMR spectroscopy and explain how it is used to determine the structure of organic molecules. They will distinguish between different types of NMR spectra and interpret the information they provide. They will use NMR spectra to determine the number and types of carbon and hydrogen atoms in organic molecules and explain how carbon-13 NMR spectroscopy provides structural information. They will also analyze NMR spectra to deduce the structures of simple organic compounds and recognize common spectral patterns associated with different functional groups and molecular environments</td></tr>
<tr><td colspan="2">N/A</td><td></td><td colspan="2">Benchmark 1: Students should be able to interpret NMR spectra to identify compounds and determine molecular structures by analyzing the environments of carbon and hydrogen atoms.</td></tr>
<tr><td>N/A</td><td>N/A</td><td></td><td>N/A</td><td>[SLO: C-12-F-10]
Analyze the different environments of carbon atoms present in a simple molecule using a 13C NMR spectrum.
(Application)

[SLO: C-12-F-11]
Use a C-13 NMR spectrum to deduce possible structures of a simple molecule.
(Application)

[SLO: C-12-F-12]
Predict the number of peaks in a C-13 NMR spectrum for a given molecule.
(Application)

[SLO: C-12-F-13]
Analyze the different environments of protons present in a simple molecule using a (proton) NMR spectrum.
(Application)</td></tr>
</table>

				[SLO: C-12-F-14] Use a H^1 (proton) NMR spectrum to deduce relative numbers of each type of proton present, the number of equivalent protons on the carbon atom adjacent to the one to which the given proton is attached, **(Application)** **[SLO: C-12-F-15]** Deduce possible structures for the molecule **(Application)** **[SLO: C-12-F-16]** Predict the chemical shifts and splitting patterns of the protons in a given molecule **(Application)** **[SLO: C-12-F-17]** explain the use of tetramethylsilane, TMS, as the standard for chemical shift measurement **(Understanding)** **[SLO: C-12-F-18]** Recognize the need for deuterated solvents, e.g. $CDCl_3$, when obtaining a proton NMR spectrum **(Understanding)**

				[SLO: C-12-F-19] Describe the identification of O–H and N–H protons by proton exchange using D_2O **(Understanding)** **[SLO: C-12-F-20]** Explore how Mass spectrometry (MS), proton nuclear magnetic resonance spectroscopy (1H NMR) and infrared spectroscopy (IR) are techniques that can be used to help identify compounds and to determine their structure **(Understanding)**

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 exothermic reactions and conduct practical work to investigate the heat released during such a reaction. In this experiment they would learn experimental design, data collection and analysis skills. Similarly in Grade 10 they may learn about stoichiometry and then conduct titration experiments. 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 G: Lab and Practical Skills **This domain is about the skills necessary to understand how to plan and practically perform chemical experiments. These skills should be applied not only in the science laboratory, but also as critical analysis skills to understand empirical data.**		
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 in general lab settings while using appropriate apparatus, equipment and methods.		

[SLO: C-09-10-G-01] identify apparatus from diagrams or descriptions **[SLO: C-09-10-G-02]** draw, complete or label diagrams of apparatus **[SLO: C-09-10-G-03]** Explain the use of, common techniques, apparatus and materials **[SLO: C-09-10-G-04]** select the most appropriate apparatus or method for the task and justify the choice made **[SLO: C-09-10-G-05]** Identify appropriate apparatus for the measurement of time, temperature, mass and volume, including: a. stopwatches b. thermometers c. balances d. burettes e. volumetric pipettes f. measuring cylinders g. gas syringes		

[SLO: C-09-10-G-06] Justify why chemists use cm^3, g and s as more practical units when working with small amounts in lab		
Standard: Students should be able to plan and carry out experiments and investigations. They should also be able to make and record observations and measurements.		
Benchmark I: Students should be able to apply scientific knowledge to conduct simple experiments using appropriate apparatus.	**Benchmark I: Students should be able to collect data under instructor supervision while ensuring quality of measurement and observation.**	**Benchmark I: Students should be able to accurately carry out titration experiments, ensuring quality observations and proper tabulation of results**
[SLO: C-09-10-G-07] Separate a given mixture by sublimation. **[SLO: C-09-10-G-08]** calculate (Molarity) concentration of a Acid/ base solution in a titration using empirical data **[SLO: C-09-10-G-09]** Explain methods of separation and purification (some example include: a) using a suitable solvent b) filtration c) crystallisation d) simple distillation e) fractional distillation)	**[SLO: C-11-G-01]** Set up apparatus following instructions given in written or diagrammatic form. **[SLO: C-11-G-02]** use apparatus to collect an appropriate quantity of data **[SLO: C-11-G-03]** make observations, including subtle differences in colour, solubility or quantity of materials **[SLO: C-11-G-04]** make measurements using pipettes, burettes, measuring cylinders, thermometers and other common laboratory apparatus;	**[SLO: C-12-G-01]** Explain the principle behind titration (Use the following types of titrations as examples: acid-alkali titration (this could be weak or strong acid and weak or strong alkali), potassium manganate(VII) titration with hydrogen peroxide, iron(II) ions, nitrite ions or ethanedioic acid or its salts and sodium thiosulfate and iodine titration) **[SLO: C-12-G-02]** Analyse reactions involving MnO_4^- / $C_2O_4^-$ in acid solution given suitable data (including describing the reaction and doing calculations) **[SLO: C-12-G-03]** Analyse reactions involving MnO_4^- / Fe^{2+} in acid solution given suitable data ((including describing the reaction and doing calculations) **[SLO: C-12-G-04]** understand how to correctly set up a burette in order to carry out titrations.

[SLO: C-09-10-G-10] Suggest suitable separation and purification techniques, given information about the substances involved, and their usage in daily life **[SLO: C-09-10-G-11]** Identify substances and assess their purity using melting point and boiling point information **[SLO: C-09-10-G-12]** Describe tests to identify important gasses (Some examples include: a. ammonia, NH_3, using damp red litmus paper b. carbon dioxide, CO_2, using limewater c. chlorine, Cl_2, using damp litmus paper d. hydrogen, H_2, using a lighted splint e. oxygen, O_2, using a glowing splint f. sulfur dioxide, SO_2, using acidified aqueous potassium manganate(VII) **[SLO: C-09-10-G-13]** Explain the use of a flame test to identify important cations: (Some examples include: a. lithium, Li^+ b. sodium, Na^+ c. potassium, K^+ d. calcium, Ca^{2+} e. copper(II), Cu^{2+} f. barium, Ba^{2+})	**[SLO: C-11-G-05]** decide how many tests or observations to perform **[SLO: C-11-G-06]** • identify where repeated readings or observations are appropriate **[SLO: C-11-G-07]** • replicate readings or observations as necessary, including where an anomaly is suspected **[SLO: C-11-G-08]** • identify where confirmatory tests are appropriate and the nature of such tests **[SLO: C-11-G-09]** • select reagents to distinguish between given ions. **[SLO: C-11-G-10]** Carry out procedures using simple apparatus, in situations where the method may not be familiar to the candidate	**[SLO: C-12-G-05]** Identify the importance of carrying out a rough titration before **[SLO: C-12-G-06]** Carry out titrations until concordant results are obtained. **[SLO: C-12-G-07]** Identify and use appropriate indicators in the titration. **Benchmark: Students should be able to accurately carry out rate experiments, ensuring quality observations and appropriate presentation of results.** **[SLO: C-12-G-08]** Carry out rate investigation by mixing reagents and recording the time for an observation to occur. **[SLO: C-12-G-09]** Suggest experimental designs to measure the rate of a reaction. **Benchmark: Students should be able to accurately carry out gravimetric experiments, ensuring quality observations and appropriate presentation of results.** **[SLO: C-12-G-10]** prepare a sample for gravimetric analysis **[SLO: C-12-G-11]** Perform a gravimetric analysis using appropriate techniques (may include precipitation and filtration)

[SLO: C-09-10-G-14] Carry out separation and purification techniques (This may include: - filtration - crystallisation - simple distillation - fractional distillation - chromatography - electrolysis) **[SLO: C-09-10-G-15]** Describe how paper chromatography is used to separate mixtures of soluble substances, using a suitable solvent **[SLO: C-09-10-G-16]** Describe the use of locating agents when separating mixtures containing colorless substances. (For context, knowledge of specific locating agents is not required **[SLO: C-09-10-G-17]** Interpret simple chromatograms (For context, students should identify: a) unknown substances by comparison with known substances b) pure and impure substances) **[SLO: C-09-10-G-18]** State and use the equation for R_f **[SLO: C-09-10-G-19]** Investigate chemical tests for the presence of water using anhydrous copper(II) sulfate		**[SLO: C-12-G-12]** ensure quality of observation by properly controlling variables, using appropriate equipment, and making accurate and precise measurements (for example heat a solid in a crucible on a pipe- clay triangle and record any mass change) **Benchmark: Students should be able to accurately carry out thermometric experiments, ensuring quality observations and appropriate presentation of results.** **[SLO: C-12-G-13]** prepare and set up a sample for a thermometric analysis to find enthalpy change of neutralisation including appropriate mixing and stirring techniques **[SLO: C-12-G-14]** accurately use and take readings from thermometers **[SLO: C-12-G-15]** Perform calculation of enthalpy change of neutralisation by using $\Delta H = mc\Delta T/n$ **Benchmark: Students should be able to accurately carry out gas volume experiments, ensuring quality observations and proper tabulation of results..** **[SLO: C-12-G-16]** Set up and prepare a gas volume experiment, including appropriate apparatus selection and assembly techniques **[SLO: C-12-G-17]** use a gas syringe, gas burette, or other appropriate equipment to measure gas volume

[SLO: C-09-10-G-20]
Explain how to test the purity of water using melting point and boiling point

[SLO: C-09-10-G-21]
Distinguish between Distilled water and tap water with their applications in practical chemistry.

[SLO: C-09-10-G-22]
suggest the most appropriate apparatus or technique and justify the choice made

[SLO: C-09-10-G-23]
– describe experimental procedures

[SLO: C-09-10-G-24]
take readings from apparatus (analogue and digital) or from diagrams of apparatus with appropriate precision,

[SLO: C-09-10-G-25]
– take sufficient observations or measurements, including repeats where appropriate

[SLO: C-09-10-G-26]
– record qualitative observations from chemical tests and other tests

[SLO: C-09-10-G-27]
record observations and measurements systematically (in a suitable table, to an appropriate degree of precision and using appropriate units)

Benchmark: Students should be able to accurately perform qualitative analysis tests while observing appropriate safety precautions and demonstrate the knowledge and skills required for the respective experiments.

[SLO: C-12-G-18]
Perform the following organic analysis tests and interpret the positive test result to identify the functional group present:

- the production of an orange/red precipitate with Fehling's reagent to indicate the presence of the aldehyde functional group
- the production of a silver mirror/black precipitate with Tollens' reagent to indicate the presence of the aldehyde functional group
- the production of a yellow precipitate with alkaline aqueous iodine to indicate the presence of the CH_3CO or $CH_3CH(OH)$ group
- the change in colour of acidified potassium manganate(VII) from purple to colourless to indicate the presence of a compound that can be oxidised.

Benchmark 2: Students will be able to evaluate the results of qualitative analysis experiments by interpreting observations and data, determining the accuracy and precision of findings, and identifying potential errors and sources of error.		
N/A		

Acid–base titrations

[SLO: C-11-G-11]

Describe an acid–base titration to include the use of a:

a. burette

b. volumetric pipette

c. suitable indicator

[SLO: C-11-G-12]

Describe how to identify the end-point of a titration using an indicator

[SLO: C-11-G-13]

Perform acid-base titrations to calculate molarity and strength of given sample solutions.

[SLO: C-11-G-14]

Select suitable indicators for acid-alkali titrations, given appropriate data (pK_a values will not be used)

Identification of ions and gases

[SLO: C-11-G-15]

Understand the appropriate methods to be used when carrying out qualitative analysis tests:

- to treat all unknown materials with caution
- to use an appropriate quantity of the material under test
- to work safely, e.g. to use a test-tube holder when heating a solid in a hard-glass test-tube
- to record all observations, even when this is ‘no change’ or ‘remains a colourless solution’
- to use excess alkali where a precipitate is produced on addition of NaOH(aq) or NH_3 (aq) to determine its solubility
- to identify a gas whose formation is shown by effervescence.

[SLO: C-11-G-16]

Describe tests to identify the anions:

d. carbonate by reaction with dilute acid and then testing for carbon dioxide gas

e. nitrate by reduction with aluminum foil and aqueous sodium hydroxide and then testing for ammonia gas

f. sulfate by acidifying with dilute nitric acid then adding aqueous barium nitrate

g. sulfite by reaction with acidified aqueous potassium manganate(VII)

h. Halides (Cl^{1-}, Br^{1-} and I^{1-}) with aqueous silver nitrate followed by aqueous ammonia

[SLO: C-11-G-17]

- Describe tests using aqueous sodium hydroxide and aqueous ammonia to identify the aqueous cations:

a. aluminum, Al^{3+}

b. ammonium, NH_4^{1+}

c. calcium, Ca^{2+}

d. chromium(III), Cr^{3+}

e. copper(II), Cu^{2+}

f. iron(II), Fe^{2+}

g. iron(III), Fe^{3+}

h. zinc, Zn^{2+}

Benchmark I: Students should be able to present data in a tabulated or graphical form.	**Benchmark I: Students should be able to present data in a meaningful way and be able to interpret it.**	**Benchmark I: Students should be able to analyse the presented data and identify sources of error.**
[SLO: C-09-10-G-28] record the results of an experiment [SLO: C-09-10-G-29] – process data, including calculations for graph plotting [SLO: C-09-10-G-30] present data graphically, including the use of best-fit lines where appropriate [SLO: C-09-10-G-31] – analyse and interpret observations and data, including data presented graphically [SLO: C-09-10-G-32] – evaluate the quality of observations and data, identifying any anomalous results	[SLO: C-11-G-18] • present numerical data, values or observations in a single table of results with headings and units that conform to accepted scientific conventions [SLO: C-11-G-19] • draw an appropriate table in advance of taking readings or making observations and record all data in the table [SLO: C-11-G-20] plot appropriate variables on appropriate, clearly labelled x- and y-axes with carefully chosen scales [SLO: C-11-G-21] draw straight lines or smooth curves of best fit to show the trend of a graph; [SLO: C-11-G-22] describe the patterns and trends shown by data in tables and graphs [SLO: C-11-G-23] • determine the gradient of a straight-line graph and extrapolate the line of a graph. •	[SLO: C-12-G-19] Identify the best way to present collected and transformed data based on the experiment being performed [SLO: C-12-G-20] record raw readings of a quantity to the same degree of precision and observations to the same level of detail [SLO: C-12-G-21] show working in calculations and key steps in reasoning [SLO: C-12-G-22] use the correct number of significant figures for calculated quantities

	[SLO: C-11-G-24] Draw conclusions from interpretations of observations, data and calculated values **[SLO: C-11-G-25]** Make scientific explanations of data, observations and conclusions that they have described.	
Standard: Students should be able to evaluate methods and suggest possible improvements.		
Benchmark I: Students should be able to suggest improvements in the experimental design	**Benchmark I: Students should be able to evaluate the method used and suggest improvements based on validity, reliability and safety.**	**N/A**
[SLO: C-09-10-G-33] identify potential sources of error in an experimental design	**[SLO: C-11-G-26]** Describe systematic errors **[SLO: C-11-G-27]** identify the most significant sources of error in an experiment	

	[SLO: C-11-G-28] State the uncertainty in a quantitative measurement and express such uncertainty in a measurement as an actual or percentage error **[SLO: C-11-G-29]** Suggest alternate chemicals in experimental design which contribute to green chemistry	

Guidelines for Authors, Teaching Strategies for SLO-Based Instruction, and Assessment Framework for Paper Setters

Introduction

The document provides detailed guidelines for textbook authors, recommended strategies compatible with SLOs and standardized assessment patterns for future paper setters, including PBA. This will also complete the curriculum package with clear and consistent link among curriculum intent, classroom instruction, laboratory practice and assessment standards to ensure uniformity and coherence in the implementation of the revised curriculum.

Section A: Guidelines for Textbook Authors

A.1 Alignment with SLOs

All chapters, topics, and subtopics strictly adhere to the prescribed SLOs. Additional content, beyond the scope of approved SLOs, should not be included. Content of the SLOs should match the local and international levels standard with examples from the local context. Content of the chapter should clearly reflect the intent and limits of the SLOs at the appropriate grade level. Author should follow the given guidelines :

- **All facts, laws, constants, and equations must be scientifically correct.**
- **Use SI units consistently.**
- **Provide correct chemical equations with balanced stoichiometry.**
- **Avoid ambiguous or outdated scientific terms.**

A.2 Depth and Cognitive Level

Author of textbook must understand and adhere to a specified, required cognitive level (Knowledge, Understanding, Application, or Higher Order) assigned to each SLO. The text shall avoid unnecessary theoretical depth, complicated derivations, or university-level explanations unless specifically required by the syllabus. Concepts should be explained in simple and clear language, supported by relevant examples from daily life. Any safety precautions related to the concepts must be clearly highlighted

A.3 Language and Presentation

The language of the textbook should be clear, precise, learner-friendly and scientifically accurate. Technical/scientific terminologies should be used instead of using translated terms. Diagrams, figures and tables should be clearly labelled, accurate, relevant to the targeted SLOs, easy for students to understand and not to be copy paste where applicable.

A.4 Examples and Illustrations

Worked examples and illustrations should directly support conceptual clarity and attainment of the SLOs. Examples should logically progress from simple to moderate levels of difficulty and Numerical problems should involve basic calculations and avoid multi-step complexity beyond the curriculum scope.

A.5 Exercises

Exercises at the end of each chapter should be clearly aligned to relevant SLOs and their cognitive levels. An appropriate balance of the following components should be ensured:

- Objective-type questions (MCQs)
- Structured questions (Both short response and extended response questions)
- Repetition of similar questions across chapters is not encouraged.
- Questions should address all cognitive levels of the SLOs in same proportion as mentioned in the chapters.

Each chapter should follow this structure:

- Introduction (link with prior knowledge)
- Key concepts

- Examples and illustrations
- Applications
- Key points
- Exercises

A.6 Use of Pedagogical Features

Include:

- Did You Know?
- Think About It
- Real-Life Applications
- Science Tidbits

Section B - Teaching Strategies for SLO-Based Instruction

B.1 General Principles

Teaching and learning practices should focus on the achievement of prescribed Student Learning Outcomes (SLOs) through logical reasoning rather than mere syllabus coverage. Lesson planning should clearly identify targeted SLOs, teaching strategies, and assessment approaches. Instruction should promote conceptual clarity and subject understanding appropriate to the specified level.

B.2 Teaching Strategies Aligned with Cognitive Levels

Interactive lectures, visuals, and recall-based activities are recommended for Knowledge based SLOs, while Understanding level SLOs can be addressed through guided discussion, concept mapping and real-life examples. Application level SLOs should be taught with problem-solving, demonstrations and laboratory activities. Whenever possible, Higher-Order SLOs may require inquiry based learning, group discussions and interpretation of data. For effective teaching and practice of multiple choice questions, students should be asked to provide reasons for their chosen options. Teacher must use new teaching methods like flipped classroom, blended learning etc.

B.3 Assessment Techniques during Teaching

a) Formative Assessment (During Learning)

- Short quizzes, class tests, and surprise tests
- Homework and worksheets
- Oral questioning
- Class participation / group discussions
- Lab work observation
- Concept mapping

b) Summative Assessment (End of Learning)

- Midterm/Sendup exams (As per the discretion of institution head)
- Mock exam/Preboard (As per the discretion of institution head)
- Final exams (Including theory/Practical) (As per the mandate)

B.4 Practical and Laboratory Based Learning

Practical work must be directly linked with the practical SLOs and focus on the development of experimental skills, observation and result interpretation. Experiments should not be beyond the prescribed scope of the curriculum.

B.5 Integration of Technology

Resources such as digital tools such as mathgpt, Bing AI, Copilot by Microsoft, Deep Seek, Magical School AI, Khan Academy, Bright Class and Edmodo etc, simulations (PHET Interactive Simulations) and multimedia can be used to build conceptual understanding. Artificial intelligence-based tools may be used to support formative assessment for concept clarification, supported appropriately by the teacher. Following tools/websites may be used to perform experiments on the virtual lab or to prepare chemical solution etc i.e. ChemReaX, ChemCollective and wolfram alpha.

Section C: Assessment Framework and Guidelines for Paper Setters

C.1 Purpose of Assessment

Assessment should adhere to the essence of SLOs within cognitive level domain. Questions should assess conceptual clarity, basic application, and instructional activities related understanding appropriate to specified level. Standard Numerical values of constants should be provided in the question paper as required.

C.2 Cognitive Level Weightage

Paper setters should maintain a balanced distribution of cognitive levels as follows: Knowledge: 20% Understanding: 50% and Application/analysis/Evaluation: 30% (Higher order items should only be included where applicable).

C.3 Types of Assessment Questions

Permissible formats include:

- Multiple-choice questions (MCQs)
- Structured questions (Short and extended response questions)

Questions should be:

- Clear and unambiguous
- Concept based
- Appropriate in length and difficulty for specified grades.

C.4 Practical-Based Assessment (PBA)

The PBA paper should be conceptual and skill-oriented. It should be set in a manner that the students who attend the laboratory sessions regularly and perform practical work in the laboratory are capable of attempting the paper. PBA questions must include experimental objectives, use of apparatus, observation, interpretation of data, good laboratory safety practices and problems that require solution in an experimental setting. The paper must avoid assessing rote learning of practical manuals or the long reproduction of procedures.

Conclusion

The revision of the Chemistry curriculum for Grades 9–12 has been carried out as a strategic policy initiative to enhance curriculum relevance, coherence, and alignment with national educational goals and internationally recognized standards. A comprehensive review revealed that the existing curriculum content was overburden, exhibited improper vertical progression of Student Learning Outcomes (SLOs), and, in several instances, SLOs are beyond the expectations of the cognitive level of students at the respective grades.

Furthermore, the presence of overlapping and repetitive SLOs across allied subjects, particularly Biology and Physics, resulted in unnecessary academic burden and dilution of subject focus. To address these challenges, redundant and misaligned SLOs were rationalized or removed, ensuring that Chemistry retains its disciplinary integrity while avoiding duplication of learning objectives already addressed in other subjects.

As part of the reform process, selected SLOs were reallocated across grade levels to establish a logical, gradual progression from foundational concepts in Grade 9 to advanced understanding in Grade 12. In addition, certain SLOs were shifted across learning domains to ensure alignment among curriculum intent, instructional practices, and assessment frameworks.

The development of clear implementation guidelines for teachers, textbook authors, and paper setters is a key policy measure to ensure uniform and effective execution of the revised curriculum. These guidelines promote outcome-based instruction, conceptual clarity, real life relevance, and assessment practices aligned with defined cognitive levels, while explicitly discouraging unwarranted theoretical depth and advanced derivations not required at this stage.

A. List of Internal Curriculum Review Committee Members

	Name & Designation	Role in Committee
1	Dr. Tabassum Naz, Director, National Curriculum Council, Islamabad	Chairperson
2	Abdul Hanan, Deputy Educational Advisor, National Curriculum Council, Islamabad	Coordinator
3	Naeem Mushtaq, Chemistry, IMCB, G-10/4, Islamabad	Member
4	Saima Noor, FGEI (C/G), Islamabad	Member
5	Sheikh Zafar Hayat, FIC, Nur Khan, Chaklala	Member
6	Prof. Dr. Moazzam H. Bhatti, Chemistry, AIUO	Member
7	Shehla Naz, IMCG, F-7/4, Islamabad	Member
8	Prof. Muhammad Iqtidar ud din, NBF, Islamabad	Member
9	Rubina Kousar, SST, FGEI (C/G), Islamabad	Member
10	Imran Ahmad Khan, Assistant Educational Advisor, National Curriculum Council, Islamabad	**Member/Secretary**

B. List of Inter-Provincial Curriculum (IPCW) Review Committee Members

	Name & Designation	Province / Region	Role in Committee
1	Naeem Mushtaq, Chemistry, IMCB, G-10/4	ICT	Member
2	Naresh Kumar, Subject Specialist, Textbook Board	Sindh	Member

3	Muhammad Naeem Aftab, SSS, Coordinator, PECTA	ICT	Member
4	Robina Kousar, Assistant Dir/SST, FEGI (C/G), PTE	ICT	Member
5	Prof. Dr. Moazzam Bhatti, Chemistry, AIOU	ICT	Member
6	Humaria Bureen, Principal, Army Public School & College	Head Mistress	Member
7	Dr. Afia Iqbal, SS (TS), DCTE ATD	KP	Member
8	Dr. Anees Saeed, Desk Officer, Chemistry, Textbook Board	AJ&K	Member
9	Kamran Nawaz, Additional Director, DCAR	Jamshoro, Sindh	Member
10	Syed Ayub Hassan, SS, Chemistry,	Layyah	Member
11	Ghulam Rabani, Principal, Education Expert,	GB	Member
12	Dr. Habib Ur Rehman, B.O.C	Quetta, Balochistan	Member
13	Muhammad Qadeer Jaral, Subject Specialist, DEE&SE	AJ&k	Member
14	Muhammad Sharjeel Sharif, Deputy Director (c)	Multan	Member
15	Mr. Imran Ahmad Khan, Assistant Educational Advisor	National Curriculum Council, Islamabad	**Member/Secretary**

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