DESIGNED FOR GIFTED, NEURODIVERSE, AND HIGHLY CAPABLE YEAR 9-10 STUDENTS

ADVANCING IN SCIENCE: PATHWAYS FOR STAGE 5 NEW SOUTH WALES SCIENCE CURRICULUM

Contents

Introduction to This Textbook

Welcome to Stage 5 Science! This textbook has been specially designed to build on your Stage 4 knowledge and help you develop deeper scientific understanding and skills. Whether you're a student who loves to explore scientific concepts in depth, someone who thinks about ideas in unique ways, or a learner who appreciates clear explanations and engaging activities, this book will support your journey.

How to Use This Book

As you explore this textbook, you'll notice several special features:

- **Margin Notes:** Extra information, definitions, and extension ideas in the margins.
- *** Challenge Questions:** Advanced questions that stretch your thinking beyond the basics.
- **Tiered Activities:** Choose your level of challenge—core questions for everyone and advanced options to push your thinking.
- **Investigations:** Hands-on experiments to develop your scientific inquiry skills.
- **Real-World Scenarios:** Apply your scientific knowledge to authentic situations, similar to those you might encounter in PISA assessments.
- **Extension Activities:** Optional explorations for students ready to go beyond the standard curriculum.

This textbook aligns with the NSW Stage 5 Science syllabus while providing enrichment opportunities and support for diverse learning styles. It also helps prepare you for PISA assessments by developing your ability to apply scientific knowledge to real-world situations.

Science at Stage 5 builds on your previous learning and prepares you for future studies or careers in science-related fields. As you engage with the concepts and activities in this book, remember that science is both a body of knowledge and a process of inquiry—continue to observe, question, investigate, and explain the fascinating world around you!

Scientific Investigations and Research Skills

Chapter Overview

In this chapter, we'll build on your scientific inquiry skills from Stage 4 and develop more sophisticated approaches to investigations. You'll learn advanced experimental design techniques, how to analyze the reliability and validity of data, and how to conduct independent research projects. These skills will prepare you for the mandatory student research project (SRP) and develop your abilities as an independent scientific investigator.

This chapter aligns with the following NSW Syllabus outcomes:

- SC5-4WS: Develops questions or hypotheses to be investigated scientifically
- SC5-5WS: Produces a plan to investigate identified questions, hypotheses or problems, individually and collaboratively
- SC5-6WS: Undertakes first-hand investigations to collect valid and reliable data and information, individually and collaboratively
- SC5-7WS: Processes, analyzes and evaluates data from first-hand investigations and secondary sources to develop evidence-based arguments and conclusions
- SC5-8WS: Applies scientific understanding and critical thinking skills to suggest possible solutions to identified problems
- SC5-9WS: Presents science ideas and evidence for a particular purpose and to a specific audience, using appropriate scientific language, conventions and representations

Before we begin, let's assess your current understanding of scientific investigations:

Stop and Think

1. What makes a scientific question or hypothesis testable?
2. How do you know if scientific data is reliable?
3. What's the difference between a variable and a control in an experiment?
4. What kinds of information should be included in a scientific report?

Advanced Experimental Design

DESIGNING RIGOROUS experiments is essential for generating valid scientific knowledge. At Stage 5, we'll refine our experimental design skills to account for more factors.

Variables and Controls Revisited

Recall from Stage 4 that well-designed experiments carefully manage variables:

Key Concept: Key Variables in Experiments

Independent variable The factor deliberately changed by the experimenter

Dependent variable The factor measured to determine the effect of the independent variable

Controlled variables Factors kept constant to ensure a fair test

At Stage 5, we need to consider additional aspects of variables:

- **Continuous vs. Categorical Variables:**
  - Continuous variables can take any numerical value (e.g., temperature, time, mass)
  - Categorical variables fall into distinct categories (e.g., types of soil, species of plant)
- **Range and Intervals:** For continuous independent variables, you need to determine an appropriate range and intervals to test (e.g., testing temperature at 10°C, 20°C, 30°C, and 40°C)
- **Confounding Variables:** Factors that might influence results but aren't part of your experimental design

Math Link: When determining sample size, consider statistical power. Larger sample sizes generally provide more reliable results. A common guideline is to have at least 30 data points for statistical significance, though this varies by field and experiment type.

Experimental Controls

Controls are crucial for valid scientific investigations:

- **Negative Controls:** Samples that aren't exposed to the experimental treatment and should show no effect
- **Positive Controls:** Samples that are exposed to a treatment known to cause an effect, confirming the experiment can detect the effect
- **Procedural Controls:** Tests that check whether experimental procedures themselves affect results

History: The concept of a "controlled experiment" with proper controls was established by Claude Bernard (1813-1878), a French physiologist who emphasized the need for comparison groups in scientific experiments.

Sampling Techniques

How you select samples can significantly impact your results:

Key Concept: Sampling Methods

Random sampling Every member of the population has an equal chance of being selected

Stratified sampling The population is divided into subgroups, and samples are taken from each

Systematic sampling Selecting every nth member from the population

Convenience sampling Using easily accessible samples (generally less reliable)

* **Challenge:** Research the concept of "pseudoreplication" in scientific experiments. Why is it a problem, and how can scientists avoid it? Find an example of a study where pseudoreplication might have affected the results.

Investigation: Designing a Rigorous Experiment

Purpose: To practice designing an experiment with appropriate variables, controls, and sampling techniques.
Scenario: Your team wants to investigate the effect of different fertilizers on plant growth.
Task:

1. Formulate a specific, testable hypothesis about fertilizers and plant growth.
2. Design an experiment that includes:
   - Clearly identified independent and dependent variables
   - At least five controlled variables with explanations of how you'll control each
   - Appropriate control groups (negative and/or positive)
   - Sample size justification and sampling method
   - Measurement techniques with attention to precision and accuracy
   - Timeline for the experiment
3. Create a detailed procedural outline that another team could follow.
4. Identify potential confounding variables and how you'll address them.
5. Design a data collection table and explain how you'll analyze the results.
6. Discuss potential limitations of your experimental design.

Extension: Develop a mini research proposal that includes a literature review section discussing previous related studies and how your experiment builds on existing knowledge.

Data Reliability and Validity

NOT ALL DATA is created equal. Scientists must assess data quality to draw sound conclusions.

Reliability vs. Validity

Key Concept: Reliability and Validity

Reliability The consistency or repeatability of measurements

- Test-retest reliability: Same results when repeated
- Inter-rater reliability: Different observers get same results
- Internal consistency: Different methods give similar results

Validity The accuracy of measurements in representing what they claim to measure

- Construct validity: Measures what it claims to measure
- Internal validity: Supports cause-and-effect relationships
- External validity: Results can be generalized beyond the study

Sources of Error and Uncertainty

Understanding sources of error helps evaluate data quality:

- **Random errors:** Unpredictable variations in measurements (can be reduced by taking multiple measurements)
- **Systematic errors:** Consistent, predictable deviations (e.g., miscalibrated instrument)
- **Human errors:** Mistakes in conducting procedures or recording data
- **Environmental factors:** Uncontrolled conditions affecting results

Improving Data Quality

Strategies to enhance reliability and validity include:

- **Replication:** Repeating experiments multiple times
- **Standardization:** Using consistent methods and conditions
- **Calibration:** Ensuring instruments give accurate readings
- **Blinding:** Preventing bias by hiding treatment information
- **Appropriate sample sizes:** Collecting sufficient data for statistical analysis
- **Triangulation:** Using multiple methods to measure the same variable

Math Link: Uncertainty in measurements can be expressed mathematically. For a set of repeated measurements, calculate the standard deviation (σ) using the formula: $\sigma = \sqrt{\frac{\sum(x-\mu)^2}{N}}$ where x is each value, μ is the mean, and N is the number of values. A smaller standard deviation indicates more precise measurements.

Investigation: Evaluating Data Reliability and Validity

Purpose: To analyze sources of error and assess data quality.
Materials:

- Different measuring instruments (e.g., rulers, measuring cylinders, electronic balances, thermometers)
- Objects or substances to measure
- Data recording sheets

Procedure (Part 1 - Instrument Precision):

1. Select an object or substance to measure (e.g., volume of water, mass of a weight, length of an object).
2. Using the same instrument, take 10 repeat measurements of the same property.
3. Calculate the mean, range, and standard deviation of your measurements.
4. Repeat with different types or brands of instruments measuring the same property.
5. Compare the precision of different instruments.

Procedure (Part 2 - Observer Reliability):

1. Have multiple class members measure the same property using the same instrument.
2. Compare the measurements and calculate inter-observer reliability.
3. Discuss factors that might cause different observers to get different results.

Analysis:

1. Which instruments showed the highest precision (lowest variation in repeated measurements)?
2. What factors contributed to measurement errors in your experiment?
3. How could you improve the reliability of these measurements?
4. Discuss how the concept of significant figures relates to instrument precision.
5. How would measurement errors affect conclusions in scientific research?

Research Methodologies

Scientific research extends beyond controlled experiments. Different research questions require different methodologies.

Types of Scientific Investigations

Key Concept: Research Methodologies

Controlled experiments Manipulating variables under controlled conditions to test cause-and-effect relationships

Field studies Collecting data in natural settings where variables cannot be fully controlled

Observational studies Recording observations without intervention or manipulation

Case studies In-depth investigations of single instances or events

Surveys and questionnaires Collecting self-reported data from participants

Meta-analyses Systematically combining results from multiple studies

Modeling Using mathematical or computational models to simulate processes

Each methodology has strengths and limitations. The choice depends on your research question, available resources, ethical considerations, and practical constraints.

History: The scientific method as we understand it today evolved gradually. Different disciplines developed specialized methodologies—for example, geology relies heavily on observational studies due to the timescales involved, while chemistry often emphasizes controlled laboratory experiments.

Choosing the Right Methodology

Consider these factors when selecting a research approach:

- **Research question type:** "How" and "why" questions often need experiments; "what" and "how many" might use surveys
- **Control of variables:** Can you manipulate variables, or must you observe them naturally?
- **Timescale:** Some phenomena occur over periods too long for direct experimentation
- **Ethical considerations:** Some experiments might not be ethical to conduct

- **Resources and practicality:** Consider equipment, time, and expertise needed

- **Sample accessibility:** Can you access appropriate samples?

Mixed Methods Approaches

Many modern scientists use mixed methods, combining multiple approaches to gain comprehensive understanding:

- Quantitative methods provide numerical data and statistical analyses

- Qualitative methods provide descriptive, contextual information

- Using both can provide complementary insights

* **Challenge:** Choose a recent scientific discovery in any field. Research the methodology used by the scientists. What made this method appropriate for their research question? Could they have used alternative approaches? What would be the advantages or disadvantages of those alternatives?

Investigation: Comparing Research Methodologies

Purpose: To evaluate different research approaches for a scientific question.
Task:

1. Select one of these research questions (or propose your own with teacher approval):
   - How does sleep duration affect academic performance?
   - What factors influence local bird species diversity?
   - How effective are different face mask types at filtering particles?
   - What is the relationship between exercise intensity and heart rate recovery time?
2. For your chosen question, design three different research approaches:
   - A controlled experiment
   - An observational study
   - A survey-based study
3. For each methodology, provide:
   - A detailed description of the method
   - The types of data you would collect
   - How you would analyze the data
   - Potential sources of error or bias
   - Strengths and limitations of the approach
4. Recommend which methodology (or combination) would be most appropriate for the research question and justify your recommendation.

Extension: Design a mixed-methods approach that combines quantitative and qualitative elements to address your research question more comprehensively.

Statistical Analysis of Data

ANALYZING DATA statistically allows scientists to draw meaningful conclusions and determine whether results are significant.

Descriptive Statistics

Descriptive statistics summarize and organize data:

Key Concept: Descriptive Statistical Measures

Measures of central tendency
- Mean: The average of all values
- Median: The middle value when arranged in order
- Mode: The most frequently occurring value

Measures of spread
- Range: The difference between the highest and lowest values
- Standard deviation: A measure of how spread out the data is from the mean
- Interquartile range: The range of the middle 50% of the data

Math Link: The formula for the mean (average) is $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ where x_i represents each value and n is the number of values. For example, the mean of 4, 7, and 10 is $\frac{4+7+10}{3} = 7$.

Interpreting Data Graphically

Visual representations help identify patterns and trends:

- **Scatter plots:** Show relationships between two continuous variables
- **Line graphs:** Display trends over time or continuous data
- **Bar graphs:** Compare discrete categories
- **Box plots:** Show distribution, central tendency, and outliers
- **Histograms:** Display frequency distributions

Inferential Statistics

Inferential statistics help determine whether results are statistically significant:

- **Statistical significance:** The likelihood that results are not due to random chance
- **P-value:** The probability of obtaining results at least as extreme as those observed, assuming the null hypothesis is true (typically, $p < 0.05$ is considered significant)
- **Confidence intervals:** The range within which the true value likely falls
- **Common tests:**
  - T-test: Compares means between two groups

- ANOVA: Compares means among three or more groups
- Chi-square test: Analyzes categorical data
- Correlation: Measures relationship strength between variables

History: The concept of statistical significance and p-values was developed by Ronald Fisher in the 1920s. His contributions revolutionized experimental design and data analysis in scientific research.

Correlation vs. Causation

A critical concept in data analysis is understanding that correlation doesn't imply causation:

- **Correlation:** Two variables change together (positive, negative, or no correlation)
- **Causation:** One variable directly causes changes in another
- **Alternative explanations:** Third variables, reverse causality, or coincidence

Investigation: Analyzing Scientific Data

Purpose: To practice statistical analysis of experimental data.
Scenario: A scientist conducted an experiment to test the effect of light intensity on plant growth. Twenty identical plants were randomly assigned to four groups, each exposed to a different light intensity (25

Plant	25% Light	50% Light	75% Light	100% Light
1	10.2	15.6	18.7	17.8
2	9.8	14.9	19.1	16.9
3	11.3	16.2	20.5	18.2
4	8.9	15.4	19.8	17.5
5	10.5	15.8	18.2	17.1

Tasks:

1. Calculate descriptive statistics for each light intensity group:
   - Mean plant height
   - Median plant height
   - Range of heights
   - Standard deviation (if you have access to calculators or software)
2. Create appropriate graphs to visualize the data:
   - A bar graph showing mean height for each light intensity
   - A scatter plot of light intensity vs. plant height
3. Analyze and interpret the results:
   - Is there a relationship between light intensity and plant height?
   - What type of relationship is it (positive, negative, nonlinear)?
   - At what light intensity did plants grow tallest?
   - Can you conclude that light intensity causes the observed differences? Why or why not?
   - What other factors might have influenced the results?
4. Draw a conclusion about the optimal light intensity for these plants, supporting your answer with statistical evidence.

Extension: Research and apply a t-test to determine if the differences between groups are statistically significant. Report your calculated p-value and interpret what it means.

* **Challenge:** Find a news article that misinterprets correlation as causation. Analyze the article, identifying the variables involved and possible alternative explanations for the relationship. Rewrite a short paragraph of the article to more accurately represent the scientific limitations of the finding.

Conducting a Student Research Project

The Student Research Project (SRP) is an opportunity to apply scientific investigation skills to a question of your choosing. This section will guide you through the process.

Selecting a Research Question

A good research question is:

- **Specific:** Clearly defines what you'll investigate
- **Measurable:** Can be answered with observable data
- **Achievable:** Feasible within your resources and timeframe
- **Relevant:** Connects to scientific concepts and has real-world applications
- **Time-bound:** Can be completed within the allotted time

Literature Review

Before conducting your own research, investigate what's already known:

- **Purpose:** Understand existing knowledge, identify gaps, and inform your methodology
- **Sources:** Textbooks, scientific journals, reputable websites, databases
- **Evaluation:** Assess source credibility, recency, and relevance
- **Organization:** Summarize key findings related to your research question

History: The systematic literature review was formalized as a scientific methodology by Archie Cochrane in the 1970s. His work led to the establishment of the Cochrane Collaboration, which produces high-quality reviews of healthcare research.

Planning Your Investigation

Develop a detailed plan including:

- **Hypothesis or aim:** What you expect to find, based on your literature review
- **Variables:** Independent, dependent, and controlled variables
- **Materials and equipment:** Everything needed to conduct the investigation

- **Methodology:** Step-by-step procedures
- **Risk assessment:** Safety considerations and precautions
- **Timeline:** Schedule for each phase of the project
- **Data collection methods:** How you'll record and organize data
- **Analysis techniques:** How you'll process the data

Conducting the Investigation

During the investigation:

- Follow your plan systematically
- Record data accurately and organize it clearly
- Document any deviations from the original plan
- Take photographs or make drawings as appropriate
- Maintain a research log with dates and observations
- Follow all safety protocols

Analyzing Results and Drawing Conclusions

After collecting data:

- Apply appropriate statistical analysis
- Create clear, informative graphs and charts
- Compare your results to your hypothesis and existing literature
- Consider alternative explanations for your findings
- Acknowledge limitations and potential sources of error
- Suggest improvements and future research directions

Communicating Your Research

Present your findings in a comprehensive scientific report:

- **Title:** Concise, informative, and specific
- **Abstract:** Brief summary of the entire project
- **Introduction:** Background, purpose, and hypothesis
- **Materials and Methods:** Detailed procedures

- **Results:** Data, calculations, and graphics

- **Discussion:** Interpretation, implications, and limitations

- **Conclusion:** Summary of key findings

- **References:** Citations in appropriate format

- **Appendices:** Raw data, additional information

Investigation: Planning Your Student Research Project

Purpose: To begin developing your Student Research Project by selecting a topic and creating a research plan.
Task:

1. **Topic Selection:**
   - Brainstorm 3-5 areas of science that interest you.
   - For each area, list 2-3 specific questions you could investigate.
   - Evaluate each question using the SMART criteria (Specific, Measurable, Achievable, Relevant, Time-bound).
   - Select your top question and refine it if necessary.
2. **Preliminary Literature Review:**
   - Find at least five reliable sources related to your topic.
   - Create a summary of each source (1-2 paragraphs) including key findings.
   - Identify gaps or unanswered questions in the existing research.
3. **Research Proposal:** Create a 2-3 page proposal including:
   - Title of your project
   - Research question and hypothesis
   - Brief literature review summary
   - Proposed methodology (with variables clearly identified)
   - Materials and equipment needed
   - Timeline for completion
   - How you'll analyze your data
   - Potential challenges and how you'll address them
   - Safety considerations
4. **Peer Review:** Exchange proposals with a classmate and provide constructive feedback to each other.
5. **Revision:** Refine your proposal based on peer and teacher feedback.

Note: This is the planning phase of your SRP. Actual implementation will occur over the coming weeks/months according to the timeline established in your proposal.

Scientific Communication and Peer Review

Communicating your findings effectively is a crucial part of the scientific process. Science progresses through the sharing and evaluation of research.

Scientific Writing

Effective scientific writing is:

- **Clear:** Uses precise, unambiguous language
- **Concise:** Avoids unnecessary words and jargon
- **Objective:** Presents facts and evidence without bias
- **Structured:** Follows conventional scientific format
- **Substantiated:** Supports claims with evidence and citations

Visual Communication in Science

Visual elements enhance understanding:

- **Purpose:** Clarify concepts, summarize data, highlight relationships
- **Types:** Tables, graphs, diagrams, photographs, flowcharts
- **Design principles:** Clarity, accuracy, appropriate scale, informative labels
- **Common mistakes:** Misleading scales, cherry-picking data, visual clutter

The Peer Review Process

Peer review is fundamental to scientific progress:

- **Purpose:** Ensure quality, validity, and integrity of scientific publications
- **Process:** Experts in the field anonymously evaluate research
- **Criteria:** Methodology, data analysis, interpretation, significance, clarity
- **Outcomes:** Accept, revise, or reject for publication
- **Limitations:** Potential for bias, time-consuming, may miss some issues

History: The modern peer review system began in the mid-20th century, but forms of scientific critique date back to the 17th century with the Royal Society's Philosophical Transactions, established in 1665 as the first scientific journal.

Investigation: Scientific Communication and Peer Review

Purpose: To practice scientific writing, visualization, and peer review.

Part 1: Scientific Writing

1. Select a simple scientific experiment that your class has conducted previously.
2. Write a short scientific report (600-800 words) following the standard format:
   - Title
   - Abstract (100 words maximum)
   - Introduction with background and hypothesis
   - Materials and Methods
   - Results
   - Discussion
   - Conclusion
   - References
3. Include at least one table and one graph presenting the data.

Part 2: Visualizing Data

1. Create three different visual representations of the same dataset.
2. For each visualization:
   - Explain why you chose that type of visual
   - Identify what aspect of the data it highlights best
   - Describe its limitations

Part 3: Peer Review Simulation

1. Exchange your report with two classmates.
2. Acting as peer reviewers, evaluate each other's work using these criteria:
   - Clarity and organization
   - Quality of methodology
   - Data presentation and analysis
   - Validity of conclusions
   - Appropriate use of scientific language
   - Quality of visual elements
3. Provide constructive feedback using the "sandwich" approach: positive aspects, suggestions for improvement, positive ending.
4. Recommend one of the following: Accept, Minor Revisions, Major Revisions, or Reject.

Ethics in Scientific Research

ETHICAL CONSIDERATIONS should guide all aspects of scientific research. As science advances, new ethical questions emerge.

* **Challenge:** Find a retracted scientific paper (the Retraction Watch database is a good resource). Research why it was retracted, how the error or misconduct was discovered, and what impact the paper had before retraction. What does this case teach us about the strengths and weaknesses of the scientific process? Write a brief analysis (500 words).

Principles of Research Ethics

Key ethical principles include:

Key Concept: Core Ethical Principles in Research

Respect for persons Treating participants with dignity; obtaining informed consent

Beneficence Minimizing harm while maximizing benefits

Justice Ensuring fair distribution of benefits and burdens

Integrity Honesty in data collection, analysis, and reporting

Transparency Open methods, data sharing, and disclosure of conflicts

Responsibility Considering broader impacts of research

Ethical Considerations in Different Fields

Ethical issues vary across scientific disciplines:

- **Biological Sciences:** Animal welfare, conservation impacts, biosafety
- **Medical Research:** Human subject protection, privacy, equitable access
- **Environmental Sciences:** Ecosystem impacts, sustainable practices
- **Chemistry:** Chemical safety, waste management, dual-use concerns
- **Physics and Engineering:** Safety testing, energy considerations, security implications
- **Data Science:** Privacy, bias in algorithms, consent for data use

History: The Nuremberg Code (1947) and the Declaration of Helsinki (1964) established fundamental principles for ethical human subjects research, in response to unethical experiments conducted during World War II.

Emerging Ethical Challenges

Scientific advances create new ethical questions:

- **Genetic technologies:** CRISPR, gene therapy, genetic privacy
- **Artificial intelligence:** Automation impact, algorithmic bias, autonomous systems
- **Climate engineering:** Geoengineering risks, intergenerational impacts
- **Synthetic biology:** Creating new organisms, biosecurity
- **Neurotechnology:** Brain-computer interfaces, cognitive enhancement

Real-World Scenario: Gene Editing and Society

Scientists can now edit genes with a technique called CRISPR-Cas9, which allows precise modifications to DNA. This technology could potentially eliminate genetic diseases, but also raises concerns about unintended effects, equity of access, and the ethics of human enhancement.

Scenario: A research team plans to use CRISPR to edit genes in human embryos to remove a mutation that causes a fatal childhood disease. The edited embryos would be implanted and develop into babies free from the disease.

Multiple Perspectives:

1. Medical researchers argue this could eliminate suffering and save lives.
2. Ethicists worry about unintended effects and slippery slopes toward enhancement.
3. Patient advocates support the treatment but worry about affordability and access.
4. Some religious groups oppose any modification of human embryos.

Data: A survey of 1,500 people showed varied opinions about gene editing:

Purpose	Support (%)	Oppose (%)	Unsure (%)
Treat fatal disease	72	18	10
Prevent non-fatal disease	60	25	15
Enhance traits (e.g., intelligence)	15	75	10

Questions:

1. Identify the key ethical considerations in this gene editing scenario.
2. Based on the survey data, how does public opinion vary depending on the purpose of gene editing? What might explain these differences?
3. If you were on an ethics review board evaluating this research proposal, what additional information would you need? What guidelines would you recommend?
4. How can society balance scientific progress with ethical considerations in emerging technologies? Provide a reasoned argument supported by evidence.

Investigation: Ethical Research Design

Purpose: To identify ethical considerations in scientific research and develop strategies to address them.
Task:

1. Select one research scenario from the list below:
   - Testing a new air pollution monitor by placing devices in different neighborhoods
   - Studying the effects of social media use on adolescent mental health
   - Investigating the impact of a new fertilizer on soil microorganisms
   - Developing facial recognition software using publicly available images
   - Testing the effectiveness of a newly developed insect repellent
2. For your chosen scenario, conduct an ethical analysis:
   - Identify all stakeholders who might be affected
   - List potential benefits of the research
   - Identify potential harms or risks
   - Discuss issues of consent, privacy, and confidentiality
   - Consider environmental impacts
   - Examine questions of justice and fairness
3. Develop an ethically sound research plan that addresses the concerns you identified:
   - How will you obtain informed consent?
   - What safeguards will you implement to minimize risks?
   - How will you ensure privacy and data security?
   - How will you address environmental considerations?
   - How will you ensure fair treatment of all involved?
4. Create an "Ethics Statement" for your research plan that could be included in a grant proposal or publication.

Extension: Research a real-world example of scientific research that raised ethical concerns. Analyze how the researchers and regulatory bodies addressed these issues, and suggest how the situation could have been handled better.

Chapter Review and Practice

LET'S REVIEW the key concepts we've covered in this chapter:

1. Advanced experimental design involves careful attention to variables, controls, and sampling methods

2. Data reliability and validity determine the quality and trustworthiness of scientific results

3. Different research questions require different methodologies, each with strengths and limitations

4. Statistical analysis helps scientists draw meaningful conclusions from data

5. The Student Research Project allows you to apply scientific investigation skills to a question of your choice

6. Scientific communication and peer review are essential for advancing knowledge

7. Ethical considerations should guide all aspects of scientific research

Practice Questions - Level 1 - Basic Understanding

1. Distinguish between independent, dependent, and controlled variables with examples.
2. Explain the difference between reliability and validity in scientific data.
3. List three different research methodologies and when each might be appropriate.
4. Define statistical significance and explain what a p-value indicates.
5. Outline the key components of a scientific research report.

Practice Questions - Level 2 - Application

1. Design an experiment to test whether the type of music affects plants growth, including variables, controls, and sampling method.
2. Given a dataset, calculate the mean, median, range, and standard deviation. Interpret what these values tell you about the data.
3. Compare and contrast experimental and observational studies. Provide an example research question best suited to each.
4. Analyze a graph that appears to show correlation between two variables. Explain why correlation doesn't necessarily imply causation, and suggest alternative explanations.
5. Develop an ethics statement for a study investigating the effects of a new study technique on student test performance.

Practice Questions - Level 3 - Extension and Analysis

1. Critique a published scientific study, analyzing its experimental design, data analysis, and conclusions. Identify strengths and weaknesses, and suggest improvements.
2. Develop a mixed-methods research approach to investigate a complex scientific question of your choice. Justify why this approach would provide more comprehensive insights than a single method.
3. Analyze how the peer review process contributes to scientific progress, including both its strengths and limitations. Suggest how the process could be improved.
4. Evaluate the ethical implications of a cutting-edge technology (e.g., CRISPR, AI, brain-computer interfaces). Consider multiple perspectives and propose guidelines for responsible development.
5. Design a comprehensive research proposal for a Student Research Project, including literature review, methodology, analysis plan, and consideration of limitations.

Glossary of Key Terms

Confounding variable A factor that affects the dependent variable but is not controlled in the experiment.

Control group A group that does not receive the experimental treatment but is otherwise treated identically to the experimental group.

Correlation A statistical relationship between two variables, indicating they tend to change together.

Causation A relationship where one variable directly causes changes in another.

Descriptive statistics Statistical measures that summarize and describe data, such as mean, median, and standard deviation.

Inferential statistics Statistical methods used to draw conclusions about populations based on sample data.

Informed consent Agreement to participate in research after being fully informed about the purpose, procedures, risks, and benefits.

Peer review The evaluation of scientific work by one or more experts in the same field.

P-value The probability of obtaining results at least as extreme as those observed, assuming the null hypothesis is true.

Qualitative data Non-numerical information that describes qualities or characteristics.

Quantitative data Numerical information that can be measured and analyzed statistically.

Reliability The consistency or repeatability of measurements or results.

Sampling The process of selecting a subset of individuals from a larger population to collect data.

Statistical significance The likelihood that a result is not due to random chance.

Validity The accuracy of measurements in representing what they claim to measure.

Beyond the Basics: Exploring Further

Want to learn more? Here are some suggestions for further exploration:

- **Research Project:** Analyze a scientific controversy or how a scientific consensus changed over time. Examine the evidence, methodologies, and peer review process that led to the evolution in thinking.
- **Citizen Science:** Join a citizen science project where you can contribute to real research. Websites like Zooniverse, FoldIt, or EyeWire allow students to participate in data collection and analysis.
- **Digital Exploration:** Use statistical software (like R, which is free) to analyze datasets available from repositories like Kaggle or government open data portals.
- **STEM Career Connection:** Interview scientific researchers about their methods, challenges, and how they address ethical issues in their work.
- **Cross-Curricular Link:** Explore how scientific methods are applied in fields like archaeology, psychology, economics, or sports science.

Atoms, Elements and Compounds

Chapter Overview

In this chapter, we'll explore the fundamental building blocks of matter—atoms, elements, and compounds. Building on your Stage 4 understanding, we'll examine atomic structure in greater detail, investigate patterns in the periodic table, and analyze how atoms combine to form compounds. You'll also learn about chemical bonding and how the arrangement of electrons influences the properties of materials.

This chapter aligns with the following NSW Syllabus outcomes:

- SC5-16CW: Explains how models, theories and laws about matter have been refined as new scientific evidence becomes available
- SC5-17CW: Discusses the importance of chemical reactions in the production of a range of substances, and the influence of society on the development of new materials

Stop and Think

1. Draw and label a model of an atom. What particles does it contain and where are they located?
2. How is the periodic table organized? What patterns can you identify?
3. What's the difference between an element, a compound, and a mixture?
4. How do atoms form bonds with other atoms? Can you name different types of bonds?

The Structure of the Atom

Our modern understanding of the atom has evolved through centuries of scientific inquiry. Let's examine the current model of atomic structure in greater detail.

Subatomic Particles Revisited

Recall that atoms contain three main types of subatomic particles:

Key Concept: Subatomic Particles

Protons Positively charged particles, located in the nucleus, with a relative mass of 1 atomic mass unit (amu)

Neutrons Neutral particles (no charge), located in the nucleus, with a relative mass of 1 amu

Electrons Negatively charged particles, located in electron orbitals around the nucleus, with a very small mass (1/1836 of a proton)

These particles have specific properties:

Particle	Relative Charge	Relative Mass	Location
Proton	+1	1	Nucleus
Neutron	0	1	Nucleus
Electron	-1	1/1836	Electron orbitals

History: The term "electron" was coined by Irish physicist George Johnstone Stoney in 1891, and J.J. Thomson demonstrated their existence in 1897. Protons were discovered by Ernest Rutherford in 1919, and neutrons by James Chadwick in 1932.

The Quantum Mechanical Model

At Stage 5, we can explore a more sophisticated model of the atom. The quantum mechanical model describes electrons not as particles orbiting the nucleus like planets around the sun, but rather as existing in "probability clouds" or orbitals.

Key Concept: Electron Orbitals

An electron orbital is a region of space around the nucleus where an electron is likely to be found. These orbitals have distinctive three-dimensional shapes and can hold a maximum of two electrons.

Key principles of the quantum mechanical model include:

- Electrons exist in specific energy levels (shells) around the nucleus
- Each energy level contains sublevel orbitals (s, p, d, f) with specific shapes
- Electrons fill the lowest energy orbitals first (Aufbau principle)
- Each orbital can hold a maximum of two electrons with opposite spins (Pauli exclusion principle)

- Electrons occupy orbitals of equal energy singly before pairing up (Hund's rule)

Math Link: The energy of an electron in a hydrogen atom can be calculated using the equation: $E_n = -R_H/n^2$, where R_H is the Rydberg constant (2.18×10^{-18} J) and n is the principal quantum number (energy level).

Electron Configuration

The arrangement of electrons in an atom's orbitals is called its electron configuration. This is crucial for understanding chemical bonding and the properties of elements.

- The first energy level (n=1) has one sublevel (1s) and can hold 2 electrons

- The second energy level (n=2) has two sublevels (2s and 2p) and can hold 8 electrons

- The third energy level (n=3) has three sublevels (3s, 3p, and 3d) and can hold 18 electrons

Electron configurations can be written using notation like $1s^2\ 2s^2\ 2p^6$, where the number and letter indicate the energy level and sublevel, and the superscript shows how many electrons occupy that sublevel.

Example: The electron configuration of oxygen (atomic number 8) is $1s^2\ 2s^2\ 2p^4$, indicating two electrons in the 1s orbital, two in the 2s orbital, and four in the 2p orbitals.

* **Challenge:** Research and explain the "diagonal rule" (or Madelung rule) for determining the order in which electron orbitals are filled. How does this relate to the arrangement of elements in the periodic table?

Investigation: Flame Tests and Electron Transitions

Purpose: To observe how electron transitions produce characteristic colors when elements are heated.

Materials:

- Bunsen burner
- Wooden splints soaked in solutions of different metal salts (e.g., sodium chloride, potassium chloride, copper sulfate, strontium chloride, barium chloride)
- Safety goggles
- Tongs
- Cobalt blue glass (if available)

Procedure:

1. Put on safety goggles.
2. Light the Bunsen burner and adjust it to produce a blue flame.
3. Using tongs, hold a splint soaked in a metal salt solution at the edge of the flame.
4. Observe the color produced in the flame.
5. Repeat with different metal salt solutions.
6. If available, view the sodium flame through cobalt blue glass and note any differences.

Results: Record the color produced by each metal salt solution.

Analysis:

1. Why do different elements produce different flame colors?
2. How does this relate to the electron configuration of atoms?
3. Why are these colors characteristic for each element?
4. How do scientists use this phenomenon to identify elements?
5. Research how these flame tests relate to emission spectra and quantum theory.

Extension: Research how flame tests led to the discovery of new elements, such as cesium (from the Latin caesius, meaning "sky blue") and rubidium (from the Latin rubidus, meaning "deep red").

The Periodic Table of Elements

The periodic table is one of the most powerful tools in chemistry. At Stage 5, we'll explore the underlying patterns and trends in greater detail.

Organization of the Periodic Table

The modern periodic table organizes elements by:

- Increasing atomic number (number of protons) from left to right
- Similar chemical properties in vertical columns (groups)
- Similar electron configurations in horizontal rows (periods)

Key Concept: Regions of the Periodic Table

Metals Located on the left and center of the table; good conductors, malleable, usually solid at room temperature

Non-metals Located on the right side of the table; poor conductors, brittle as solids, may be solid, liquid, or gas at room temperature

Metalloids Located along the "stair step" line separating metals and non-metals; have properties of both metals and non-metals

Main Group Elements Groups 1, 2, and 13-18; also called representative elements

Transition Elements Groups 3-12; often form colored compounds and have multiple oxidation states

History: The periodic table was developed by Dmitri Mendeleev in 1869. What made his table revolutionary was that he left gaps for undiscovered elements and accurately predicted their properties. For example, he predicted the properties of "eka-silicon" (now known as germanium), which was discovered in 1886.

Electron Configuration and Periodic Trends

The organization of the periodic table directly relates to electron configurations:

- Group 1 (alkali metals): [noble gas] ns^1 (one electron in the outermost s orbital)
- Group 2 (alkaline earth metals): [noble gas] ns^2 (two electrons in the outermost s orbital)
- Group 17 (halogens): [noble gas] ns^2np^5 (seven electrons in the outermost s and p orbitals)

- Group 18 (noble gases): [noble gas] ns^2np^6 (eight electrons in the outermost s and p orbitals, except helium)

This electronic structure explains why elements in the same group have similar chemical properties.

Periodic Trends

The periodic table shows clear trends in physical and chemical properties:

Key Concept: Key Periodic Trends

Atomic radius Generally decreases across a period (left to right) and increases down a group

Ionization energy Energy required to remove an electron; increases across a period and decreases down a group

Electronegativity Ability to attract electrons in a bond; increases across a period and decreases down a group

Reactivity For metals, increases down a group; for non-metals, increases across a period (right to left)

Math Link: The effective nuclear charge (Z_{eff}) an electron experiences can be approximately calculated using Slater's rule: $Z_{eff} = Z - S$, where Z is the nuclear charge (atomic number) and S is the screening constant. This helps explain why atomic radius decreases across a period.

Investigation: Patterns in the Periodic Table

Purpose: To analyze periodic trends and relate them to electron configuration.

Materials:

- Periodic table
- Data tables of atomic radius, ionization energy, electronegativity, and melting point for elements
- Graph paper or graphing software

Procedure:

1. For the elements lithium (Li) through neon (Ne), create a graph plotting atomic number (x-axis) against:
   - Atomic radius
   - First ionization energy
   - Electronegativity
   - Melting point
2. Repeat by graphing these properties for the elements in Group 1 (alkali metals) from lithium (Li) to francium (Fr).
3. For each graph, identify any patterns or trends.

Analysis:

1. Describe the trends you observed across Period 2 (Li to Ne) for each property.
2. Describe the trends you observed down Group 1 for each property.
3. How does the electron configuration of these elements explain the patterns you observed?
4. Which elements don't seem to follow the expected trends? Research why these exceptions occur.
5. How do these trends relate to the reactivity of elements?

Extension: Research and explain how these periodic trends influence the biological roles of elements. Why are certain elements essential for life while others are toxic?

Chemical Bonding

CHEMICAL BONDING is the process by which atoms form bonds with other atoms, leading to compounds with distinct properties. The type of bonding depends primarily on electron configurations.

Types of Chemical Bonds

Key Concept: Major Types of Chemical Bonds

Ionic bonding Transfer of electrons between a metal and a non-metal, resulting in oppositely charged ions held together by electrostatic attraction

Covalent bonding Sharing of electrons between non-metals, forming molecules

Metallic bonding Sharing of electrons in a "sea" of delocalized electrons among metal atoms

Ionic Bonding

Ionic bonds form between metals (which tend to lose electrons) and non-metals (which tend to gain electrons). The resulting ions have opposite charges and are attracted to each other.

Example: Sodium chloride (NaCl) forms when sodium atoms lose one electron (forming Na^+ ions) and chlorine atoms gain one electron (forming Cl^- ions). The electrostatic attraction between these ions creates a three-dimensional crystal lattice.

Properties of ionic compounds include:

- High melting and boiling points
- Crystalline structure at room temperature
- Conduct electricity when dissolved in water or melted
- Often soluble in water but insoluble in non-polar solvents

History: The concept of ions was introduced by Michael Faraday in 1834, but it was Svante Arrhenius who proposed in 1884 that salts dissociate into charged particles when dissolved in water, a theory for which he was awarded the Nobel Prize in Chemistry in 1903.

Covalent Bonding

Covalent bonds form when atoms share electrons to achieve stable electron configurations. These bonds can be classified based on the degree of electron sharing:

- **Non-polar covalent bonds:** Electrons are shared equally between atoms of similar electronegativity
- **Polar covalent bonds:** Electrons are shared unequally between atoms of different electronegativity

Lewis structures (electron dot diagrams) are used to represent the sharing of electrons in covalent bonds.

Example: In a water molecule (H_2O), the oxygen atom shares electrons with two hydrogen atoms. Since oxygen is more electronegative, the shared electrons are pulled closer to the oxygen, creating a polar molecule with partial charges (δ+ on hydrogen, δ- on oxygen).

Properties of covalent compounds include:

- Generally lower melting and boiling points than ionic compounds
- Often exist as gases, liquids, or soft solids at room temperature
- Generally poor conductors of electricity
- Solubility varies ("like dissolves like" - polar molecules dissolve in polar solvents, non-polar molecules in non-polar solvents)

Math Link: The polarity of a bond can be estimated by the difference in electronegativity (ΔEN) between the bonded atoms. As a general rule: ΔEN < 0.5: non-polar covalent; $0.5 \leq \Delta\text{EN} \leq 2.0$: polar covalent; ΔEN > 2.0: ionic.

Metallic Bonding

Metallic bonds form in metals where valence electrons are relatively free to move throughout the structure.

Key Concept: Metallic Bonding

In metallic bonding, the valence electrons from metal atoms form a "sea" of delocalized electrons that move freely throughout the crystal. The positively charged metal ions form a regular lattice structure and are held together by their attraction to this electron sea.

Properties of metals resulting from this bonding include:

- Good conductors of heat and electricity
- Malleable and ductile
- Lustrous appearance
- Generally high melting and boiling points (except for mercury and gallium)

* **Challenge:** Research and explain how the concepts of "band theory" expand on the simple "electron sea" model of metallic bonding. How does band theory explain why some materials are conductors, some are insulators, and others are semiconductors?

Investigation: Comparing Bond Types

Purpose: To investigate how different types of chemical bonding affect the properties of substances.

Materials:

- Samples of substances with different bond types:
  - Ionic: sodium chloride (table salt), calcium chloride
  - Covalent (molecular): sugar (sucrose), vegetable oil, wax
  - Covalent (network): graphite, quartz (if available)
  - Metallic: copper wire, aluminum foil
- Conductivity tester
- Beakers
- Distilled water
- Various solvents (water, ethanol, vegetable oil)
- Thermometer
- Heat source

Procedure:

1. Examine the physical properties of each substance (appearance, hardness, brittleness).
2. Test the electrical conductivity of each substance in solid form.
3. For soluble substances, create solutions and test their electrical conductivity.
4. Test the solubility of each substance in water, ethanol, and vegetable oil.
5. Determine or research the melting points of the substances.

Results: Create a data table organizing your observations.

Analysis:

1. How do the physical properties of each substance relate to its bond type?
2. Explain why some substances conduct electricity in solid form, some only when dissolved, and others not at all.
3. How does solubility relate to bond type and molecular polarity?
4. Compare the melting points of substances with different bond types. What patterns do you notice?
5. How does the bonding in graphite (a form of carbon) explain why it can be used as a lubricant and in pencil lead?

Extension: Research how semiconductor materials combine

Molecular Structure and Properties

THE ARRANGEMENT OF ATOMS in a molecule, along with the nature of the bonds between them, determines the properties of substances. In this section, we'll explore how molecular structure influences physical and chemical properties.

VSEPR Theory and Molecular Geometry

The Valence Shell Electron Pair Repulsion (VSEPR) theory helps predict the three-dimensional shape of molecules.

Key Concept: VSEPR Theory

VSEPR theory states that electron pairs around a central atom repel each other and arrange themselves to minimize repulsion, determining the shape of the molecule. Both bonding and non-bonding electron pairs affect molecular geometry.

Common molecular geometries include:

- Linear: two electron groups (e.g., CO_2, BeF_2)
- Trigonal planar: three electron groups (e.g., BF_3, CO_3^{2-})
- Tetrahedral: four electron groups (e.g., CH_4, NH_4^+)
- Trigonal pyramidal: four electron groups with one lone pair (e.g., NH_3)
- Bent/angular: four electron groups with two lone pairs (e.g., H_2O)

Math Link: The bond angle in a tetrahedral molecule is approximately 109.5°. This can be calculated using the inverse cosine function: $\cos^{-1}(-1/3) = 109.5$. This is the angle that maximizes the distance between four points on a sphere.

Polarity of Molecules

The polarity of a molecule depends on:

- The polarity of individual bonds (electronegativity difference)
- The molecular geometry (arrangement of polar bonds)

A molecule with polar bonds may still be non-polar overall if the bond dipoles cancel due to symmetrical arrangement.

Example: Carbon dioxide (CO_2) has polar C=O bonds (oxygen is more electronegative than carbon), but because the molecule is linear with bonds at 180° to each other, the dipoles cancel, making CO_2 a non-polar molecule.

In contrast, water (H_2O) has polar O–H bonds, and its bent structure means the dipoles do not cancel, resulting in a polar molecule.

Molecular polarity affects properties such as:

- Solubility ("like dissolves like")
- Boiling and melting points
- Intermolecular forces
- Chemical reactivity

Intermolecular Forces

Intermolecular forces are attractions between molecules that influence physical properties like boiling point, melting point, and solubility.

Key Concept: Types of Intermolecular Forces

Dispersion forces (London forces) Weak attractions present in all molecules, caused by temporary dipoles; strength increases with molecular size

Dipole-dipole forces Attractions between polar molecules; stronger than dispersion forces

Hydrogen bonding Special case of dipole-dipole forces between H atoms bonded to highly electronegative atoms (N, O, F) and lone pairs on other electronegative atoms; particularly strong

Ion-dipole forces Attractions between ions and polar molecules (important in solutions of ionic compounds in polar solvents)

History: Hydrogen bonding was first described by Wendell Latimer and Worth Rodebush in 1920. This concept was crucial for understanding the structure of DNA, as discovered by Watson and Crick in 1953, where hydrogen bonds between complementary base pairs hold the two DNA strands together.

Investigation: Investigating Surface Tension

Purpose: To investigate how intermolecular forces contribute to surface tension in liquids.

Materials:

- Different liquids: water, soapy water, ethanol, vegetable oil
- Small containers
- Droppers
- Coins
- Paper clips
- Small squares of wax paper
- Dish detergent
- Camera (optional)

Procedure:

1. Coin Test:
    - Place a clean, dry coin on a flat surface.
    - Using a dropper, carefully add drops of water to the coin, counting how many drops can be added before the water spills.
    - Repeat with the other liquids.
    - Observe the shape of the liquid drops on the coin surface.
2. Paper Clip Float:
    - Fill containers with each liquid.
    - Carefully place a paper clip on the surface of each liquid, using a fork to gently lower it.
    - Observe whether the paper clip floats or sinks.
    - For liquids where the paper clip floats, add a drop of dish detergent and observe what happens.
3. Wax Paper Drops:
    - Place drops of each liquid on wax paper.
    - Observe the shape of the drops and measure their diameter.
    - Tilt the wax paper and observe how the drops behave.

Analysis:

1. Which liquid demonstrated the highest surface tension? Which had the lowest?
2. Explain how intermolecular forces create surface tension.
3. Why does adding detergent reduce surface tension?
4. How does the shape of drops on wax paper relate to the

Naming Compounds and Writing Formulas

Systematic naming of chemical compounds allows chemists to communicate precisely about substances. At Stage 5, we'll expand on the basic principles you learned earlier.

Naming Binary Ionic Compounds

Binary ionic compounds contain a metal and a non-metal. The naming convention is:

- Name the metal (cation) first, using the element name
- Name the non-metal (anion) second, changing the ending to -ide
- For metals that can form multiple ions (transition metals), use Roman numerals to indicate the charge

Example:

- NaCl: sodium chloride
- CaO: calcium oxide
- Fe_2O_3: iron(III) oxide
- $CuCl_2$: copper(II) chloride

Naming Compounds with Polyatomic Ions

Many compounds contain polyatomic ions—charged groups of atoms that behave as a unit.

Key Concept: Common Polyatomic Ions

Hydroxide OH^-

Ammonium NH_4^+

Carbonate CO_3^{2-}

Nitrate NO_3^-

Sulfate SO_4^{2-}

Phosphate PO_4^{3-}

Naming follows similar patterns as binary compounds:

- Name the cation first (metal or ammonium)

- Name the polyatomic anion second, keeping its name

Example:

- NaOH: sodium hydroxide
- $(NH_4)_2SO_4$: ammonium sulfate
- $Ca(NO_3)_2$: calcium nitrate
- $CuSO_4$: copper(II) sulfate

Naming Covalent Compounds

Binary covalent compounds contain two non-metals. The naming convention is:

- Name the first element using its full name
- Name the second element, changing the ending to -ide
- Use prefixes to indicate the number of atoms (mono-, di-, tri-, tetra-, penta-, hexa-, etc.)
- The prefix "mono-" is usually omitted for the first element

Example:

- CO_2: carbon dioxide
- N_2O_4: dinitrogen tetroxide
- SF_6: sulfur hexafluoride
- P_4O_{10}: tetraphosphorus decaoxide

Writing Chemical Formulas

To write a chemical formula from a name:

- Identify the elements or ions involved
- Determine the charge of each ion
- Combine them in the ratio that makes the compound neutral (total positive charge = total negative charge)

For compounds with polyatomic ions, use parentheses around the polyatomic ion when more than one is needed.

Example: To write the formula for aluminum sulfate:

- Aluminum ion: Al^{3+} (charge of 3+)

- Sulfate ion: SO_4^{2-} (charge of 2-)

- To balance charges: 2 Al^{3+} (total 6+) and 3 SO_4^{2-} (total 6-)

- Formula: $Al_2(SO_4)_3$

Investigation: Naming and Formula Writing Practice

Purpose: To develop proficiency in naming compounds and writing chemical formulas.
Materials:

- Chemical formula and name cards
- Periodic table
- Reference sheet with common polyatomic ions

Procedure (Part 1 - Matching Game):

1. Create a set of cards with chemical formulas on one set and corresponding names on another.
2. Shuffle the cards and place them face down in two separate piles.
3. Take turns drawing one card from each pile.
4. If the formula and name match, keep the pair. If not, return them face down.
5. The game continues until all pairs are matched.

Procedure (Part 2 - Formula Challenge):

1. For each compound name below, write the correct chemical formula:
   - Potassium permanganate
   - Ammonium phosphate
   - Magnesium hydroxide
   - Iron(II) sulfate
   - Copper(II) nitrate
   - Carbon tetrachloride
   - Dinitrogen pentoxide
2. For each chemical formula below, write the correct systematic name:
   - Al_2O_3
   - $Pb(NO_3)_2$
   - NH_4Cl
   - $K_2Cr_2O_7$
   - PCl_5
   - $Fe(OH)_3$
   - $CuSO_4{\cdot}5H_2O$

Procedure (Part 3 - Compound Creation):

1. Using a periodic table and list of polyatomic ions, create five compounds that include:

Chapter Review and Practice

Let's review the key concepts we've covered in this chapter:

1. Atoms are composed of protons, neutrons, and electrons, with electrons arranged in orbitals according to quantum mechanical principles

2. The periodic table organizes elements based on atomic number and electron configuration, revealing patterns in properties

3. Chemical bonds (ionic, covalent, and metallic) form when atoms interact to achieve stable electron configurations

4. Molecular structure influences the physical and chemical properties of substances

5. Systematic nomenclature provides a consistent way to name compounds and write chemical formulas

Practice Questions - Level 1 - Basic Understanding

1. What are the three main subatomic particles, and where are they located in an atom?
2. Define atomic number and mass number, and explain how they relate to the number of protons, neutrons, and electrons.
3. Distinguish between metals, non-metals, and metalloids on the periodic table.
4. Explain the difference between ionic, covalent, and metallic bonding.
5. Write the chemical formulas for these compounds: sodium oxide, calcium nitrate, carbon dioxide, iron(III) chloride.

Practice Questions - Level 2 - Application

1. Draw the electron configuration diagram for oxygen (O) and explain how this relates to its position in the periodic table.
2. Predict the type of bond that would form between each pair of elements: Na and Cl, C and O, Fe and Fe. Explain your reasoning.
3. Draw Lewis structures for water (H_2O), ammonia (NH_3), and methane (CH_4). Predict the molecular geometry of each based on VSEPR theory.
4. Explain why water has a higher boiling point than expected for a molecule of its size, referring to intermolecular forces.
5. For the compound $Al_2(SO_4)_3$: name it, calculate the total number of atoms per formula unit, and determine the charge of each ion.

Practice Questions - Level 3 - Extension and Analysis

1. The element technetium (Tc) was the first artificially produced element. Analyze its electron configuration and predict where it would be placed in the periodic table if it hadn't been discovered. What properties would you expect it to have?
2. Compare and contrast the models of the atom proposed by Thomson, Rutherford, Bohr, and the quantum mechanical model. Explain how each model addressed limitations of previous models and how experimental evidence supported each development.
3. Analyze why carbon can form millions of different compounds while some elements form very few. Refer to carbon's electron configuration, bonding capabilities, and ability to form single, double, and triple bonds.
4. Design an experiment to distinguish between samples of ionic, covalent, and metallic substances using only household materials and simple tests.
5. Research and explain the concept of resonance structures in molecules like benzene (C_6H_6) or the nitrate ion (NO_3^-). How does resonance affect the properties of these substances?

Glossary of Key Terms

Atomic number The number of protons in an atom's nucleus, which determines the element's identity.

Electron configuration The arrangement of electrons in an atom's orbitals.

Electronegativity A measure of an atom's tendency to attract electrons in a chemical bond.

Ion An atom or molecule that has gained or lost one or more electrons, giving it a positive or negative charge.

Ionic bond A chemical bond formed by the electrostatic attraction between oppositely charged ions.

Covalent bond A chemical bond formed when atoms share electron pairs.

Metallic bond A chemical bond formed by the attraction between metal ions and delocalized electrons.

Lewis structure A diagram showing valence electrons as dots around atomic symbols to represent bonding.

Molecule A group of atoms bonded together, representing the smallest fundamental unit of a chemical compound.

Orbital A region around an atomic nucleus where an electron is likely to be found.

Polyatomic ion A charged group of atoms that behaves as a unit in chemical reactions.

Valence electrons Electrons in the outermost energy level of an atom, typically involved in bonding.

VSEPR theory A model that predicts the three-dimensional arrangement of atoms in a molecule based on the repulsion between electron pairs.

Beyond the Basics: Exploring Further

WANT TO LEARN MORE? Here are some suggestions for further exploration:

- **Research Project:** Investigate how atomic theory evolved from ancient Greek philosophy to modern quantum mechanics, identifying key experiments and discoveries.

- **Digital Exploration:** Use molecular visualization software (like Jmol, which is free) to explore 3D structures of molecules and how they relate to properties.
- **STEM Career Connection:** Interview a materials scientist about how understanding atomic structure and bonding leads to the development of new materials with specific properties.
- **Cross-Curricular Link:** Explore how electronic configurations influence the colors of transition metal compounds, connecting chemistry to art and design.
- **Critical Thinking:** Research the "island of stability" hypothesis in nuclear physics, which predicts that some superheavy elements might have unusually long half-lives.