Science standards

Grade 12

Advanced level

Summary of students' performance by the end of Grade 12

Scientific enquiry

Students identify, develop and make predictions related to a clearly focused research question. They control variables, work as a team and use appropriate equipment and materials. They evaluate experimental design, identify weaknesses and develop realistic strategies for improvement. They work in an ethical manner. They understand the historical development of major scientific ideas, know scientific work is affected by its context and are aware of the power and limitations of science in addressing questions. They understand how scientific ideas develop over time and recognise the importance of refutation. They record and process raw data appropriately and draw valid conclusions, allowing for errors and uncertainties. They handle equipment competently with due regard for safety. They follow instructions accurately but are able to adapt to unforeseen circumstances.

Biology

Students understand the basic biochemistry of anaerobic respiration and compare this with aerobic respiration. They know the structure of ATP and ADP, the reactions in the three stages of aerobic respiration and the role of NAD and ATP. They understand why aerobic and anaerobic respiration yield different amounts of energy in the form of ATP. They understand respiratory quotient and relate this to energy values of respiratory substrates. They know the reactions in the two stages of photosynthesis and the importance of the Calvin cycle. They know about cyclic and non-cyclic photophosphorylation and the use of ATP in the light-independent stage of photosynthesis. They know how carbon-14 has been used to investigate photosynthesis. They understand the absorption spectrum of chlorophyll and know that the pigments of chlorophyll can be separated by chromatography. They know the structure and functions of red and white blood cells and the role of blood, fluid tissue and lymph in transport. They understand the roles of the constituents of blood in the transport of oxygen and carbon dioxide. They know the human blood groups and their significance. They know that organic materials are transported in plant phloem by translocation and that there are several hypotheses to explain the mechanism. They understand the factors affecting the rate of transpiration and the adaptations of xerophytic plants for water conservation. They know the structure of the mammalian kidney and its role in dealing with water and metabolic waste. They understand how the body controls water balance and the function of ADH. They know about thermoreceptors in the hypothalamus and understand body thermoregulation. They know the causes and effects of heatstroke. They know the structure and function of neurones and how nerve impulses are transmitted. They know the main structures and functions of the brain. They know the main endocrine glands of the human body and their functions. They understand how human blood glucose levels are controlled. They

know the roles of plant auxins, gibberellins and abscisic acid. They understand the production of antibodies by the body and their mechanism of action against antigens. They distinguish between active and passive immunity and relate this to vaccination. They know the significance of stem cells and monoclonal antibodies. They know the role of the immune system in an allergic response. They understand the action of antibiotics and why resistance develops. They know the causes of cholera, influenza, malaria and TB, and explain their transmission, control and significance. They outline the mechanism of gene therapy. They calculate the frequency of different progeny from a cross with incomplete dominant alleles, from back crosses and from dihybrid crosses. They understand co-dominance and the inheritance of phenotypic traits through multiple alleles. They use the chi-squared test to determine the significance of results of genetic crosses. They know about the Human Genome Project, genetic fingerprinting and genetic screening and counselling. They know how some organisms are structurally and physiologically adapted to their environment and distinguish between acclimatisation and adaptation. They understand carrying capacity of a habitat and can use population curves. They understand ecological colonisation and succession. The know examples of biological control of unwanted organisms. They distinguish between environmental preservation and conservation and understand the conflicts between nature conservation and production. They understand how biosensors are used to monitor blood glucose levels in diabetes and how diabetes can be treated with genetically produced insulin. They know some applications of monoclonal antibodies and immobilised enzymes.

Chemistry

Students know that economic considerations determine what commercial processes commonly exist and where, and that economic advantages of such processes must be balanced against environmental threats. They recognise the periodic variation in ionisation energies, electron affinity and electronegativity, and predict properties of elements from their position in the periodic table. They know the trends in the general properties of the s-, p- and d-block elements and the specific properties and structures of some of their compounds. Students explain reaction rates in terms of particle collisions and energy, and distinguish between first- and second-order reactions. They calculate the half-life of first-order reactions and understand the relationship between rate constant and temperature. They deduce mathematical expressions for equilibrium constants and use them in gas and solution reactions. They address mathematically problems related to acid–base reactions, buffer solutions and solutions of sparingly soluble salts. They use mathematically the concepts of enthalpy change and relate them to energy cycles. They understand the application of the second law of thermodynamics to chemical systems and can use the concepts of entropy and free energy in relation to the spontaneity of a reaction. Students understand the mechanisms of electrophilic addition and substitution, nucleophilic substitution and elimination reactions. They know the fundamental chemistry of arenes and substituted arenes and describe the production of the more important derivatives of benzene. They explain the stability of the benzene ring in terms of electron delocalisation. They understand structural and optical isomerism and their chemical consequences. They know how addition and condensation polymers are formed and how their properties can be modified by additives.

Physics

Students treat problems in circular motion mathematically. They understand the law of universal gravitation and use it to solve problems of motion under gravity. They classify solids according to stiffness, tensile strength, compressive stress and shear stress, plot and interpret stress–strain graphs for different solids and define and use Young's modulus. They know how these properties are used by engineers and understand the usefulness of composite materials. They explain surface tension. They solve problems related to ideal gas behaviour and show mathematically the relationship between temperature and the kinetic energy of molecules. They understand the concept of absolute zero of temperature and can relate changes in internal energy, heat changes and work done on a thermodynamic system. They relate entropy to disorder and describe the second law of thermodynamics, and its consequences in terms of entropy. Students solve mathematical problems in simple harmonic motion and explain practical examples of resonance, critically and non-critically damped oscillations and forced oscillations. They apply Coulomb's law to charged particles in air, solve problems related to potential difference and potential energy and recognise the similarities between electric and gravitational fields. They understand capacitors and solve problems relating capacitance to voltage and current. They distinguish between emission and absorption spectra and know how these yield information about distant stars and galaxies. They recall and use the relationships $E = hf$ and $E = mc^2$ and explain the quantisation of charge and electromagnetic radiation and know some applications and consequences of this. They explain electron orbitals in terms of quantisation of angular momentum and know how quantum theory leads to the idea of electron 'probability clouds'. They know the source of nuclear energy. They explain the structure of the visible Universe in terms of the gravitational attraction between objects. They define and use the parsec and the light-year. They explain the creation and evolution of stars and know how their ultimate fate depends on their mass. They know how elements are formed in stars and how planetary systems arise. They know the 'big bang' theory of the origin of the Universe and can adduce evidence for it. They know how the Universe can be, at the same time, finite but without boundaries.

Assessment weightings for Grade 12 advanced level

There are three general assessment objectives for the science curriculum:

- knowledge and understanding;
- application of knowledge and understanding, analysis and evaluation of information;
- scientific enquiry skills and procedures.

In Grade 12, advanced level, the three subject strands, physics, chemistry and biology will be assessed as separate subjects. The fourth strand, scientific enquiry, will not be assessed independently but will be an integral part of the assessment of each of the three subjects.

For Grade 12 advanced level, the weightings of the assessment objectives to be applied to each content strand are as follows:

	Knowledge and understanding	Application, analysis and evaluation	Scientific enquiry skills and procedures
Assessment weighting	45 to 55%	25 to 35%	20 to 25%

Science standards

Grade 12

Advanced level

Scientific enquiry

Key standards

Key standards are shown in shaded rectangles, e.g. 1.3.

Examples of learning exercises

The examples of active learning exercises shown in italics are intended to be illustrative and do not represent the full range of possible exercises.

By the end of Grade 12, students identify, develop and make predictions related to a clearly focused research question. They control variables, work as a team and use appropriate equipment and materials. They evaluate experimental design, identify weaknesses and develop realistic strategies for improvement. They work in an ethical manner. They understand the historical development of major scientific ideas, know scientific work is affected by its context and are aware of the power and limitations of science in addressing questions. They understand how scientific ideas develop over time and recognise the importance of refutation. They record and process raw data appropriately and draw valid conclusions, allowing for errors and uncertainties. They handle equipment competently with due regard for safety. They follow instructions accurately but are able to adapt to unforeseen circumstances.

Students should:

1 Use methods of scientific investigation

1.1 Identify and develop a clearly focused research question.

Compare by experimentation the relative energy values of fat and carbohydrate.

Determine the rate of transpiration of different plants.

Use chromatography to compare the pigments of different algae.

Devise an experiment to show the variation of a rate constant on temperature.

Determine the acceleration due to gravity using a pendulum.

Work out the resonant frequency of the Tacoma Narrows bridge from the well-known film of its collapse.

1.2 Make predictions directly related to a research question.

Predict and test the action of auxin on plants.

Predict the outcomes of dihybrid crosses and compare the predictions with collected data.

Make and test predictions concerning the characteristics of animal groups.

Predict the characteristic properties of an element (e.g. tin or nickel) from its position in the periodic table and suggest ways to test some of the predictions.

Test the prediction that anodising a sample of aluminium increases its resistance to corrosion.

Predict the effect of adding a given small quantity of concentrated hydrochloric acid to a saturated solution of lead chloride. Test the prediction.

1.3 Identify and control variables.

Identify and control variables when measuring transpiration of plants.

Design an experiment to test a new drug to protect against malaria.

Compare the behaviour of different materials under stress.

1.4 Work constructively and adaptively with others as a team on a scientific investigation.

Work as a team to map the plant succession on a rocky seashore.

Collectively research the incidence of cholera in selected countries.

Prepare a booklet on the animals of Qatar.

1.5 Evaluate experimental design, identify weaknesses and develop realistic strategies for improvement.

Develop an appropriate way to determine the wavelength of light absorbed by chlorophyll.

Design a study to determine the impact of creating a conservation area in Qatar.

Identify the most significant areas of uncertainty in the determination of Young's modulus for a variety of materials, and devise strategies to address them.

1.6 Work in an ethical manner with regard to acknowledging data sources and authenticity of results.

Prepare information sheets about the major diseases of the world.

Script a radio play about the lifestyle of a diabetic who uses insulin.

Draw pie charts of blood composition.

Make a collection of photographs of xerophytic adaptations of plants.

Acknowledge the use of illustrations of different kinds of stars and galaxies downloaded from the Internet.

1.7 Work in an ethical manner with regard to living things and the environment.

Take appropriate measures to limit disturbance to wildlife and habitats when engaged in field work.

Behave responsibly when working with peers to measure human traits such as skin sensitivity, sight, hearing.

1.8 Identify, and make critical use of, secondary information.

Use WHO data to draw maps of the incidence of malaria.

Use census data to plot population growth curves.

Study and assess information on the Internet related to climate change.

Study and assess information on the Internet related to the 'ozone hole' and the effectiveness of international agreements to combat it.

2 Know how scientists work

2.1 Understand the historical development of major scientific ideas.

Find out about the development of genetic fingerprinting.

Track the evolution in our in understanding of HIV/AIDS.

Study the evolution of our understanding of the Universe (noting particularly the seminal role of Islamic philosophers in developing the concept of the heliocentric Solar System).

See standard groups 34 and 35

Study the evolution of our ideas about the nature of light.

2.2 Know how scientific work is affected by its economic, social, cultural, moral and spiritual contexts.

Discuss the cultural and moral constraints placed by societies on research on genetic manipulation, cloning and stem cells.

Collect press information that debates the arguments for and against child vaccination.

2.3 Show an understanding of the power and limitations of science in addressing industrial, social and environmental questions.

Review the evidence that science has provided the knowledge needed to breed plant and animals that could feed the world and consider why people starve.

Find out which plant and animal species are in danger of extinction and what, if any, steps are being taken to halt their decline.

Debate the reasons for fishing in areas where the fish population is in decline.

2.4 Understand the importance of refutation in the replacement of a prevailing scientific paradigm with a new one.

Note the examples of the photoelectric effect, which appeared to refute traditional theories relating to energy prevailing in 1900 but could be explained by the quantum theory, and of the Rutherford scattering experiment, which overturned the idea of atoms as solid particles.

2.5 Recognise that the development of scientific ideas often proceeds in periods of major changes followed by periods of slow elaboration.

See Standard 30.2

Identify major changes in the history of science (e.g. the heliocentric Universe of the early Islamic philosophers, Newtonian mechanics, the development of our understanding of atomic structure, the development of the science of thermodynamics, the development of quantum theory).

2.6 Appreciate the significance of the development of probabilistic foundations of our understanding of natural phenomena.

Discuss the apparent contradiction between the probabilistic, random nature of the fundamental matter of which the Universe is built and the determinist teachings of major world religions.

3 Process and communicate information

3.1 Record raw data appropriately in a manner that allows easy interpretation.

Sketch the position of the solvent front and pigment positions from chromatograms.

Draw tables of the phenotypes of genetic crosses.

3.2 Process raw data by the most appropriate means.

Draw maps to show the incidence of major diseases.

Graph population statistics over time.

3.3 Draw valid conclusions, allowing for errors and uncertainties.

Calculate the probability of obtaining the progeny of genetic crosses by chance.

Use a graphical method for determining g using a pendulum that allows errors to be spotted and eliminated.

3.4 Use an appropriate range of methods to communicate scientific information.

Use charts to illustrate metabolic pathways.

Prepare a PowerPoint presentation on monoclonal antibodies.

Use models to illustrate the action of antibodies.

Use applets to illustrate a variety of three-dimensional physical processes.

ICT opportunity

Prepare a PowerPoint presentation.

4 Handle equipment and make measurements

4.1 Select and use correctly and competently the appropriate equipment and materials for an investigation, with due regard for the safety of self and others.

Use chromatography to separate plant pigments.

Use blood group identification cards.

Work with a DNA testing kit.

Use a xenon stroboscope to determine the frequency of a vibration.

Use a laser and a microwave generator to show interference.

Use a spectroscope to study emission and absorption spectra.

4.2 Follow instructions accurately but be able to adapt to unforeseen circumstances.

Biology

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in an allergic response. They understand the action of antibiotics and why resistance develops. They know the causes of cholera, influenza, malaria and TB, and explain their transmission, control and significance. They outline the mechanism of gene therapy. They calculate the frequency of different progeny from a cross with incomplete dominant alleles, from back crosses and from dihybrid crosses. They understand co-dominance and the inheritance of phenotypic traits through multiple alleles. They use the chi-squared test to determine the significance of results of genetic crosses. They know about the Human Genome Project, genetic fingerprinting and genetic screening and counselling. They know how some organisms are structurally and physiologically adapted to their environment and distinguish between acclimatisation and adaptation. They understand carrying capacity of a habitat and can use population curves. They understand ecological colonisation and succession. The know examples of biological control of unwanted organisms. They distinguish between environmental preservation and conservation and understand the conflicts between nature conservation and production. They understand how biosensors are used to monitor blood glucose levels in diabetes and how diabetes can be treated with genetically produced insulin. They know some applications of monoclonal antibodies and immobilised enzymes.

Students should:

5 Understand the biochemistry of respiration

5.1 Explain how the biochemistry, products and energy release of anaerobic respiration differ from those of aerobic respiration and how anaerobic respiration builds up an oxygen debt.

Ferment yeast and capture the carbon dioxide.

Construct a chart of the reactions in anaerobic respiration.

Watch a video of a sprint race and discuss why the athletes breathe heavily for several minutes after the race.

5.2 Explain the structure and function of ADP and ATP and the synthesis of ATP in the electron transport chain on the membranes of the mitochondria.

Study models of ADP and ATP.

Examine diagrams and models of mitochondria.

Calculate the size of mitochondria.

5.3 Outline glycolysis as the phosphorylation of glucose and the subsequent splitting of hexose phosphate (6C) into two triose phosphate molecules, which are further oxidised with a small yield of ATP and reduced NAD.

Draw a flow chart of the metabolic pathways of respiration.

Construct a card game to sequence the reactions of respiration.

5.4 Explain that when oxygen is available, pyruvate is converted into acetyl coenzyme A (2C), which then combines with oxaloacetate (4C) to form citrate (6C).

Make a model to illustrate the reactions being considered.

Use the Internet to find out about coenzymes.

ICT opportunity

Use the Internet to gather information.

5.5 Explain the Krebs cycle as a series of decarboxylation and dehydrogenation reactions in the matrix of the mitochondria that reconvert citrate to oxaloacetate; explain the role of NAD.

Prepare cards that depict the reactants and reactions of the Krebs cycle and arrange these in sequence.

Find out about Krebs and why a series of reactions is named after him.

5.6 Explain the role of oxygen in the process of oxidative phosphorylation.

Construct a wall chart of the biochemistry of respiration.

Act out the reactions of oxidative phosphorylation.

5.7 Explain respiratory quotient and the relative energy values of carbohydrates, proteins and lipids as respiratory substrates.

Use a calorimeter to compare relative energies of food chemicals.

Match data on respiratory quotients to diets.

6 Understand the biochemistry of photosynthesis

6.1 Explain that energy is transferred by the photoactivation of chlorophyll resulting in the splitting of water molecules and the transfer of energy to ATP and NADPH; that this involves cyclic and non-cyclic photophosphorylation; that this generates hydrogen for the light-independent stage of the process; that gaseous oxygen is produced.

Construct a flow diagram to trace the role of the reactants involved in the processes being considered.

Trace the history of the development of our understanding of photosynthesis.

Use an oxygen probe and meter to measure the amount of oxygen released by a plant in a day.

6.2 Explain that the Calvin cycle involves the light-independent fixation of carbon dioxide by combination with RuBP (5C) to form two molecules of GP (3C), that ATP and NADP are required for the reduction of GP to carbohydrate, and that RuDP is regenerated.

Construct a wall chart of the biochemistry of photosynthesis.

Find out about Calvin and why a series of reactions is named after him.

ICT opportunity

Use the Internet to gather information.

6.3 Describe how carbon-14 has been used to establish the biochemistry of photosynthesis.

Study radiographs showing carbon-14 as a chemical tracer.

Use textbooks to find out about the safety issues associated with the use of carbon-14.

6.4 Know that chlorophyll reflects green light and absorbs in the red and blue areas of the spectrum, and that the pigments of chlorophyll can be separated by chromatography.

Use a spectrometer to determine the wavelengths of light absorbed and reflected by chlorophyll.

Use paper chromatography to separate the pigments of chlorophyll of different plants and compare the results.

7 Understand how blood functions in transportation

7.1 Explain the structure and function of human red blood cells, phagocytes and lymphocytes and the differences between the functions of blood, fluid tissue and lymph in the transportation of substances to and from cells.

Examine prepared slides of blood at high magnification under a microscope.

Ask a nurse to talk about blood tests.

7.2 Know the composition of the blood and explain the roles of red cells, plasma, haemoglobin and carbonic anhydrase in the transportation of oxygen and carbon dioxide.

Construct a pie chart to illustrate the composition of human blood.

Use a centrifuge to separate the components of animal blood.

7.3 Describe and explain the significance of the dissociation curves of haemoglobin at different carbon dioxide levels (the Bohr effect).

Interpret dissociation curves of haemoglobin constructed from measurements taken at different concentrations of carbon dioxide.

7.4 Know that human blood can be classified into one of four groups and the implications of this for blood transfusions.

Play a game with blood group cards in which individuals requiring a transfusion must find others who can be a donor while potential donors must find individuals who could receive their blood.

Use blood group identification cards to determine blood groups.

8 Understand mechanisms of transpiration and translocation

8.1 Explain how temperature, wind speed and humidity affect the rate of transpiration and how plants control their water loss by regulating stomatal opening.

Use a microscope to study slides of the cross-sections of leaves with open and closed stomata.

Using a potometer, carry out experiments to compare the rate of transpiration of a leafy shoot in different conditions.

8.2 Explain some of the adaptations that help xerophytic plants to conserve water.

Examine the structure of the leaves and stems of desert and seashore plants.

Make a photographic record of the xerophytic adaptation of plants in Qatar.

8.3 Explain some of the hypotheses being put forward to explain translocation.

Study summaries of competing explanations for translocation and discuss the strength of the evidence for and against the claims.

Use library sources and the Internet to track the development of our understanding of translocation.

ICT opportunity

Use the Internet to gather information.

8.4 Know how autoradiography and aphids have been used in the study of translocation.

Study pictures of autoradiographs from experiments on translocation and discuss possible interpretations.

Debate the ethics of using aphids in research on translocation.

9 Understand control systems in mammals

9.1 Describe the gross external and internal structure of the kidney and the detailed structure of the nephron and associated blood vessels.

Study a model kidney.

Use a microscope to study prepared sections through a kidney.

9.2 Using water potential terminology, explain the functioning of the kidney in osmoregulation and in controlling metabolic wastes.

Dissect a kidney obtained from a butcher and locate the main structures.

9.3 Explain the role of the pituitary gland, ADH and aldosterone in osmoregulation.

Use a chart of the body to locate the pituitary and other endocrine glands.

Model the relative size of the pituitary and other glands and body organs.

9.4 Explain the role of thermoreceptors in the hypothalamus in thermoregulation and describe some physiological and behavioural responses of mammals to hot and cold conditions.

Keep a diary of the behaviour of domestic animals in relation to the weather.

Use an outline of the brain to record the position of the hypothalamus and related glands.

Draw a flow chart to illustrate the communication system involved in thermoregulation.

Watch and discuss a video illustrating responses of mammals to hot and cold conditions.

ICT opportunity

Use video for illustration.

9.5 Describe the symptoms of heatstroke and explain why it occurs and how it can be avoided.

Write an account describing the symptoms of someone suffering from heatstroke.

Produce a tourist guide to avoiding heatstroke.

9.6 Describe, compare and contrast the structure and function of sensory, motor and intermediate neurones and know where they are found.

Make wall posters with drawings of different neurones.

Examine prepared slides of neurones with a microscope.

9.7 Explain the function and importance of a reflex arc and differentiate between a simple reflex and a conditioned reflex.

Compare the reflexes of students using different stimuli.

9.8 Explain: the nature of a nerve impulse and the way it is transmitted; resting potential; membrane depolarisation and action potential; refractory period; the passage of sodium and potassium ions.

Watch and discuss a video on the transmission of nerve impulses.

ICT opportunity

Use video for illustration.

9.9 Explain the operation of sensory receptors as energy transducers.

Make a chart of the sensory receptors in humans, their location and the senses they detect.

Investigate the interaction of different senses (e.g. taste and smell, sight and sound).

9.10 Describe the roles of synapses in the nervous system in determining the direction of nerve impulse transmission and in allowing interconnections of nerve pathways.

Write an account of nerve transmission across a synapse.

9.11 Describe the main structures of the human brain – cerebral hemispheres, cerebellum, medulla oblongata – and their functions. Know that the hypothalamus is the link between the nervous and the endocrine control systems.

Study a model of the brain and locate the main structures.

Make a chart of the brain structures and their functions.

9.12 Know the names, locations and functions of the main endocrine glands of humans.

Draw a large outline of the body and mark the locations of the main endocrine glands and the hormones they produce.

Match cards of glands, hormones and functions.

9.13 Explain how insulin and glucagon control the blood glucose level and how failure of the system results in diabetes.

Construct a feedback diagram to illustrate the control of blood sugar levels.

Ask a diabetic to describe how the condition is controlled.

Keep a diary of sugar intake and discuss whether this is posing a risk of diabetes.

10 Describe the roles of hormones in plants

10.1 Describe how auxins affect plant growth by cell extension, how abscisic acid prepares plants to withstand stress and how gibberellins cause effects such as internode extension, premature flowering and break dormancy.

Treat seedlings with auxins and observe the effects.

Repeat some of the classic textbook experiment on auxins and compare the results with those reported in the texts.

11 Understand the operation of the human immune system

11.1 Explain the production and action of human antibodies against antigens and distinguish between the actions of beta lymphocytes and T lymphocytes.

Draw a flow chart to show how the immune system responds to an antigen.

11.2 Explain the function of memory cells in long-term immunity.

Write a short article for a science magazine explaining the function of memory cells.

Use the Internet to locate scientists who have done research on memory cells and find out about their contributions to our understanding.

ICT opportunity

Use the Internet to gather information.

11.3 Relate the molecular structure of antibodies to their function.

Compare the molecular structure of different antibodies and note similarities and differences.

Make models to illustrate antibody–antigen reactions.

11.4 Explain the importance to health care of the pluripotency of stem cells and the culturing of monoclonal antibodies.

Use the Internet to find out about the potential of stem cells in the treatment of diseases such as cancer.

Discuss the ethics of stem cell research.

ICT opportunity

Use the Internet to gather information.

11.5 Describe the role of the immune system in allergies such as hay fever.

Do a survey to find out how many students have allergies, what symptoms are apparent and how they are treated.

11.6 Distinguish between the actions of active and passive immunity and explain the role of vaccination in combating disease.

Complete immunity profiles based on illnesses and vaccinations received.

Find out about the pioneers of vaccination.

Discuss why some people are not in favour of vaccination.

11.7 Explain the role of antibiotics in health care and understand how pathogenic bacteria can become resistant to a particular antibiotic that was once effective.

Investigate the effect of different concentrations of different antibiotics on cultures of bacteria.

Write a letter to a friend explaining why an antibiotic once active against illness-causing bacteria is not longer effective.

Make a list of common antibiotics and the bacteria and illnesses they are effective against.

11.8 Explain the causes, transmission, control and global significance of cholera, influenza, malaria and tuberculosis (TB).

Analyse WHO annual statistics on the incidence of cholera, identify areas of the world with the greatest incidences and try to account for peaks and troughs.

Write a leaflet for travellers with advice on the avoidance of malaria.

11.9 Explain gene therapy, with reference to examples such as cystic fibrosis, and understand the possible benefits and hazards of such treatments.

Make a short video that describes gene therapy and presents the possible benefits and hazards.

ICT opportunity

Make a video.

Make a collection of news articles on gene therapy and use these to help inform a debate on the subject.

12 Understand genetic inheritance

12.1 Calculate the ratios of the genotypes and phenotypes in the progeny of incomplete dominant monohybrid crosses, dihybrid crosses (9:3:3:1 ratio) and back crosses.

Use a computer simulation of a genetic cross.

ICT opportunity

Use a computer simulation.

Use the library to find out about the work of Mendel.

12.2 Explain co-dominance and the inheritance of phenotypic traits such as blood grouping through multiple alleles.

Calculate the ratios of genotypes in multiple crosses.

Draw diagram and/or charts to illustrate the possible patterns of inheritance of blood groups.

12.3 Use the chi-squared test to determine the significance of observed and expected frequencies of different progeny in genetic crosses.

Carry out calculations to determine the significance of the results from breeding experiments.

12.4 Know the purpose of the Human Genome Project.

Extract information from the Human Genome Project website.

ICT opportunity

Use the Internet to gather information.

12.5 Explain the basis of genetic fingerprinting and understand its advantages and potential dangers.

Study the genetic fingerprints of 'suspects' and decide which set best matches the evidence collected at a 'crime scene'.

Find out about the research of Alex Jeffries, who is credited with the development of genetic fingerprinting techniques.

12.6 Explain the basis of genetic screening for alleles of disadvantaging inherited conditions; understand the advantages and potential dangers of such screening and the need for genetic counselling.

Discuss the nature of a conversation that a counsellor might have with a husband and wife, one of whom thinks they are carrying an allele for a disadvantaging condition.

Make a list of conditions for which genetic screening is known to be available.

13 Understand how organisms are adapted to their environments

13.1 Explain examples of structural and physiological adaptations of animals to their environment.

Match descriptions of adaptations of animals to the environments they are best suited to.

Make a field trip to the desert and record adaptations of plants and animals to the conditions there.

13.2 Distinguish between the permanent adaptation of an organism to its normal environment and the temporary acclimatisation of a visitor.

Interpret graphs of the red blood cell counts of people who live at high altitude and those of temporary visitors before, during and after their visit.

14 Understand the dynamics of population growth and succession

14.1 Explain and give examples to illustrate the carrying capacity of an environment.

Interpret data on the dynamics of animal populations.

Use computer models to explore population growth and decline.

ICT opportunity

Use computer models.

14.2 Know how to construct and interpret population curves for different organisms; identify the stages in population growth and decline.

Monitor the growth of a colony of unicellular algae.

ICT opportunity

Use a datalogger to monitor growth.

Examine population graphs of different organisms.

14.3 Describe the progression of the development of an ecological community from primary colonisation to climax community.

Carry out fieldwork to establish the plant succession on a rocky or sandy shore.

Trace the development of a biological community through a photographic record.

15 Understand biological control

15.1 Explain examples of biological control of population growth in natural and commercial settings.

Interpret case study data on control of wild rabbits and control of greenhouse pests.

View videos that illustrate biological control.

ICT opportunity

Use video for illustration.

15.2 Assess the advantages and disadvantages of biological pest control.

Carry out a role-play exercise in which one student acts as an advocate for biological pest control and another acts as a protester against it.

16 Understand tensions related to the environment

16.1 Explain the similarities and differences between environmental preservation and conservation; understand that conservation is a dynamic process involving management and reclamation.

Make contact with environmental groups in Qatar and determine their policies regarding preservation and conservation.

Find out about National Parks and how they are managed.

16.2 Explain how a wish to use an environment for food production can conflict with a wish for its conservation.

Debate the desirability of restricting fishing to conserve fish stocks.

Discuss why people protest when forests are felled to allow farmers to grow food crops.

17 Understand some applications of biotechnology

17.1 Explain how genetically engineered human insulin was developed and is now manufactured for use by diabetics.

Determine the number of diabetics in Qatar and the amount of insulin they require in a year.

Draw a flow chart to depict the commercial production of human insulin.

17.2 Explain what is meant by a biosensor. Know about the use of glucose oxidase as a bio-recognition substance in biosensors used for monitoring the blood glucose levels of diabetics.

Find out who makes biosensors. Contact some of the companies (or visit their websites) and ask for information about their operation.

Ask a nurse, doctor or a diabetic person to talk about the use of biosensors in the control of diabetes.

17.3 Explain some biomedical uses of monoclonal antibodies in procedures such as pregnancy testing.

Use the Internet to determine the role of monoclonal antibodies in pregnancy testing.

ICT opportunity

Use the Internet to gather information.

17.4 Explain the technique of enzyme immobilisation, understand the advantages and disadvantages of the use of immobilised enzymes and describe some commercial applications.

Carry out experiments on the rates of reaction of immobilised enzymes.

Make a list of products that are dependent on enzyme technology and find out where they are produced.

Chemistry

By the end of Grade 12, students know that economic considerations determine what commercial processes commonly exist and where, and that economic advantages of such processes must be balanced against environmental threats. They recognise the periodic variation in ionisation energies, electron affinity and electronegativity, and predict properties of

elements from their position in the periodic table. They know the trends in the general properties of the s-, p- and d-block elements and the specific properties and structures of some of their compounds. Students explain reaction rates in terms of particle collisions and energy, and distinguish between first- and second-order reactions. They calculate the half-life of first-order reactions and understand the relationship between rate constant and temperature. They deduce mathematical expressions for equilibrium constants and use them in gas and solution reactions. They address mathematically problems related to acid–base reactions, buffer solutions and solutions of sparingly soluble salts. They use mathematically the concepts of enthalpy change and relate them to energy cycles. They understand the application of the second law of thermodynamics to chemical systems and can use the concepts of entropy and free energy in relation to the spontaneity of a reaction. Students understand the mechanisms of electrophilic addition and substitution, nucleophilic substitution and elimination reactions. They know the fundamental chemistry of arenes and substituted arenes and describe the production of the more important derivatives of benzene. They explain the stability of the benzene ring in terms of electron delocalisation. They understand structural and optical isomerism and their chemical consequences. They know how addition and condensation polymers are formed and how their properties can be modified by additives.

Students should:

18 Know a variety of factors that influence how chemicals are manufactured

18.1 Know the essential chemistry of the two main processes for producing alkali: the Solvay process and the diaphragm cell. Know the products of these processes and the uses to which they are put, and understand the economic impact on the processes of the demand for chlorine.

Prepare illustrated flow charts showing the two processes for producing alkali and the use made of the products.

Study the Qatar alkali industry through an industrial visit, noting particularly the importance of the by-product chlorine to the Qatar chemical industry.

Study the worldwide balance between the two processes for making alkali, noting that this depends not only on the supply of raw materials but on the demand for the products, particularly the by-product of the electrolytic process, chlorine.

18.2 Analyse Ellingham diagrams to provide information about the feasibility of the reduction of metal oxides by carbon at different temperatures.

Use Ellingham diagrams to predict the viability of the use of carbon to extract a metal (e.g. zinc) from its ore and to provide information on the conditions that are necessary for this to be effective.

18.3 Recognise that Qatar natural gas can act as both a fuel and a feedstock for industrial processes and that a wide variety of industrial processes are arising in the country that take advantage of the availability of both the gas and the products of other processes.

See Standard 2.2

Make a study of the evolution of industries in Qatar that arise from the presence of the gas field, with particular attention to their interdependence; that is, the way that each industry exploits the products and by-products of others.

18.4 Show an understanding of the balance that often has to be made between the economic advantages that industrial processes bring to Qatar and the environmental threat that they pose.

See Standards 2.2, 2.3

Arrange discussion groups using scientists from industries and from Friends of the Environment as resource people. Link these to industrial visits and to environmental field trips.

19 Understand periodic trends in the properties of elements

19.1 Understand and use the term *ionisation energy*. Explain the factors influencing the ionisation energies of elements and the trends in ionisation energies across a period and down a group of the periodic table.

Study graphically the changes in ionisation energy across periods and down groups in the periodic table. Account for trends and discontinuities.

19.2 Understand the terms *electron affinity* and *electronegativity* and recognise and explain their periodic variation.

Study graphically the periodicity in changes in electron affinity with change in atomic number. Study graphically and explain changes in electron affinity within periods and within groups.

Show the existence of dipolar covalent molecules in compounds such as water.

Compare the ionic/covalent character of a variety of chlorides to illustrate the concept of electronegativity.

Study the chemistry of the elements lithium and magnesium and note similarities. Study and explain the changes in electronegativity across a period and down a group and note and explain diagonal similarities in properties of elements.

19.3 Know the general chemistry of the s-block elements, including:

- trends in the physical properties of the elements;
- trends in the chemical properties of the elements;
- general common properties of the compounds of the elements, including the solubility, colour and thermal stability of the nitrates, carbonates and hydroxides;
- the occurrence and extraction of the elements.

Compare and contrast the chemistry of the group I elements lithium, sodium and potassium, and the group II elements magnesium and calcium, and their compounds.

Safety

Students should not handle sodium or potassium.

19.4 Outline and explain qualitatively the trends in the thermal stability of group II nitrates and carbonates and the variation in solubility of group II sulfates.

Investigate the trends practically and relate the explanation to electronegativity.

See Standard 19.2

19.5 Outline and explain trends in a number of properties down group VII:

- physical properties;
- the reactivity of the elements as oxidising agents;
- the thermal stability of the hydride;
- the reaction of the halide ions with silver nitrate followed by aqueous ammonia.

Develop experimentally a displacement series for the group VII elements.

Use the silver nitrate test to distinguish between different halides in solution.

Carry out some characteristic reactions of the elements with metals (e.g. burning s-block metals in chlorine, the reaction between iodine and aluminium powder).

Safety

Take due care when using halogens and when using alkali metals.

19.6 Know how aluminium occurs and how it is extracted. Describe the main properties of aluminium, including:

- the amphiprotic nature of the ion in its salts and solution;

- the suppression of the natural reactivity of the metal;
- anodising.

Study the extraction of aluminium, with particular reference to the plant in Qatar.

Investigate the action of acids and alkalis on a precipitate of aluminium hydroxide.

Study the reaction of aluminium salts (particularly the chloride) with water.

Anodise an aluminium object by electrolysis.

19.7 Explain how the small size and high charge of the aluminium ion leads to partial covalent bonding and its amphiprotic properties.

19.8 Outline and explain, in terms of structure and bonding, trends in a number of properties down group IV:

- melting point and electrical conductivity of the elements;
- the increased stability of the lower oxidation state;
- the bonding, acid–base nature and thermal stability of the oxides;
- the bonding in the chlorides, their volatility and their reaction with water.

Study graphically the increase in metallic properties of the elements down the group, as represented by such characteristics as conductivity and ionisation energies.

Make a comparative study of the physical and chemical properties of the oxides of the elements carbon to lead, noting the trends in the relative stability of the oxidation state +2 down the group.

Make a comparative study of the physical and chemical properties of the chlorides of the elements carbon to lead, noting the anomalous behaviour of carbon, the acidic behaviour of the elements in their +4 oxidation states and the basic behaviour of the elements in their +2 states.

19.9 Know that in transition metals, d-electrons can be involved in bonding as well as the outer s-electrons, resulting in multiple oxidation states. Predict from its electronic configuration, the likely oxidation states of a transition element.

19.10 Explain how the variable oxidation states can result in transition metal ions acting as oxidising and reducing agents. Give examples of transition metal redox systems.

Investigate the variation in oxidation state and colour of transition metal elements (e.g. vanadium, chromium, manganese and iron) through a variety of redox reactions.

19.11 Know that transition elements combine with ligands through dative bonding to form complexes and that these are often coloured. Give examples of ligand exchange reactions.

Study the mechanism of oxygenation and deoxygenation of haemoglobin and the effect of ligands such as cyanide and carbon monoxide on this balance.

Investigate typical complex formation, such as the reaction between copper ions in the presence of varying concentrations of ligands (e.g. water, chloride, ammonium).

19.12 Know that ligands in transition metal complexes may be neutral or anionic, and that the complexes usually exhibit four-fold (planar or tetrahedral) or six-fold (octahedral) coordination.

Illustrate with models of a variety of complex ions.

19.13 Explain the formation of complexes in terms of coordinate bonds and the splitting of d-electron energy levels and know how this explains the colour of many transition metals' complex ions.

19.14 Know the biochemical importance of cobalt and iron.

List the names and physiological functions of biochemical molecules that involve transition elements.

20 Understand reaction kinetics and equilibria

20.1 Recognise that different reactions proceed at different rates and explain reaction rate in terms of particle collisions and particle energy.

Use models to show how reaction rates depend on both the number of collisions and the kinetic energy of the colliding particles. The energy of the colliding particles could be described in terms of the Boltzmann distribution.

See Standard 20.6

20.2 Derive and use rate expressions of the form rate = k[A]m[B]n from data and draw and analyse graphical representations for zero, first- and second-order reactions in a specified reactant.

Mathematics

A knowledge of calculus is useful but not essential.

Carry out a simulation of a first-order reaction using drawing pins or coins and represent the result graphically.

Investigate simple reactions in which rate can be measured easily and plot graphs of rate against the concentration of a reactant to determine order of reaction. Suitable reactions are the iodine clock reaction, the action of acid on thiosulfate and the action of hydrochloric acid on calcium carbonate.

20.3 Calculate the half-life of first-order reactions and show an understanding of why it is concentration independent.

Investigate the dependence of rate on concentration of hydrogen peroxide in the iodine clock reaction. This can be done using ICT simulations.

ICT opportunity

Use simulations of laboratory processes.

20.4 Describe qualitatively the relationship between the rate constant and temperature.

Investigate the effect of temperature on the reactions described in Standard 20.2.

20.5 Use the Arrhenius equation to determine the energy of activation given values of the rate constant for different temperatures.

Mathematics

Knowledge of natural logarithms required.

Investigate the effect of temperature on the acid–thiosulfate reaction and obtain graphically a value for the activation energy.

20.6 Understand the Boltzmann distribution and demonstrate its importance in reaction kinetics, with particular reference to activation energy.

Relate activation energy to the Boltzmann distribution of kinetic energy in particles to explain why some reactions proceed faster than others.

20.7 Deduce expressions for forward and backward rate constants for a simple bimolecular reaction and hence deduce expressions for equilibrium constants in terms of concentrations (K_c) and partial pressures (K_p).

Mathematics

A knowledge of calculus is useful but not essential.

20.8 Calculate the values of equilibrium constants in terms of concentrations or partial pressures from appropriate data, and calculate the quantities present at equilibrium, given appropriate data.

Use data for homogeneous equilibria studied (e.g. the Haber and contact processes).

20.9 Understand and use the term *position of equilibrium* as applied to a reversible reaction and know that the size of an equilibrium constant is an indication of the extent to which a reaction nears completion.

Consider reactions (e.g. that between hydrogen and oxygen) where the equilibrium constant is very large. Consider also mechanisms for influencing the position of an equilibrium as encapsulated in Le Chatelier's principle and applied to reactions such as the Haber and contact processes.

20.10 Show an understanding of the Brønsted–Lowry theory of acidity. Derive and explain the terms *pH*, K_a, pK_a and K_w, and use these concepts in calculations such as the calculation of the pH of solutions of weak acids and bases.

Calculate the dissociation constants of weak acids from measured values of the pH at given concentrations.

Calculate the pH of weak acids and alkalis and give their dissociation constants.

Explain the pH scale in terms of hydrogen ion concentration.

20.11 Know that indicators are weak acids and explain the choice of suitable indicators in acid–base titrations, in terms of the dissociation constant of the indicator.

Calculate the dissociation constant of an indicator required to indicate a specific end-point.

20.12 Understand how buffer solutions control pH (including the role of HCO_3^- in controlling blood pH) and calculate the pH of buffer solutions, given appropriate data.

Calculate the pH of a buffer solution containing known concentrations of sodium ethanoate and ethanoic acid. Make it and test the pH.

20.13 Apply quantitatively the concept of dynamic equilibrium to the solubility of ionic compounds by calculating the solubility product K_{sp} from concentrations, and vice versa, and demonstrate an understanding of the common ion effect.

Determine the solubility product of magnesium hydroxide by quantitative analysis of a saturated solution.

Predict quantitatively the common ion effect of adding some concentrated hydrochloric acid to a saturated solution of lead chloride and confirm the prediction by experiment.

21 Understand reaction energetics

21.1 Explain and use the concept of standard enthalpy change (ΔH), with particular reference to combustion, formation, solution and neutralisation. Calculate enthalpy changes from experimental results.

Determine experimentally the standard enthalpy changes for a number of reactions.

Use, for example, the relationship $\Delta H = (mc_p\Delta T)/n$, where $(mc_p\Delta T)$ represents the heat produced from the reactions and absorbed by an appropriate medium, such as water, of specific heat capacity c_p.

Compare the heat energy released during the burning of different fuels; calculate the molar enthalpies of the reactions.

21.2 Use Hess's law to construct simple energy cycles and determine enthalpy changes that cannot be found by direct experiment, such as enthalpies of formation and of ionisation.

Calculate the molar enthalpy of formation of hydrogen peroxide from the molar enthalpy of formation of water and the molar enthalpy of decomposition of hydrogen peroxide (either of which could be determined experimentally).

21.3 Understand the concept of the Born–Haber cycle and use it to determine unknowns such as electron affinity and ionisation energy.

Use the Born–Haber cycle to calculate the lattice energy of sodium chloride, noting how all other thermodynamic values in the calculation can be independently measured.

21.4 Understand how the natural tendencies in the Universe towards minimum potential energy and maximum disorder are reconciled in the second law of thermodynamics, and understand how these tendencies are applied to chemical systems.

Identify a number of spontaneous physical and chemical processes and classify them according to whether they involve an increase or decrease in entropy (disorder) and an increase or decrease stored energy. For those that involve an increase in stored energy (e.g. the endothermic reaction between potassium hydrogen carbonate and acid), comment on the magnitude of the entropy change.

21.5 State and explain the factors that lead to an increase in the entropy (disorder) of a chemical system.

Consider bond-breaking and bond-making processes and the state of matter of the reactants and products.

21.6 Calculate the standard entropy change for a reaction using absolute entropy values and recognise and explain the impact of changes of state on this value.

Calculate entropy changes for well-known reactions (e.g. burning magnesium) using standard molar entropies of reactants and products.

21.7 Calculate standard free energy changes for reactions from enthalpy and entropy changes and use this to predict the spontaneity of a reaction at a particular temperature.

Use the relationship $\Delta G = \Delta H - T\Delta S$ to calculate the free energy of a reaction.

Show how endothermic reactions can be spontaneous when there is an increase in entropy, where the evolution of gas contributes to the entropy increase (e.g. the action of dilute acid on potassium carbonate).

22 Understand organic reaction mechanisms and factors influencing them

22.1 Describe the shape of aliphatic organic compounds in terms of orbital overlap and electron-pair repulsion.

Draw three-dimensional structures to show how electron-pair repulsion can influence molecular shape.

Discuss, using examples such as chloroform and tetrachloroethane, how steric hindrance can influence expected rate of reaction.

22.2 Describe the restricted rotation and the resulting stereochemistry of multiple bonds in terms of σ (sigma) and π (pi) bonds.

Use space-filling models or three-dimensional rotatable applets to show electron distribution in bonds and how electrophilic and nucleophilic reactions can be initiated.

ICT opportunity

Use Java applets to show stereochemistry and bonding.

22.3 Describe structural isomerism, cis–trans isomerism in alkenes, and how chiral centres give rise to optical isomerism.

22.4 Describe the mechanisms of electrophilic addition in alkenes and nucleophilic substitution in compounds such as halogenoalkanes.

22.5 Show an understanding of the Lewis theory of acids and bases and relate it to nucleophilic reactions in organic chemistry.

22.6 Describe the chemistry of the carbonyl group in terms of nucleophilic substitution and show how its reactivity depends on the electronegativity of the group or groups attached to it.

Classify carbonyl compounds in terms of order of reactivity, with acyl chlorides at the top. Account for the reactivity by noting the extent to which the atom or group attached to the carbonyl tends to oppose or enhance the movement of electrons away from the carbonyl carbon atom.

22.7 Know that acyl chlorides (exemplified by ethanoyl chloride) are readily hydrolysed and that they are useful agents for acylating alcohols, phenols and amines.

Prepare ethanoyl chloride by the action of sulfur dichloride on ethanoic acid.

Use ethanoyl chloride as an acylating agent in a variety of reactions (e.g. the acylation of alcohols and amines).

22.8 Distinguish between amines and amides, recognise that they are both substituted ammonia compounds and therefore describe their basic properties.

Note the trends in physical properties of primary amines.

Investigate the hydrolysis of amines and amides in the presence of an acid or a base as a catalyst.

Note the characteristic smell of amines, which occur naturally in decaying flesh as proteins break down.

Investigate the basicity of amines (e.g. their reactions with dilute hydrochloric acid).

23 Understand aromatic organic chemistry

23.1 Interpret and use the nomenclature and structural formulae of the following classes of compound:

- arenes;
- halogenoarenes;
- phenols;
- aromatic aldehydes and ketones;
- aromatic carboxylic acids, esters and acyl chlorides;
- aromatic amines, nitriles, amides and amino acids.

23.2 Describe the shapes of the ethane, ethene and benzene molecules in terms of σ and π carbon–carbon bonds.

Make three-dimensional models or applets to show the electron concentrations in aromatic compounds and how these are influenced by substituents in the aromatic ring.

23.3 Describe the chemistry of arenes (such as benzene and methylbenzene), as exemplified by substitution reactions with electrophiles, nitration and oxidation of the side chain.

Prepare nitrobenzene from benzene.

Compare the properties of derivatives of methylbenzene with those of the corresponding derivative of ethane.

Safety

Benzene is carcinogenic.

All practical aromatic chemistry involves a fire risk and appropriate precautions should be taken.

23.4 Understand the mechanism of electrophilic substitution in arenes and the effect of the delocalisation of electrons in arenes in such reactions.

Explain the path of the reaction using models (e.g. of phenol and nitrobenzene) showing why, because of electron delocalisation, some ring positions become more accessible to electrophiles than others in a substituted ring.

23.5 Know the chemistry of phenol, as exemplified by its reactions with bases and sodium and by electrophilic substitution in the aromatic ring.

Compare the physical and chemical properties of phenol and aliphatic alcohols (e.g. cyclohexanol).

Compare the ease of nucleophilic substitution in phenol and benzene.

Safety

Nitration of phenol at too high a temperature can lead to the formation of trinitrophenol, which is explosive.

23.6 Describe the formation of aromatic amines by the reduction of nitroarenes.

Prepare phenylamine by the reduction of nitrobenzene.

Compare the ease of nucleophilic substitution in phenylamine and benzene.

23.7 Describe the production of azo-dyes from phenylamine and understand their commercial importance.

Make and use a selection of azo-dyes using the diazonium reaction.

24 Understand the chemistry of some macromolecules

24.1 Know that proteins are formed from combinations of 20 different amino acids through peptide bonds and that they have a variety of functions in living things. Know that they can be broken down by hydrolysis into their constituent amino acids, which can be separated by electrophoresis and ion-exchange chromatography.

Hydrolyse a simple protein and test for amino acids by paper chromatography, using ninhydrin as a locating agent.

24.2 Understand the importance of the shape of the protein molecule and the importance of hydrogen bonding and disulfide bridges in maintaining the shape; know that heating or treating with acid can destroy the shape (denaturing).

Investigate the denaturing of proteins (e.g. egg white) using acid and heat.

Download from the Internet three-dimensional diagrams of some key proteins (e.g. insulin) and note how the structures are maintained using hydrogen bonding and disulfide bridges.

ICT opportunity

Use the Internet to obtain diagrams.

24.3 Describe, in simple terms, the structure of nucleotides and nucleic acids. Describe the differences between DNA and RNA molecules, including the concept of base pairing and the part played by hydrogen bonding.

Make a model to show how the two strands in DNA are held together by hydrogen bonding between specific matching base pairs.

24.4 Understand how DNA can replicate itself and understand its role as the repository of genetic information, including the triplet code, and describe the function of mRNA in protein synthesis.

Show how the arrangement of bases on a DNA strand can give rise to a code for generating specific amino acids.

Study the events leading up to the discovery of the structure of DNA, showing the two very different ways in which scientists work towards major discoveries.

ICT opportunity

Study the film made of the discovery of the structure of DNA.

24.5 Describe the structural features of monosaccharides and know that they form polysaccharides such as starch and cellulose.

Show how the different arrangements of the monosaccharides in starch and cellulose give rise to structures with very different physical and chemical properties.

24.6 Describe how the properties of polymers, both natural and synthetic, depend on their structural features, such as the extent of branching and the linkages between chains.

Compare the physical properties of polyethene and polypropylene.

Make a phenol-methanal resin and study its properties, noting that it has extensive cross-linking between chains, particularly after heating.

24.7 Know that the properties of polymers can be modified by the use of additives.

Study the widespread use of platicisers (silicone polymer additives) to make polymers more flexible. Leave a selection of polymers outside in full sun for several weeks and note the effect on their properties, particularly their loss of plasticity as the plasticisers evaporate.

Study the use of volatile hydrocarbons and carbon dioxide in the manufacture of foams. Make a sample of polyurethane foam and note the reaction that generates the gas.

Physics

By the end of Grade 12, students treat problems in circular motion mathematically. They understand the law of universal gravitation and use it to solve problems of motion under gravity. They classify solids according to stiffness, tensile strength, compressive stress and shear stress, plot and interpret stress–strain graphs for different solids and define and use Young's modulus. They know how these properties are used by engineers and understand the usefulness of composite materials. They explain surface tension. They solve problems related to ideal gas behaviour and show mathematically the relationship between temperature and the kinetic energy of molecules. They understand the concept of absolute zero of temperature and can relate changes in internal energy, heat changes and work done on a thermodynamic system. They relate entropy to disorder and describe the second law of thermodynamics, and its consequences in terms of entropy. Students solve mathematical problems in simple harmonic motion and explain practical examples of resonance, critically and non-critically damped oscillations and forced oscillations. They apply Coulomb's law to charged particles in air, solve problems related to potential difference and potential energy and recognise the similarities between electric and gravitational fields. They understand capacitors and solve problems relating capacitance to voltage and current. They distinguish between emission and absorption spectra and know how these yield information about distant stars and galaxies. They recall and use the relationships $E = hf$ and $E = mc^2$ and explain the quantisation of charge and electromagnetic radiation and know some applications and consequences of this. They explain electron orbitals in terms of quantisation of angular momentum and know how quantum theory leads to the idea of electron 'probability clouds'. They know the source of nuclear energy. They explain the structure of the visible Universe in terms of the gravitational attraction between objects. They define and use the parsec and the light-year. They explain the creation and evolution of stars and know how their ultimate fate depends on their mass. They know how elements are formed in stars and how planetary systems arise. They know the 'big bang' theory of the origin of the Universe and can adduce evidence for it. They know how the Universe can be, at the same time, finite but without boundaries.

Students should:

25 Understand gravity and circular motion

25.1 Express angular displacement in radians and describe, qualitatively and quantitatively, motion in a circular path due to a perpendicular force causing a centripetal acceleration.

Study the motion of a tethered, and then released, puck on a friction-free table.

Investigate the centripetal force on a trolley tethered by a spring on a revolving turntable.

25.2 Understand and use the concept of angular velocity to solve problems in various situations using the formulae $v = r\omega$, $a = r\omega^2$ and $a = v^2/r$.

Perform problem-solving calculations using real situations (e.g. calculating the desirable camber on the bend of a road or the banking angle of an aircraft).

25.3 Understand and use the concept of a gravitational field as an example of a force field and define gravitational field strength as force per unit mass.

Determine g on the Earth's surface using a free-fall method.

25.4 Recall and use Newton's law of universal gravitation in the form $F = G(m_1m_2)/r^2$ and relationships derived from it.

Calculate the mass of the Sun, the Moon and the planets.

25.5 Relate gravitational force to the centripetal acceleration it causes, with particular reference to Earth satellite orbits, and show an understanding of the applications of geostationary orbits.

Calculate the orbital radius of a satellite knowing its velocity, and calculate the orbital radius and velocity of geostationary satellites.

25.6 Derive and use expressions relating the kinetic, potential and total energy of an orbiting satellite.

Calculate the increase in kinetic energy of a descending spacecraft.

Mathematics

The ability to use calculus is desirable, but not essential, for this section.

ICT opportunity

Use videophotography.

26 Understand the nature of matter

26.1 Classify solids according to stiffness, tensile strength, compressive strength and shear strength. Plot and interpret stress–strain graphs for different solid. Define and use the concept of Young's modulus.

Determine Young's modulus for a variety of materials (e.g. metals, nylon, polythene).

26.2 Relate the uses of materials to their characteristic behaviour under different types of stress and note the importance of composite materials, both natural and synthetic.

Devise tests to compare different materials under stress.

26.3 Explain surface tension in terms of interparticle forces.

Investigate the effect on the surface tension of water of adding a detergent.

26.4 Explain qualitatively how fluid flow past solid bodies can generate pressure changes in the fluid; give practical examples of this.

Design and test different aerofoil sections in a simple wind tunnel.

26.5 Apply the kinetic particle model to an ideal gas and explain, in terms of molecular size and intermolecular forces, how the behaviour of real gases deviates from the ideal model at high pressures and low temperatures.

26.6 Derive, know and use the gas laws and the general gas equation $PV = nRT$ and show how the general gas equation leads to a concept of absolute zero of temperature.

Determine the laws of Boyle and Charles.

Show how an extrapolation of Charles's law leads to the theoretical concept of absolute zero of temperature.

Solve problems relating to the changes in temperature, pressure and volume of a gas in both theoretical and real situations (e.g. bubble size in deep water, the volume of gas in a weather balloon).

26.7 Show that a theoretical treatment of molecular movement and gas pressure leads to the relationship $pV = \frac{1}{3}mN\bar{c}^2$ and hence, by combining with the gas equation, that the average kinetic energy of a particle is proportional to its absolute temperature.

Use the particle theory to discuss how scientists build theoretical models to explain practical observations. Note also how our understanding of the fundamental nature of matter developed unevenly through history, with the postulation of major theories followed by long periods of slow development, which either reinforced the ideas or refuted them.

See Standards 2.1–2.5

Discuss the apparent contradiction between the probabilistic, random nature of the fundamental matter of which the Universe is built and the determinist teachings of major world religions.

See Standard 2.6

27 Understand the fundamentals of thermodynamics

27.1 Show an understanding, in terms of particle energy, of the concept of absolute zero and the absolute scale of temperature, which does not depend on the property of any particular substance. Convert temperatures measured in kelvin to degrees Celsius.

27.2 Recognise that temperature is a measure of the average kinetic energy of molecules of a substance.

See Standard 26.7

27.3 Recognise that the first law of thermodynamics is a statement of the principle of conservation of energy.

Recall everyday examples of energy conservation, noting the hierarchy of usefulness of energy, with 'waste heat' always at the bottom.

27.4 Explain what is meant by a thermodynamic system and describe the concepts of heat, work and internal energy in the case of an ideal gas.

27.5 Use the first law of thermodynamics relating changes in internal energy, heat changes in the system and the work done on the system.

Show that pumping a bicycle pump to compress a gas is an (almost) adiabatic process that raises the internal energy of the gas that is compressed, which causes the pump to become warm. Treat this theoretically, relating heat leaving the system, ΔQ, to the internal energy of the particles, ΔU, and the work done on the system, ΔW.

27.6 Calculate work done by a gas expanding against a constant external pressure using $W = p\Delta V$.

27.7 Know that internal energy is determined by the state of the system and that it can be expressed as the sum of the kinetic and potential energies associated with the molecules of a system.

27.8 State that the entropy of a system expresses its degree of disorder and describe the second law of thermodynamics in terms of entropy change.

Discuss everyday examples of energy changes in terms of changes of entropy. Note that the production of heat is related to increased molecular disorder of the system and therefore that energy changes that lead to the production of heat tend to be spontaneous.

Note that that the second law of thermodynamics gives a natural direction to our everyday experiences. Cite examples of processes that only happen naturally in one direction (e.g. the decay in the bouncing of a ball, the scattering of a box of matches).

27.9 State the Kelvin–Planck formulation of the second law of thermodynamics and show an understanding of how it leads to the imposition of limits to the efficiency of any heat engine that are related to the temperatures of the heat sources and heat sinks.

Show how the maximum theoretical efficiency of a power station is related to the difference between the temperature of the heat source and the temperature of the waste gases emerging from the power station. Similarly show how the maximum theoretical efficiency of a car engine can be calculated knowing the temperature of the explosion in the cylinder and the ambient temperature of the cylinder block (the heat sink).

28 Understand the properties of oscillations and waves

28.1 Describe examples of free oscillations and understand and use the terms *amplitude*, *period*, *frequency*, *angular frequency* and *phase difference*. Express the period in terms of both frequency and angular frequency.

Mathematics

A knowledge of trigonometry is essential for this section. A knowledge of differential and integral calculus is very desirable.

28.2 Deduce, by calculus or graphical methods, and use the equations for expressing the displacement, period, velocity and acceleration in simple harmonic motion.

Determine of g using a simple pendulum.

Demonstrate simple harmonic motion using mechanical methods (e.g. an oscillating paper funnel full of sand) and electronic methods (e.g. a pendulum suspended from the shaft of a potentiometer, a magnet on a spring oscillating in and out of a coil).

28.3 Describe, using graphical illustrations, the changes in displacement, velocity and acceleration during simple harmonic motion. Describe the changes between kinetic and potential energy during the motion.

Carry out measurements, calculations and graphical representations of displacement, velocity and acceleration against time of an oscillating object.

Calculate the potential energy given to a spring when it is stretched using a known force. Calculate the velocity of the spring at it passes its equilibrium position.

28.4 Describe and explain practical examples of critically and non-critically damped oscillations.

Damp the oscillation of an object on a spring by allowing it to oscillate in a denser medium, such as water.

Study real examples of damping (e.g. a car shock absorber).

28.5 Describe practical examples of forced oscillations and resonance and show how the amplitude of a forced oscillation changes with frequency near to the natural frequency of the system.

Study the oscillation of Barton's pendulums.

Measure the resonant frequency of the Tacoma Narrows bridge from the film of its collapse in 1940.

ICT opportunity

Download material from the Internet. Use a digital video player.

28.6 Describe circumstances in which resonance is desirable and others when it should be avoided.

29 Understand the basics of electrostatic charge and force

29.1 Recall and use $E = V/d$ to calculate the field strength of a uniform field between charged parallel plates, calculate the forces on charges in uniform electric fields and describe the effect of a uniform electric field on the motion of charged particles.

Demonstrate electrostatic field lines using seeds in glycerol placed under a high voltage. (A piezoelectric gas lighter can be used as a safe source of the voltage.)

Investigate the field between two plates using a charged strip of foil.

Safety

Students should not use mains high-voltage supplies.

29.2 State and apply Coulomb's law relating to the force between two or more charged particles in air and on the field strength due to a charged particle.

Demonstrate Coulomb's law experimentally by measuring the separation of two conducting spheres charged to a known potential.

29.3 Define electrical potential at a point in an electric field, relate field strength to potential gradient, solve problems involving potential energy and potential difference and know and use the term *electron-volt*.

29.4 Recognise the similarities between electrical and gravitational fields.

Show the similarities between electrostatic, magnetic and gravitational forces, in particular their common inverse square law.

Trace the development of our understanding of electricity and its effects from early two-fluid models (Du Fay), through a single fluid model (Franklin) to the modern atomic model of matter. Note the deficiencies in each model in accounting for observed phenomena.

See Standard 2.1

29.5 Demonstrate an understanding of the construction and use of capacitors in electrical circuits, and of how the charge is stored.

Discharge capacitors through a microammeter, an LED or a small motor.

Show full-wave rectification using a diode circuit and an oscilloscope and show the smoothing effect of a capacitor.

Design and make simple delayed-action switching circuits.

29.6 Define capacitance and solve problems using $C = Q/V$; derive and use formulae for capacitors in series and in parallel.

Investigate the changes in current and voltage as a capacitor is discharged through a resistor.

Study the discharge through a resistor of capacitors in series and in parallel using an oscilloscope.

29.7 Derive and use the relationship between the energy stored in a capacitor, its charge and the potential between its plates.

Show that energy is stored in a capacitor by discharging it through a motor set to lift a small weight.

30 Understand the basic concepts of quantum and nuclear physics

30.1 Distinguish between emission and absorption spectra; know how these can provide information on the elements present in stellar objects and how far away the objects are.

Use a hand-held spectroscope to study atomic spectra and Fraunhofer lines in the spectrum of the Sun.

Study the emission spectra of mercury and iodine using vapour lamps.

30.2 Know about the particulate nature of electromagnetic radiation; recall and use the formula $E = hf$.

Study Einstein's explanation of the photoelectric effect in terms of the quantisation of light and in terms of threshold frequency and photon energy.

Study the historical development of our understanding of the nature of light.

See Standard 2.1

30.3 Explain atomic spectra and permitted electron orbitals in terms of the quantisation of angular momentum.

Discuss the origins of atomic line spectra, showing that they can be explained in terms of the quantisation of radiation and that the existence of the spectra provides important evidence to support the quantum theory.

See Standard 2.1

30.4 Show an understanding of the quantisation of electronic charge as demonstrated, for example, by Millikan's experiment.

Determine the charge to mass ratio of an electron using a fine beam tube.

30.5 Show an understanding of wave–particle duality in the properties of the electron.

Refer to the use of the electron microscope and back to the early experiments on cathode rays.

30.6 Show an understanding of the interconversion of matter and energy and use the equation $E = mc^2$ and recognise that this explains the phenomenon of nuclear energy.

Describe how this equation is a first-order approximation of the equation for general relativity and note how for a long time this was felt to be meaningless, until the discovery of nuclear energy.

See Standards 2.1, 2.5

30.7 Know how the Schrödinger model for the hydrogen atom leads to the concept of discrete energy states for electrons and to the idea of the probability of finding an electron at any point (related to the square of the amplitude of the wave function) and hence to the concept of 'electron clouds'.

31 Understand the foundations of astrophysics and cosmology

31.1 Describe, and explain in terms of gravitational attraction, the structure of the visible Universe today and know that our Sun is a star in the Milky Way galaxy.

ICT opportunity

Images for many standards in this section can be downloaded from the Internet.

Study stars in the night sky with binoculars, noting different brightnesses and colours.

Download pictures of galaxies from the Internet.

Define and use the light-year and the parsec as units of astronomical measurement.

Study the different ways of estimating stellar distances and the limitations of each.

31.2 Know why powerful telescopes allow us to look back in time to when the Universe was much younger than it is now.

Download images of the early Universe taken by the Hubble Space Telescope from the Internet and compare them with images of the structures of neighbouring galaxies, also downloaded.

31.3 Show an understanding of the size and number of stars and galaxies, the distances between them, and the size of the Universe. Know and define the size of the light-year and the parsec.

Identify a number of bright stars in the night sky using star maps. Find out on the Internet how big they are compared to our sun and how far away they are.

31.4 Know how stars are created, that they are made mainly from the element hydrogen and that their ultimate fate depends on their size and can lead to supernovae, white dwarfs, neutron stars (pulsars) or black holes.

Download from the Internet photographs of nebulae (clouds of hot glowing gas) where new stars are being created and also nebulae that are the remnants of stars that have exploded as supernovae in the past.

Make an Internet study of the known history of the Crab Nebula, the remnants of a supernova that exploded in the thirteenth century, at the centre of which is now a pulsar.

Make an Internet study of the evidence for the existence of black holes.

Study the Hertzsprung–Russell diagram of star types to compare the main characteristics of stars of different sizes and ages.

31.5 Explain the process of element formation in stars and know how this leads to the generation of energy.

See Standard 30.6

31.6 Describe the process of planet formation by gravitational attraction from the remains of an older exploded star.

Download from the Internet photographs of Saturn and its environs taken by the spacecraft Cassini, together with related discussions on planetary formation.

31.7 Know that current thinking favours the ‘big bang’ model of the Universe, which postulates that all matter, time and space were created in a ‘big bang’ around 14 billion years ago, and that since then the Universe has been expanding.

Make a display charting the evolution of the Universe.

Refer to Grade 11 work on the Doppler effect and explain how the ‘redshift’ and the cosmic microwave background radiation provide evidence for the ‘big bang’ model of the creation and evolution of the Universe.

Study Olber’s paradox and the consequences of different solutions to it.

31.8 Understand how the Universe can at the same time be finite but have no boundaries.

Examine the concept of spacetime and its origins with the big bang and recognise that the Universe is not expanding into a void. Study also the consequence of relativity theory that the motion of light is influenced by the gravitational attraction of the matter in the Universe; examine the experimental evidence for this.