<u>Grade 11-12 Physics Curriculum</u>

<u>Unit of Study</u>: Mechanics (17 hours)

Curriculum Standards	**Learner Outcomes**
Kinematics	• Define *displacement*, *velocity*, *speed* and *acceleration*. • Explain the difference between instantaneous and average values of speed, velocity and acceleration. • Outline the conditions under which the equations for uniformly accelerated motion may be applied. • Identify the acceleration of a body falling in a vacuum near the Earth's surface with the acceleration g of free fall. • Solve problems involving the equations of uniformly accelerated motion. • Describe the effects of air resistance on falling objects. • Draw and analyse distance–time graphs, displacement–time graphs, velocity–time graphs and acceleration–time graphs. • Calculate and interpret the gradients of displacement–time graphs and velocity–time graphs, and the areas under velocity–time graphs and acceleration–time graphs. • Determine relative velocity in one and in two dimensions.
Forces and dynamics	• Calculate the weight of a body using the expression $W = mg$. • Identify the forces acting on an object and draw free-body diagrams representing the forces acting. • Determine the resultant force in different situations. • State Newton's first law of motion. • Describe examples of Newton's first law. • State the condition for translational equilibrium. • Solve problems involving translational equilibrium. • State Newton's second law of motion. • Solve problems involving Newton's second law • Define linear momentum and impulse. • Determine the impulse due to a time-varying force by interpreting a force–time graph. • State the law of conservation of linear momentum. • Solve problems involving momentum and impulse. • State Newton's third law of motion. • Discuss examples of Newton's third law.

Work, energy and power	• Outline what is meant by work. • Determine the work done by a non-constant force by interpreting a force–displacement graph. • Solve problems involving the work done by a force. • Outline what is meant by kinetic energy. • Outline what is meant by change in gravitational potential energy. • State the principle of conservation of energy. • List different forms of energy and describe examples of the transformation of energy from one form to another. • Distinguish between elastic and inelastic collisions. • Define *power*. • Define and apply the concept of *efficiency*. • Solve problems involving momentum, work, energy and power.
Uniform circular motion	• Draw a vector diagram to illustrate that the acceleration of a particle moving with constant speed in a circle is directed towards the centre of the circle. • Apply the expression for centripetal acceleration. • Identify the force producing circular motion in various situations. • Solve problems involving circular motion.

<u>Unit of Study</u>: Thermal physics (7 hours)

Curriculum Standards	**Learner Outcomes**
Thermal concepts	• State that temperature determines the direction of thermal energy transfer between two objects. • State the relation between the Kelvin and Celsius scales of temperature. • State that the internal energy of a substance is the total potential energy and random kinetic energy of the molecules of the substance. • Explain and distinguish between the macroscopic concepts of temperature, internal energy and thermal energy (heat). • Define the *mole* and *molar mass*. • Define the *Avogadro constant*.

Thermal properties of matter	Specific heat capacity, phase changes and latent heat • Define *specific heat capacity* and *thermal capacity*. • Solve problems involving specific heat capacities and thermal capacities. • Explain the physical differences between the solid, liquid and gaseous phases in terms of molecular structure and particle motion. • Describe and explain the process of phase changes in terms of molecular behavior. • Explain in terms of molecular behavior why temperature does not change during a phase change. • Distinguish between evaporation and boiling. • Define *specific latent heat*. • Solve problems involving specific latent heats. Kinetic model of an ideal gas • Define *pressure*. • State the assumptions of the kinetic model of an ideal gas. • State that temperature is a measure of the average random kinetic energy of the average random kinetic energy of the molecules of an ideal gas. • Explain the macroscopic behavior of an ideal gas in terms of a molecular model.

<u>Unit of Study</u>: Oscillations and waves (10 hours)

Curriculum Standards	**Learner Outcomes**
Kinematics of simple harmonic motion (SHM)	• Describe examples of oscillations. • Define the terms *displacement*, *amplitude*, *frequency*, *period* and *phase difference*. • Define *simple harmonic motion* (*SHM)* and state the defining equation as $a = -\omega^2 x$. • Solve problems using the defining equation for SHM. • Apply the equations $v = v_0 \sin \omega t$, $\pm \omega\sqrt{(x_0^2 - x^2)}$, $v = v_0 \cos \omega t$, $v = \pm \omega \; - x^2$ $x = x_0 \cos \omega t$ and $x = x_0 \sin \omega t$ as solutions to the defining equation for SHM. • Solve problems, both graphically and by calculation, for acceleration, velocity and displacement during SHM.

Energy changes during simple harmonic motion (SHM)	• Describe the interchange between kinetic energy and potential energy during SHM. • Apply the expressions $E_K = \frac{1}{2} m\omega^2 (x_0^2 - x^2)$ for the kinetic energy of a particle undergoing SHM, $E_T = \frac{1}{2} m\omega^2 x_0^2$ for the total energy and $E_P = \frac{1}{2} m\omega^2 x^2$ for the potential energy. • Solve problems, both graphically and by calculation, involving energy changes during SHM.
Forced oscillations and resonance	• State what is meant by damping. • Describe examples of damped oscillations. • State what is meant by natural frequency of vibration and forced oscillations. • Describe graphically the variation with forced frequency of the amplitude of vibration of an object close to its natural frequency of vibration. • State what is meant by resonance. • Describe examples of resonance where the effect is useful and where it should be avoided.
Wave characteristics	• Describe a wave pulse and a continuous progressive (traveling) wave. • State that progressive (traveling) waves transfer energy. • Describe and give examples of transverse and of longitudinal waves. • Describe waves in two dimensions, including the concepts of wave fronts and of rays. • Describe the terms crest, trough, compression and rarefaction. • Define the terms *displacement*, *amplitude*, *frequency*, *period*, *wavelength*, *wave speed* and *intensity*. • Draw and explain displacement–time graphs and displacement–position graphs for transverse and for longitudinal waves. • Derive and apply the relationship between wave speed, wavelength and frequency. • State that all electromagnetic waves travel with the same speed in free space, and recall the orders of magnitude of the wavelengths of the principal radiations in the electromagnetic spectrum.

Wave properties	• Describe the reflection and transmission of waves at a boundary between two media. • State and apply Snell's law. • Explain and discuss qualitatively the diffraction of waves at apertures and obstacles. • Describe examples of diffraction. • State the principle of superposition and explain what is meant by constructive interference and by destructive interference. • State and apply the conditions for constructive and for destructive interference in terms of path difference and phase difference. • Apply the principle of superposition to determine the resultant of two waves.

<u>Unit of Study</u>: Electric currents (7 hours)

Curriculum Standards	Learner Outcomes
Electric potential difference, current and resistance	Electric potential difference • Define *electric potential difference*. • Determine the change in potential energy when a charge moves between two points at different potentials. • Define the *electronvolt*. • Solve problems involving electric potential difference. Electric current and resistance • Define *electric current*. • Define *resistance*. • Apply the equation for resistance in the form $R = \frac{\rho L}{A}$ where ρ is the resistivity of the material of the resistor. • State Ohm's law. • Compare ohmic and non-ohmic behaviour. • Derive and apply expressions for electrical power dissipation in resistors. • Solve problems involving potential difference, current and resistance.

Electric Circuits	• Define *electromotive force* (*emf*). • Describe the concept of internal resistance. • Apply the equations for resistors in series and in parallel. • Draw circuit diagrams. • Describe the use of ideal ammeters and ideal voltmeters. • Describe a potential divider. • Explain the use of sensors in potential divider circuits. • Solve problems involving electric circuits.

<u>Unit of Study:</u> Fields and forces (7 hours)

Curriculum Standards	**Learner Outcomes**
Gravitational force and field	• State Newton's universal law of gravitation. • Define *gravitational field strength*. • Determine the gravitational field due to one or more point masses. • Derive an expression for gravitational field strength at the surface of a planet, assuming that all its mass is concentrated at its centre. • Solve problems involving gravitational forces and fields.
Electric force and field	• State that there are two types of electric charge. • State and apply the law of conservation of charge. • Describe and explain the difference in the electrical properties of conductors and insulators. • State Coulomb's law. • Define *electric field strength*. • Determine the electric field strength due to one or more point charges. • Draw the electric field patterns for different charge configurations. • Solve problems involving electric charges, forces and fields.
Magnetic force and field	• State that moving charges give rise to magnetic fields. • Draw magnetic field patterns due to currents. • Determine the direction of the force on a current-carrying conductor in a magnetic field. • Determine the direction of the force on a charge moving in a magnetic field. • Define the *magnitude* and *direction* of a magnetic field. • Solve problems involving magnetic forces, fields and currents.

<u>Unit of Study</u>: Atomic and nuclear physics (9 hours)

Curriculum Standards	**Learner Outcomes**
The atom	Atomic structure • Describe a model of the atom that features a small nucleus surrounded by electrons. • Outline the evidence that supports a nuclear model of the atom. • Outline one limitation of the simple model of the nuclear atom. • Outline evidence for the existence of atomic energy levels. Nuclear structure • Explain the terms nuclide, isotope and nucleon. • Define *nucleon number A*, *proton number Z* and *neutron number N*. • Describe the interactions in a nucleus.
Radioactive decay	Radioactivity • Describe the phenomenon of natural radioactive decay. • Describe the properties of alpha (α) and beta (β) particles and gamma (γ) radiation. • Describe the ionizing properties of alpha (α) and beta (β) particles and gamma (γ) radiation. • Outline the biological effects of ionizing radiation. • Explain why some nuclei are stable while others are unstable. Half- life • State that radioactive decay is a random and spontaneous process and that the rate of decay decreases exponentially with time. • Define the term *radioactive half-life*. • Determine the half-life of a nuclide from a decay curve. • Solve radioactive decay problems involving integral numbers of half-lives.
Nuclear reactions, fission and fusion	Nuclear reactions • Describe and give an example of an artificial (induced) transmutation. • Construct and complete nuclear equations. • Define the term *unified atomic mass unit*. • Apply the Einstein mass–energy equivalence relationship. • Define the concepts of *mass defect*, *binding energy* and *binding energy per nucleon*. • Draw and annotate a graph showing the variation with nucleon number of the binding energy per nucleon. • Solve problems involving mass defect and binding energy. Fission and fusion

	• Describe the processes of nuclear fission and nuclear fusion. • Apply the graph in 7.3.6 to account for the energy release in the processes of fission and fusion. • State that nuclear fusion is the main source of the Sun's energy. • Solve problems involving fission and fusion reactions.

<u>Unit of Study</u>: Energy, power and climate change (18 hours)

Curriculum Standards	**Learner Outcomes**
Energy degradation and power generation	• State that thermal energy may be completely converted to work in a single process, but that continuous conversion of this energy into work requires a cyclical process and the transfer of some energy from the system. • Explain what is meant by degraded energy. • Construct and analyse energy flow diagrams (Sankey diagrams) and identify where the energy is degraded. • Outline the principal mechanisms involved in the production of electrical power.
World energy sources	• Identify different world energy sources. • Outline and distinguish between renewable and non-renewable energy sources. • Define the *energy density* of a fuel. • Discuss how choice of fuel is influenced by its energy density. • State the relative proportions of world use of the different energy sources that are available. • Discuss the relative advantages and disadvantages of various energy sources.
Fossil fuel power production	• Outline the historical and geographical reasons for the widespread use of fossil fuels. • Discuss the energy density of fossil fuels with respect to the demands of power stations. • Discuss the relative advantages and disadvantages associated with the transportation and storage of fossil fuels. • State the overall efficiency of power stations fuelled by different fossil fuels. • Describe the environmental problems associated with the recovery of fossil fuels and their use in power stations.

Non-fossil fuel power production	Nuclear power • Describe how neutrons produced in a fission reaction may be used to initiate further fission reactions (chain reaction). • Distinguish between controlled nuclear fission (power production) and uncontrolled nuclear fission (nuclear weapons). • Describe what is meant by fuel enrichment. • Describe the main energy transformations that take place in a nuclear power station. • Discuss the role of the moderator and the control rods in the production of controlled fission in a thermal fission reactor. • Discuss the role of the heat exchanger in a fission reactor. • Describe how neutron capture by a nucleus of uranium-238 (^{238}U) results in the production of a nucleus of plutonium-239 (^{239}Pu). • Describe the importance of plutonium-239 (^{239}Pu) as a nuclear fuel. • Discuss safety issues and risks associated with the production of nuclear power. • Outline the problems associated with producing nuclear power using nuclear fusion. • Solve problems on the production of nuclear power. Solar power • Distinguish between a photovoltaic cell and a solar heating panel. • Outline reasons for seasonal and regional variations in the solar power incident per unit area of the Earth's surface. • Solve problems involving specific applications of photovoltaic cells and solar heating panels. Hydroelectric power • Distinguish between different hydroelectric schemes. • Describe the main energy transformations that take place in hydroelectric schemes. • Solve problems involving hydroelectric schemes. Wind power • Outline the basic features of a wind generator. • Determine the power that may be delivered by a wind generator, assuming that the wind kinetic energy is completely converted into mechanical kinetic energy, and explain why this is impossible. • Solve problems involving wind power.

	Wave power • Describe the principle of operation of an oscillating water column (OWC) ocean-wave energy converter. • Determine the power per unit length of a wave front, assuming a rectangular profile for the wave. • Solve problems involving wave power.
Greenhouse effect	Solar radiation • Calculate the intensity of the Sun's radiation incident on a planet. • Define *albedo*. • State factors that determine a planet's albedo. The greenhouse effect • Describe the greenhouse effect. • Identify the main greenhouse gases and their sources. • Explain the molecular mechanisms by which greenhouse gases absorb infrared radiation. • Analyse absorption graphs to compare the relative effects of different greenhouse gases. • Outline the nature of black-body radiation. • Draw and annotate a graph of the emission spectra of black bodies at different temperatures. • State the Stefan–Boltzmann law and apply it to compare emission rates from different surfaces. • Apply the concept of emissivity to compare the emission rates from the different surfaces. • Define *surface heat capacity* C_s. • Solve problems on the greenhouse effect and the heating of planets using a simple energy balance climate model.
Global warming	• Describe some possible models of global warming. • State what is meant by the enhanced greenhouse effect. • Identify the increased combustion of fossil fuels as the likely major cause of the enhanced greenhouse effect. • Describe the evidence that links global warming to increased levels of greenhouse gases. • Outline some of the mechanisms that may increase the rate of global warming. • Define *coefficient of volume expansion*. • State that one possible effect of the enhanced greenhouse effect is a rise in mean sea-level. • Outline possible reasons for a predicted rise in mean sea-level. • Identify climate change as an outcome of the enhanced greenhouse effect. • Solve problems related to the enhanced greenhouse effect. • Identify some possible solutions to reduce the enhanced greenhouse effect. • Discuss international efforts to reduce the enhanced greenhouse effect.

Unit of Study: Motion in fields (8 hours)

Curriculum Standards	**Learner Outcomes**
Projectile motion	• State the independence of the vertical and the horizontal components of velocity for a projectile in a uniform field. • Describe and sketch the trajectory of projectile motion as parabolic in the absence of air resistance. • Describe qualitatively the effect of air resistance on the trajectory of a projectile. • Solve problems on projectile motion.
Gravitational field, potential and energy	• Define *gravitational potential* and *gravitational potential energy*. • State and apply the expression for gravitational potential due to a point mass. • State and apply the formula relating gravitational field strength to gravitational potential gradient. • Determine the potential due to one or more point masses. • Describe and sketch the pattern of equipotential surfaces due to one and two point masses. • State the relation between equipotential surfaces and gravitational field lines. • Explain the concept of escape speed from a planet. • Derive an expression for the escape speed of an object from the surface of a planet. • Solve problems involving gravitational potential energy and gravitational potential.
Electric field, potential and energy	• Define *electric potential* and *electric potential energy*. • State and apply the expression for electric potential due to a point charge. • State and apply the formula relating electric field strength to electric potential gradient. • Determine the potential due to one or more point charges. • Describe and sketch the pattern of equipotential surfaces due to one and two point charges. • State the relation between equipotential surfaces and electric field lines. • Solve problems involving electric potential energy and electric potential.
Orbital motion	• State that gravitation provides the centripetal force for circular orbital motion. • Derive Kepler's third law. • Derive expressions for the kinetic energy, potential energy and total energy of an orbiting satellite. • Sketch graphs showing the variation with orbital radius of the kinetic energy, gravitational potential energy and total energy of a satellite. • Discuss the concept of"weightlessness" in orbital motion, in free fall and in deep space. • Solve problems involving orbital motion.

<u>Unit of Study</u>: Thermal physics (6 hours)

Curriculum Standards	Learner Outcomes
Thermodynamics	Gas laws • State the equation of state for an ideal gas. • Describe the difference between an ideal gas and a real gas. • Describe the concept of the absolute zero of temperature and the Kelvin scale of temperature. • Solve problems using the equation of state of an ideal gas.
Processes	The first law of thermodynamics • Deduce an expression for the work involved in a volume change of a gas at constant pressure. • State the first law of thermodynamics. • Identify the first law of thermodynamics as a statement of the principle of energy conservation. • Describe the isochoric (isovolumetric), isobaric, isothermal and adiabatic changes of state of an ideal gas. • Draw and annotate thermodynamic processes and cycles on *P*–*V* diagrams. • Calculate from a *P*–*V* diagram the work done in a thermodynamic cycle. • Solve problems involving state changes of a gas.
Second law of thermodynamics and entropy	• State that the second law of thermodynamics implies that thermal energy cannot spontaneously transfer from a region of low temperature to a region of high temperature. • State that entropy is a system property that expresses the degree of disorder in the system. • State the second law of thermodynamics in terms of entropy changes. • Discuss examples of natural processes in terms of entropy changes.

<u>Unit of Study</u>: Wave phenomena (12 hours)

Curriculum Standards	Learner Outcomes
Standing (stationary) waves	• Describe the nature of standing (stationary) waves. • Explain the formation of one-dimensional standing waves. • Discuss the modes of vibration of strings and air in open and in closed pipes. • Compare standing waves and traveling waves. • Solve problems involving standing waves.

Doppler effect	• Describe what is meant by the Doppler effect. • Explain the Doppler effect by reference to wave front diagrams for moving-detector and moving-source situations. • Apply the Doppler effect equations for sound. • Solve problems on the Doppler effect for sound. • Solve problems on the Doppler effect for electromagnetic waves using the approximation $\Delta f = \frac{v}{c} f.$ • Outline an example in which the Doppler effect is used to measure speed.
Diffraction	Diffraction at a single slit • Sketch the variation with angle of diffraction of the relative intensity of light diffracted at a single slit. • Derive the formula $\theta = \frac{\lambda}{b}$ for the position of the first minimum of the diffraction pattern produced at a single slit. • Solve problems involving single-slit diffraction.
Resolution	• Sketch the variation with angle of diffraction of the relative intensity of light emitted by two point sources that has been diffracted at a single slit. • State the Rayleigh criterion for images of two sources to be just resolved. • Describe the significance of resolution such as CDs and DVDs, the electron microscope and radio telescopes. • Solve problems involving resolution.
Polarization	• Describe what is meant by polarized light. • Describe polarization by reflection. • State and apply Brewster's law. • Explain the terms polarizer and analyser. • Calculate the intensity of a transmitted beam of polarized light using Malus' law. • Describe what is meant by an optically active substance. • Describe the use of polarization in the determination of the concentration of certain solutions. • Outline qualitatively how polarization may be used in stress analysis. • Outline qualitatively the action of liquid-crystal displays (LCDs). • Solve problems involving the polarization of light.

<u>Unit of Study</u>: Electromagnetic induction (6 hours)

Curriculum Standards	**Learner Outcomes**
Induced electromotive force (emf)	• Describe the inducing of an emf by relative motion between a conductor and a magnetic field. • Derive the formula for the emf induced in a straight conductor moving in a magnetic field. • Define *magnetic flux* and *magnetic flux linkage*. • Describe the production of an induced emf by a time-changing magnetic flux. • State Faraday's law and Lenz's law. • Solve electromagnetic induction problems.
Alternating current	• Describe the emf induced in a coil rotating within a uniform magnetic field. • Explain the operation of a basic alternating current (ac) generator. • Describe the effect on the induced emf of changing the generator frequency. • Discuss what is meant by the root mean squared (rms) value of an alternating current or voltage. • State the relation between peak and rms values for sinusoidal currents and voltages. • Solve problems using peak and rms values. • Solve ac circuit problems for ohmic resistors. • Describe the operation of an ideal transformer. • Solve problems on the operation of ideal transformers.
Transmission of electrical power	• Outline the reasons for power losses in transmission lines and real transformers. • Explain the use of high-voltage step- up and step-down transformers in the transmission of electrical power. • Solve problems on the operation of real transformers and power transmission. • Suggest how extra-low-frequency electromagnetic fields, such as those created by electrical appliances and power lines, induce currents within a human body. • Discuss some of the possible risks involved in living and working near high-voltage power lines.

<u>Unit of Study</u>: Quantum physics and nuclear physics (15 hours)

Curriculum Standards	**Learner Outcomes**
Quantum physics	The quantum nature of radiation • Describe the photoelectric effect. • Describe the concept of the photon, and use it to explain the photoelectric effect. • Describe and explain an experiment to test the Einstein model. • Solve problems involving the photoelectric effect. The wave nature of matter • Describe the de Broglie hypothesis and the concept of matter waves. • Outline an experiment to verify the de Broglie hypothesis. • Solve problems involving matter waves. Atomic spectra and atomic energy states • Outline a laboratory procedure for producing and observing atomic spectra. • Explain how atomic spectra provide evidence for the quantization of energy in atoms. • Calculate wavelengths of spectral lines from energy level differences and vice versa. • Explain the origin of atomic energy levels in terms of the "electron in a box" model. • Outline the Schrödinger model of the hydrogen atom. • Outline the Heisenberg uncertainty principle with regard to position–momentum and time–energy.
Nuclear physics	• Explain how the radii of nuclei may be estimated from charged particle scattering experiments. • Describe how the masses of nuclei may be determined using a Bainbridge mass spectrometer. • Describe one piece of evidence for the existence of nuclear energy levels. Radioactive decay • Describe β^+ decay, including the existence of the neutrino. • State the radioactive decay law as an exponential function and define the *decay constant.* • Derive the relationship between decay constant and half-life. • Outline methods for measuring the half-life of an isotope. • Solve problems involving radioactive half-life.

<u>Unit of Study:</u> Digital technology (8 hours)

Curriculum Standards	**Learner Outcomes**
Analogue and digital signals	• Solve problems involving the conversion between binary numbers and decimal numbers. • Describe different means of storage of information in both analogue and digital forms. • Explain how interference of light is used to recover information stored on a CD. • Calculate an appropriate depth for a pit from the wavelength of the laser light. • Solve problems on CDs and DVDs related to data storage capacity. • Discuss the advantage of the storage of information in digital rather than analogue form. • Discuss the implications for society of ever-increasing capability of data storage.
Data capture; digital imaging using charge-coupled devices(CCDs)	• Define *capacitance*. • Describe the structure of a charge coupled device (CCD). • Explain how incident light causes charge to build up within a pixel. • Outline how the image on a CCD is digitized. • Define *quantum efficiency* of a pixel. • Define *magnification*. • State that two points on an object may be just resolved on a CCD if the images of the points are at least two pixels apart. • Discuss the effects of quantum efficiency, magnification and resolution on the quality of the processed image. • Describe a range of practical uses of a CCD, and list some advantages compared with the use of film. • Outline how the image stored in a CCD is retrieved. • Solve problems involving the use of CCDs.

<u>Unit of Study (Option A):</u> Sight and wave phenomena (15 hours)

Curriculum Standards	**Learner Outcomes**
The eye and sight	• Describe the basic structure of the human eye. • State and explain the process of depth of vision and accommodation. • State that the retina contains rods and cones, and describe the variation in density across the surface of the retina. • Describe the function of the rods and of the cones in photopic and scotopic vision. • Describe colour mixing of light by addition and subtraction. • Discuss the effect of light and dark, and colour, on the perception of objects.
Standing (stationary) waves	• Describe the nature of standing (stationary) waves. • Explain the formation of one-dimensional standing waves. • Discuss the modes of vibration of strings and air in open and in closed pipes. • Compare standing waves and traveling waves. • Solve problems involving standing waves.
Doppler effect	• Describe what is meant by the Doppler effect. • Explain the Doppler effect by reference to wave front diagrams for moving-detector and moving-source situations. • Apply the Doppler effect equations for sound. • Solve problems on the Doppler effect for sound. • Solve problems on the Doppler effect for electromagnetic waves using the approximation $\Delta f = \frac{v}{c} f.$ • Outline an example in which the Doppler effect is used to measure speed.
Diffraction	Diffraction at a single slit • Sketch the variation with angle of diffraction of the relative intensity of light diffracted at a single slit. • Derive the formula $\theta = \frac{\lambda}{b}$ for the position of the first minimum of the diffraction pattern produced at a single slit. • Solve problems involving single-slit diffraction.

Resolution	• Sketch the variation with angle of diffraction of the relative intensity of light emitted by two point sources that has been diffracted at a single slit. • State the Rayleigh criterion for images of two sources to be just resolved. • Describe the significance of resolution in the development of devices such as CDs and DVDs, the electron microscope and radio telescopes. • Solve problems involving resolution.
Polarization	• Describe what is meant by polarized light. • Describe polarization by reflection. • State and apply Brewster's law. • Explain the terms polarizer and analyser. • Calculate the intensity of a transmitted beam of polarized light using Malus' law. • Describe what is meant by an optically active substance. • Describe the use of polarization in the determination of the concentration of certain solutions. • Outline qualitatively how polarization may be used in stress analysis. • Outline qualitatively the action of liquid-crystal displays (LCDs). • Solve problems involving the polarization of light.

<u>Unit of Study (Option B):</u> Quantum physics and nuclear physics (15 hours)

Curriculum Standards	**Learner Outcomes**
Quantum physics	The quantum nature of radiation • Describe the photoelectric effect. • Describe the concept of the photon and use it to explain the photoelectric effect. • Describe and explain an experiment to test the Einstein model. • Solve problems involving the photoelectric effect. The wave nature of matter • Describe the de Broglie hypothesis and the concept of matter waves. • Outline an experiment to verify the de Broglie hypothesis. • Solve problems involving matter waves.

Quantum physics	Atomic spectra and atomic energy states • Outline a laboratory procedure for producing and observing atomic spectra. • Explain how atomic spectra provide evidence for the quantization of energy in atoms. • Calculate wavelengths of spectral lines from energy level differences and vice versa. • Explain the origin of atomic energy levels in terms of the "electron in a box" model. • Outline the Schrödinger model of the hydrogen atom. • Outline the Heisenberg uncertainty principle with regard to position–momentum and time–energy.
Nuclear physics	• Explain how the radii of nuclei may be estimated from charged particle scattering experiments. • Describe how the masses of nuclei may be determined using a Bainbridge mass spectrometer. • Describe one piece of evidence for the existence of nuclear energy levels. Radioactive decay • Describe β^+ decay, including the existence of the neutrino. • State the radioactive decay law as an exponential function and define the *decay constant*. • Derive the relationship between decay constant and half-life. • Outline methods for measuring the half-life of an isotope. • Solve problems involving radioactive half-life.

<u>Unit of Study (Option C):</u> Digital technology (15 hours)

Curriculum Standards	**Learner Outcomes**
Analogue and digital signals	• Solve problems involving the conversion between binary numbers and decimal numbers. • Describe different means of storage of information in both analogue and digital forms. • Explain how interference of light is used to recover information stored on a CD. • Calculate an appropriate depth for a pit from the wavelength of the laser light. • Solve problems on CDs and DVDs related to data storage capacity. • Discuss the advantage of the storage of information in digital rather than analogue form. • Discuss the implications for society of ever-increasing capability of data storage.

Data capture; digital imaging using charge-coupled devices (CCDs)	• Define *capacitance*. • Describe the structure of a charge coupled device (CCD). • Explain how incident light causes charge to build up within a pixel. • Outline how the image on a CCD is digitized. • Define *quantum efficiency* of a pixel. • Define *magnification*. • State that two points on an object may be just resolved on a CCD if the images of the points are at least two pixels apart. • Discuss the effects of quantum efficiency, magnification and resolution on the quality of the processed image. • Describe a range of practical uses of a CCD, and list some advantages compared with the use of film. • Outline how the image stored in a CCD is retrieved. • Solve problems involving the use of CCDs.
Electronics	• State the properties of an ideal operational amplifier (op-amp). • Draw circuit diagrams for both inverting and non-inverting amplifiers(with a single input) incorporating operational amplifiers. • Derive an expression for the gain of an inverting amplifier and for a non- inverting amplifier. • Describe the use of an operational amplifier circuit as a comparator. • Describe the use of a Schmitt trigger for the reshaping of digital pulses. • Solve problems involving circuits incorporating operational amplifiers.
The mobile phone system	• State that any area is divided into a number of cells (each with its own base station) to which is allocated a range of frequencies. • Describe the role of the cellular exchange and the public switched telephone network (PSTN) in communications using mobile phones. • Discuss the use of mobile phones in multimedia communication. • Discuss the moral, ethical, economic, environmental and international issues arising from the use of mobile phones.

<u>Unit of Study (Option D):</u> Relativity and particle physics (15 hours)

Curriculum Standards	**Learner Outcomes**
Introduction to relativity	• Describe what is meant by a frame of reference. • Describe what is meant by a Galilean transformation. • Solve problems involving relative velocities using the Galilean transformation equations.
Concepts and postulates of special relativity	• Describe what is meant by an inertial frame of reference. • State the two postulates of the special • Discuss the concept of simultaneity.
Relativistic kinematics	Time dilation • Describe the concept of a light clock. • Define *proper time interval*. • Derive the time dilation formula. • Sketch and annotate a graph showing the variation with relative velocity of the Lorentz factor. • Solve problems involving time dilation. Length contraction • Define *proper length*. • Describe the phenomenon of length contraction. • Solve problems involving length contraction.
Particles and interactions	Description and classification of particles • State what is meant by an elementary particle. • Identify elementary particles. • Describe particles in terms of mass and various quantum numbers. • Classify particles according to spin. • State what is meant by an antiparticle. • State the Pauli exclusion principle. Fundamental interactions • List the fundamental interactions. • Describe the fundamental interactions in terms of exchange particles. • Discuss the uncertainty principle for time and energy in the context of particle creation.

	Feynman diagrams • Describe what is meant by a Feynman diagram. • Discuss how a Feynman diagram may be used to calculate probabilities for fundamental processes. • Describe what is meant by virtual particles. • Apply the formula for the range *R* for interactions involving the exchange of a particle. • Describe pair annihilation and pair production through Feynman diagrams. • Predict particle processes using Feynman diagrams.
Quarks	• List the six types of quark. • State the content, in terms of quarks and antiquarks, of hadrons (that is, baryons and mesons). • State the quark content of the proton and the neutron. • Define *baryon number* and apply the law of conservation of baryon number. • Deduce the spin structure of hadrons (that is, baryons and mesons). • Explain the need for colour in forming bound states of quarks. • State the colour of quarks and gluons • Outline the concept of strangeness. • Discuss quark confinement. • Discuss the interaction that binds nucleons in terms of the colour force between quarks.

<u>Unit of Study (Option E):</u> Astrophysics (15/22 hours)

Curriculum Standards	**Learner Outcomes**
Introduction to the universe	The solar system and beyond • Outline the general structure of the solar system. • Distinguish between a stellar cluster and a constellation. • Define the *light year.* • Compare the relative distances between stars within a galaxy and between galaxies, in terms of order of magnitude. • Describe the apparent motion of the stars/constellations over a period of a night and over a period of a year, and explain these observations in terms of the rotation and revolution of the Earth.
Stellar radiation and stellar types	Energy source • State that fusion is the main energy source of stars. • Explain that, in a stable star (for example, our Sun), there is an equilibrium between radiation pressure and gravitational pressure.

	Luminosity • Define the *luminosity* of a star. • Define *apparent brightness* and state how it is measured. Wien's law and the Stefan–Boltzmann law • Apply the Stefan–Boltzmann law to compare the luminosities of different stars. • State Wien's (displacement) law and apply it to explain the connection between the colour and temperature of stars. Stellar spectra • Explain how atomic spectra may be used to deduce chemical and physical data for stars. • Describe the overall classification system of spectral classes.
	Types of star • Describe the different types of star. • Discuss the characteristics of spectroscopic and eclipsing binary stars. The Hertzsprung–Russell diagram • Identify the general regions of star types on a Hertzsprung–Russell (HR) diagram.
Stellar distances	Parallax method • Define the *parsec*. • Describe the stellar parallax method of determining the distance to a star. • Explain why the method of stellar parallax is limited to measuring stellar distances less than several hundred parsecs. • Solve problems involving stellar parallax. Absolute and apparent magnitudes • Describe the apparent magnitude scale. • Define *absolute magnitude*. • Solve problems involving apparent magnitude, absolute magnitude and distance. • Solve problems involving apparent brightness and apparent magnitude.

	Spectroscopic parallax • State that the luminosity of a star may be estimated from its spectrum. • Explain how stellar distance may be determined using apparent brightness and luminosity . • State that the method of spectroscopic parallax is limited to measuring stellar distances less than about 10 Mpc. • Solve problems involving stellar distances, apparent brightness and luminosity. Cepheid variables • Outline the nature of a Cepheid variable. • State the relationship between period and absolute magnitude for Cepheid variables. • Explain how Cepheid variables may be used as “standard candles”. Determine the distance to a Cepheid variable using the luminosity–period relationship.
Cosmology	Olbers’ paradox • Describe Newton’s model of the universe. • Explain Olbers’ paradox. The Big Bang model • Suggest that the red-shift of light from galaxies indicates that the universe is expanding. • Describe both space and time as originating with the Big Bang. • Describe the discovery of cosmic microwave background (CMB) radiation by Penzias and Wilson. • Explain how cosmic radiation in the microwave region is consistent with the Big Bang model. • Suggest how the Big Bang model provides a resolution to Olbers’ paradox. The development of the universe • Distinguish between the terms open, flat and closed when used to describe the development of the universe. • Define the term *critical density* by reference to a flat model of the development of the universe. • Discuss how the density of the universe determines the development of the universe. • Discuss problems associated with determining the density of the universe. • State that current scientific evidence suggests that the universe is open. • Discuss an example of the international nature of recent astrophysics research. • Evaluate arguments related to investing significant resources into researching the nature of the universe.

Stellar processes and stellar evolution	Nucleosynthesis • Describe the conditions that initiate fusion in a star. • State the effect of a star's mass on the end product of nuclear fusion. • Outline the changes that take place in nucleosynthesis when a star leaves the main sequence and becomes a red giant. Evolutionary paths of stars and stellar processes • Apply the mass–luminosity relation. • Explain how the Chandrasekhar and Oppenheimer–Volkoff limits are used to predict the fate of stars of different masses. • Compare the fate of a red giant and a red super giant. • Draw evolutionary paths of stars on an HR diagram. • Outline the characteristics of pulsars.
Galaxies and the expanding universe	Galactic motion • Describe the distribution of galaxies in the universe. • Explain the red-shift of light from distant galaxies. • Solve problems involving red-shift and the recession speed of galaxies. Hubble's law • State Hubble's law. • Discuss the limitations of Hubble's law. • Explain how the Hubble constant may be determined. • Explain how the Hubble constant may be used to estimate the age of the universe. • Solve problems involving Hubble's law. • Explain how the expansion of the universe made possible the formation of light nuclei and atoms.

<u>Unit of Study (Option F)</u>: Communications (15/22 hours)

Curriculum Standards	**Learner Outcomes**
Radio communication	• Describe what is meant by the modulation of a wave. • Distinguish between a carrier wave and a signal wave. • Describe the nature of amplitude modulation (AM) and frequency modulation (FM). • Solve problems based on the modulation of the carrier wave in order to determine the frequency and amplitude of the information signal. • Sketch and analyse graphs of the power spectrum of a carrier wave that is amplitude-modulated by a single-frequency signal. • Define what is meant by *sideband frequencies* and *bandwidth*. • Solve problems involving sideband frequencies and bandwidth. • Describe the relative advantages and disadvantages of AM and FM for radio transmission and reception. • Describe, by means of a block diagram, an AM radio receiver.
Digital signals	• Solve problems involving the conversion between binary numbers and decimal numbers. • Distinguish between analogue and digital signals. • State the advantages of the digital transmission, as compared to the analogue transmission, of information. • Describe, using block diagrams, the principles of the transmission and reception of digital signals. • Explain the significance of the number of bits and the bit-rate on the reproduction of a transmitted signal. • Describe what is meant by time-division multiplexing. • Solve problems involving analogue-to-digital conversion. • Describe the consequences of digital communication and multiplexing on worldwide communications. • Discuss the moral, ethical, economic and environmental issues arising from access to the Internet.
Optic fibre transmission	• Explain what is meant by critical angle and total internal reflection. • Solve problems involving refractive index and critical angle. • Apply the concept of total internal reflection to the transmission of light along an optic fibre. • Describe the effects of material dispersion and modal dispersion. • Explain what is meant by attenuation and solve problems involving attenuation measured in decibels (dB). • Describe the variation with wavelength of the attenuation of radiation in the core of a monomode fibre. • State what is meant by noise in an optic fibre. • Describe the role of amplifiers and reshapers in optic fibre transmission. • Solve problems involving optic fibres.

Channels of communication	• Outline different channels of communication, including wire pairs, coaxial cables, optic fibres, radio waves and satellite communication. • Discuss the uses and the relative advantages and disadvantages of wire pairs, coaxial cables, optic fibres and radio waves. • State what is meant by a geostationary satellite. • State the order of magnitude of the frequencies used for communication with geostationary satellites, and explain why the up-link frequency and the down-link frequency are different. • Discuss the relative advantages and disadvantages of the use of geostationary and of polar-orbiting satellites for communication. • Discuss the moral, ethical, economic and environmental issues arising from satellite communication.
Electronics	• State the properties of an ideal operational amplifier (op-amp). • Draw circuit diagrams for both inverting and non-inverting amplifiers(with a single input) incorporating operational amplifiers. • Derive an expression for the gain of an inverting amplifier and for a non- inverting amplifier. • Describe the use of an operational amplifier circuit as a comparator. • Describe the use of a Schmitt trigger for the reshaping of digital pulses. • Solve problems involving circuits incorporating operational amplifiers.
The mobile phone system	• State that any area is divided into a number of cells (each with its own base station) to which is allocated a range of frequencies. • Describe the role of the cellular exchange and the public switched telephone network (PSTN) in communications using mobile phones. • Discuss the use of mobile phones in multimedia communication. • Discuss the moral, ethical, economic, environmental and international issues arising from the use of mobile phones.

<u>Unit of Study (Option G):</u> Electromagnetic waves (15/22 hours)

Curriculum Standards	**Learner Outcomes**
The nature of EM waves and light sources	Nature and properties of EM waves • Outline the nature of electromagnetic(EM) waves. • Describe the different regions of the electromagnetic spectrum. • Describe what is meant by the dispersion of EM waves. • Describe the dispersion of EM waves in terms of the dependence of refractive index on wavelength. • Distinguish between transmission, absorption and scattering of radiation. • Discuss examples of the transmission, absorption and scattering of EM radiation. Lasers • Explain the terms monochromatic and coherent. • Identify laser light as a source of coherent light. • Outline the mechanism for the production of laser light. • Outline an application of the use of a laser.
Optical instruments	• Define the terms *principal axis*, *focal point*, *focal length* and *linear magnification* as applied to a converging (convex) lens. • Define the *power* of a *convex lens* and the *dioptre*. • Define *linear magnification*. • Construct ray diagrams to locate the image formed by a convex lens. • Distinguish between a real image and a virtual image. • Apply the convention "real is positive, virtual is negative" to the thin lens formula. • Solve problems for a single convex lens using the thin lens formula. The simple magnifying glass • Define the terms *far point* and *near point* for the unaided eye. • Define *angular magnification*. • Derive an expression for the angular magnification of a simple magnifying glass for an image formed at the near point and at infinity.

	The compound microscope and astronomical telescope • Construct a ray diagram for a compound microscope with final image formed close to the near point of the eye (normal adjustment). • Construct a ray diagram for an astronomical telescope with the final image at infinity (normal adjustment). • State the equation relating angular magnification to the focal lengths of the lenses in an astronomical telescope in normal adjustment. • Solve problems involving the compound microscope and the astronomical telescope. Aberrations • Explain the meaning of spherical aberration and of chromatic aberration as produced by a single lens. • Describe how spherical aberration in a lens may be reduced. Describe how chromatic aberration in a lens may be reduced.
Two-source interference of waves	• State the conditions necessary to observe interference between two sources. • Explain, by means of the principle of superposition, the interference pattern produced by waves from two coherent point sources. • Outline a double-slit experiment for light and draw the intensity distribution of the observed fringe pattern. • Solve problems involving two-source interference.
Diffraction grating	Multiple-slit diffraction • Describe the effect on the double-slit intensity distribution of increasing the number of slits. • Derive the diffraction grating formula for normal incidence. • Outline the use of a diffraction grating to measure wavelengths. • Solve problems involving a diffraction grating.
X-rays	• Outline the experimental arrangement for the production of X-rays. • Draw and annotate a typical X-ray spectrum. • Explain the origins of the features of a characteristic X-ray spectrum. • Solve problems involving accelerating potential difference and minimum wavelength. X-ray diffraction • Explain how X-ray diffraction arises from the scattering of X-rays in a crystal. • Derive the Bragg scattering equation. • Outline how cubic crystals may be used to measure the wavelength of X-rays. • Outline how X-rays may be used to determine the structure of crystals. • Solve problems involving the Bragg equation.

Thin-film interference	Wedge films • Explain the production of interference fringes by a thin air wedge. • Explain how wedge fringes can be used to measure very small separations. • Describe how thin-film interference is used to test optical flats. • Solve problems involving wedge films. Parallel films • State the condition for light to undergo either a phase change of π, or no phase change, on reflection from an interface. • Describe how a source of light gives rise to an interference pattern when the light is reflected at both surfaces of a parallel film. • State the conditions for constructive and destructive interference. • Explain the formation of coloured fringes when white light is reflected from thin films, such as oil and soap films. • Describe the difference between fringes formed by a parallel film and a wedge film. • Describe applications of parallel thin films. • Solve problems involving parallel films.

<u>Unit of Study (Option H):</u> Relativity (22 hours)

Curriculum Standards	**Learner Outcomes**
Introduction to relativity	Frames of reference • Describe what is meant by a frame of reference. • Describe what is meant by a Galilean transformation. • Solve problems involving relative velocities using the Galilean transformation equations.
Concepts and postulates of special relativity	• Describe what is meant by an inertial frame of reference. • State the two postulates of the special theory of relativity. • Discuss the concept of simultaneity.

Relativistic kinematics	Time dilation • Describe the concept of a light clock. • Define *proper time interval*. • Derive the time dilation formula. • Sketch and annotate a graph showing the variation with relative velocity of the Lorentz factor. • Solve problems involving time dilation. Length contraction • Define *proper length*. • Describe the phenomenon of length contraction. • Solve problems involving length contraction.
Some consequences of special relativity	The twin paradox • Describe how the concept of time dilation leads to the "twin paradox". • Discuss the Hafele–Keating experiment. Velocity addition • Solve one-dimensional problems involving the relativistic addition of velocities. Mass and energy • State the formula representing the equivalence of mass and energy. • Define *rest mass*. • Distinguish between the energy of a body at rest and its total energy when moving. • Explain why no object can ever attain the speed of light in a vacuum. • Determine the total energy of an accelerated particle.
Evidence to support special relativity	• Discuss muon decay as experimental evidence to support special relativity. • Solve problems involving the muon decay experiment. • Outline the Michelson–Morley experiment. • Discuss the result of the Michelson–Morley experiment and its implication. • Outline an experiment that indicates that the speed of light in vacuum is independent of its source.
Relativistic momentum and energy	• Apply the relation for the relativistic momentum $p = \gamma m_0 u$ of particles. • Apply the formula $E_K = (\gamma - 1)m_0c^2$ for the kinetic energy of a particle. • Solve problems involving relativistic momentum and energy.

General relativity	The equivalence principle • Explain the difference between the terms gravitational mass and inertial mass. • Describe and discuss Einstein's principle of equivalence. • Deduce that the principle of equivalence predicts bending of light rays in a gravitational field. • Deduce that the principle of equivalence predicts that time slows down near a massive body. Spacetime • Describe the concept of spacetime. • State that moving objects follow the shortest path between two points in spacetime. • Explain gravitational attraction in terms of the warping of spacetime by matter. Black holes • Describe black holes. • Define the term *Schwarzschild radius*. • Calculate the Schwarzschild radius. • Solve problems involving time dilation close to a black hole. Gravitational red-shift • Describe the concept of gravitational red-shift. • Solve problems involving frequency shifts between different points in a uniform gravitational field. • Solve problems using the gravitational time dilation formula.
Evidence to support general relativity	• Outline an experiment for the bending of EM waves by a massive object. • Describe gravitational lensing. • Outline an experiment that provides evidence for gravitational red-shift.

<u>Unit of Study (Option I):</u> Medical physics (22 hours)

Curriculum Standards	**Learner Outcomes**
The ear and hearing	• Describe the basic structure of the human ear. • State and explain how sound pressure variations in air are changed into larger pressure variations in the cochlear fluid. • State the range of audible frequencies experienced by a person with normal hearing. • State and explain that a change in observed loudness is the response of the ear to a change in intensity. • State and explain that there is a logarithmic response of the ear to intensity. • Define intensity and also intensity level (*IL*). • State the approximate magnitude of the intensity level at which discomfort is experienced by a person with normal hearing. • Solve problems involving intensity levels. • Describe the effects on hearing of short-term and long-term exposure to noise. • Analyse and give a simple interpretation of graphs where IL is plotted against the logarithm of frequency for normal and for defective hearing.
Medical imaging	X-rays • Define the terms *attenuation coefficient* and *half-value thickness*. • Derive the relation between attenuation coefficient and half-value thickness. • Solve problems using the equation $I = I_0 e^{-\mu x}$. • Describe X-ray detection, recording and display techniques. • Explain standard X-ray imaging techniques used in medicine. • Outline the principles of computed tomography (CT). Ultrasound • Describe the principles of the generation and the detection of ultrasound using piezoelectric crystals. • Define *acoustic impedance* as the product of the density of a substance and the speed of sound in that substance. • Solve problems involving acoustic impedance. • Outline the differences between A-scans and B-scans. • Identify factors that affect the choice of diagnostic frequency. NMR and lasers • Outline the basic principles of nuclear magnetic resonance (NMR) imaging. • Describe examples of the use of lasers in clinical diagnosis and therapy.

I3 Radiation in medicine	• State the meanings of the terms exposure, absorbed dose, quality factor (relative biological effectiveness) and does equivalent as used in radiation dosimetry. • Discuss the precautions taken in situations involving different types of radiation. • Discuss the concept of balanced risk. • Distinguish between physical half-life, biological half-life and effective half-life. • Solve problems involving radiation dosimetry. • Outline the basis of radiation therapy for cancer. • Solve problems involving the choice of radio-isotope suitable for a particular diagnostic or therapeutic application. • Solve problems involving particular diagnostic applications.

<u>Unit of Study (Option J):</u> Particle physics (22 hours)

Curriculum Standards	**Learner Outcomes**
Particles and interactions	Description and classification of particles • State what is meant by an elementary particle. • Identify elementary particles. • Describe particles in terms of mass and various quantum numbers. • Classify particles according to spin. • State what is meant by an antiparticle. • State the Pauli exclusion principle. Fundamental interactions • List the fundamental interactions. • Describe the fundamental interactions in terms of exchange particles. • Discuss the uncertainty principle for time and energy in the context of particle creation.

	Feynman diagrams • Describe what is meant by a Feyman diagram. • Describe how a Feynman diagram may be used to calculate probabilities for fundamental processes. • Describe what is meant by virtual particles. • Apply the formula for the range *R* for interactions involving the exchange of a particle. • Describe pair annihilation and pair production through Feynman diagrams. Predict particle processes using Feynman diagrams.
Particle accelerators and detectors	Particle accelerators • Explain the need for high energies in order to produce particles of large mass. • Explain the need for high energies in order to resolve particles of small size. • Outline the structure and operation of a linear accelerator and of a cyclotron. • Outline the structure and explain the operation of a synchrotron. • State what is meant by bremsstrahlung (braking) radiation. • Compare the advantages and disadvantages of linear accelerators, cyclotrons and synchrotrons. • Solve problems related to the production of particles in accelerators. Particle detectors • Outline the structure and operation of the bubble chamber, the photomultiplier and the wire chamber. • Outline international aspects of research into high-energy particle physics. • Discuss the economic and ethical implications of high-energy particle physics research.
Quarks	• List the six types of quark. • State the content, in terms of quarks and antiquarks, of hadrons (that is, baryons and mesons). • State the quark content of the proton and the neutron. • Define *baryon number* and apply the law of conservation of baryon number. • Deduce the spin structure of hadrons(that is, baryons and mesons). • Explain the need for colour in forming bound states of quarks. • State the colour of quarks and gluons. • Outline the concept of strangeness. • Discuss quark confinement. • Discuss the interaction that binds nucleons in terms of the colour force between quarks.
Leptons and the standard model	• State the three-family structure of quarks and leptons in the standard model. • State the lepton number of the leptons in each family. • Solve problems involving conservation laws in particle reactions. • Evaluate the significance of the Higgs particle (boson).

Experimental evidence for the quark and standard models	• State what is meant by deep inelastic scattering. • Analyse the results of deep inelastic scattering experiments. • Describe what is meant by asymptotic freedom. • Describe what is meant by neutral current. • Describe how the existence of a neutral current is evidence for the standard model.
Cosmology and strings	• State the order of magnitude of the temperature change of the universe since the Big Bang. • Solve problems involving particle interactions in the early universe. • State that the early universe contained almost equal numbers of particles and antiparticles. • Suggest a mechanism by which the predominance of matter over antimatter has occurred. • Describe qualitatively the theory of strings.