IB PHYSICS SL
ASSESSMENT STATEMENTS

Topic 1: Physics and physical measurement (5 hours)

1.1The realm of physics

1 hour

	Assessment statement	Obj	Teacher's notes
Range of magnitudes of quantities in our universe			
1.1.1	State and compare quantities to the nearest order of magnitude.	3	
1.1.2	State the ranges of magnitude of distances, masses and times that occur in the universe, from smallest to greatest.	1	Distances: from 10^{-15} m to 10^{+25} m (sub-nuclear particles to extent of the visible universe). Masses: from 10^{-30} kg to 10^{+50} kg (electron to mass of the universe). Times: from 10^{-23} s to 10^{+18} s (passage of light across a nucleus to the age of the universe). **Aim 7:** There are some excellent simulations to illustrate this. **TOK:** This is a very stimulating area for a discussion of ways of knowing.
1.1.3	State ratios of quantities as differences of orders of magnitude.	1	For example, the ratio of the diameter of the hydrogen atom to its nucleus is about 10^5, or a difference of five orders of magnitude.
1.1.4	Estimate approximate values of everyday quantities to one or two significant figures and/or to the nearest order of magnitude.	2	

1.2Measurement and uncertainties

2 hours

TOK: Data and its limitations is a fruitful area for discussion.

	Assessment statement	Obj	Teacher's notes
The SI system of fundamental and derived units			
1.2.1	State the fundamental units in the SI system.	1	Students need to know the following: kilogram, metre, second, ampere, mole and kelvin.
1.2.2	Distinguish between fundamental and derived units and give examples of derived units.	2	
1.2.3	Convert between different units of quantities.	2	For example, J and kW h, J and eV, year and second, and between other systems and SI.
1.2.4	State units in the accepted SI format.	1	Students should use m s^{-2} not m/s^2 and m s^{-1} not m/s.
1.2.5	State values in scientific notation and in multiples of units with appropriate prefixes.	1	For example, use nanoseconds or gigajoules.

Uncertainty and error in measurement			
1.2.6	Describe and give examples of random and systematic errors.	2	
1.2.7	Distinguish between precision and accuracy.	2	A measurement may have great precision yet may be inaccurate (for example, if the instrument has a zero offset error).
1.2.8	Explain how the effects of random errors may be reduced.	3	Students should be aware that systematic errors are not reduced by repeating readings.
1.2.9	Calculate quantities and results of calculations to the appropriate number of significant figures.	2	The number of significant figures should reflect the precision of the value or of the input data to a calculation. Only a simple rule is required: for multiplication and division, the number of significant digits in a result should not exceed that of the least precise value upon which it depends. The number of significant figures in any answer should reflect the number of significant figures in the given data.
Uncertainties in calculated results			
1.2.10	State uncertainties as absolute, fractional and percentage uncertainties.	1	
1.2.11	Determine the uncertainties in results.	3	A simple approximate method rather than root mean squared calculations is sufficient to determine maximum uncertainties. For functions such as addition and subtraction, absolute uncertainties may be added. For multiplication, division and powers, percentage uncertainties may be added. For other functions (for example, trigonometric functions), the mean, highest and lowest possible answers may be calculated to obtain the uncertainty range. If one uncertainty is much larger than others, the approximate uncertainty in the calculated result may be taken as due to that quantity alone.
Uncertainties in graphs **Aim 7:** This is an opportunity to show how spreadsheets are commonly used to calculate and draw error bars on graphs.			
1.2.12	Identify uncertainties as error bars in graphs.	2	
1.2.13	State random uncertainty as an uncertainty range (±) and represent it graphically as an "error bar".	1	Error bars need be considered only when the uncertainty in one or both of the plotted quantities is significant. Error bars will not be expected for trigonometric or logarithmic functions.
1.2.14	Determine the uncertainties in the gradient and intercepts of a straight-line graph.	3	Only a simple approach is needed. To determine the uncertainty in the gradient and intercept, error bars need only be added to the first and the last data points.

1.3Vectors and scalars

2 hours

This may be taught as a stand-alone topic or can be introduced when vectors are encountered in other topics such as 2.2, forces and dynamics, and 6.2, electric force and field.

	Assessment statement	Obj	Teacher's notes
1.3.1	Distinguish between vector and scalar quantities, and give examples of each.	2	A vector is represented in print by a bold italicized symbol, for example, ***F***.
1.3.2	Determine the sum or difference of two vectors by a graphical method.	3	Multiplication and division of vectors by scalars is also required.
1.3.3	Resolve vectors into perpendicular components along chosen axes.	2	For example, resolving parallel and perpendicular to an inclined plane.

Topic 2: Mechanics (17 hours)

Aim 7: This topic is a fruitful one for using spreadsheets and data logging in practical work as well as computer simulations in teaching various concepts.

2.1Kinematics

6 hours

	Assessment statement	Obj	Teacher's notes
2.1.1	Define *displacement*, *velocity*, *speed* and*acceleration*.	1	Quantities should be identified as scalar or vector quantities. See sub-topic 1.3.
2.1.2	Explain the difference between instantaneous and average values of speed, velocity and acceleration.	3	
2.1.3	Outline the conditions under which the equations for uniformly accelerated motion may be applied.	2	
2.1.4	Identify the acceleration of a body falling in a vacuum near the Earth's surface with the acceleration *g* of free fall.	2	
2.1.5	Solve problems involving the equations of uniformly accelerated motion.	3	
2.1.6	Describe the effects of air resistance on falling objects.	2	Only qualitative descriptions are expected. Students should understand what is meant by terminal speed.
2.1.7	Draw and analyse distance–time graphs, displacement–time graphs, velocity–time graphs and acceleration–time graphs.	3	Students should be able to sketch and label these graphs for various situations. They should also be able to write descriptions of the motions represented by such graphs.
2.1.8	Calculate and interpret the gradients of displacement–time graphs and velocity–time graphs, and the areas under velocity–time graphs and acceleration–time graphs.	2	
2.1.9	Determine relative velocity in one and in two dimensions.	3	

2.2Forces and dynamics

6 hours

TOK: The development of the laws of motion raises interesting issues relating to correlation and cause and scientific theories.

	Assessment statement	Obj	Teacher's notes
2.2.1	Calculate the weight of a body using the expression *W* = *mg*.	2	
2.2.2	Identify the forces acting on an object and draw free-body diagrams representing the forces acting.	2	Each force should be labelled by name or given a commonly accepted symbol. Vectors should have lengths approximately proportional to their magnitudes. See sub-topic 1.3.
2.2.3	Determine the resultant force in different situations.	3	
2.2.4	State Newton's first law of motion.	1	
2.2.5	Describe examples of Newton's first law.	2	
2.2.6	State the condition for translational equilibrium.	1	
2.2.7	Solve problems involving translational equilibrium.	3	
2.2.8	State Newton's second law of motion.	1	Students should be familiar with the law expressed as: $F = ma$ and $F = \frac{\Delta p}{\Delta t}$.
2.2.9	Solve problems involving Newton's second law.	3	
2.2.10	Define *linear momentum* and *impulse*.	1	
2.2.11	Determine the impulse due to a time-varying force by interpreting a force–time graph.	3	
2.2.12	State the law of conservation of linear momentum.	1	
2.2.13	Solve problems involving momentum and impulse.	3	
2.2.14	State Newton's third law of motion.	1	
2.2.15	Discuss examples of Newton's third law.	3	Students should understand that when two bodies A and B interact, the force that A exerts on B is equal and opposite to the force that B exerts on A.

2.3Work, energy and power

3 hours

	Assessment statement	Obj	Teacher's notes
2.3.1	Outline what is meant by work.	2	Students should be familiar with situations where the displacement is not in the same direction as the force.
2.3.2	Determine the work done by a non-constant force by interpreting a force–displacement graph.	3	A typical example would be calculating the work done in extending a spring. See 2.3.7.

2.3.3	Solve problems involving the work done by a force.	3	
2.3.4	Outline what is meant by kinetic energy.	2	
2.3.5	Outline what is meant by change in gravitational potential energy.	2	
2.3.6	State the principle of conservation of energy.	1	
2.3.7	List different forms of energy and describe examples of the transformation of energy from one form to another.	2	
2.3.8	Distinguish between elastic and inelastic collisions.	2	Students should be familiar with elastic and inelastic collisions and explosions. Knowledge of the coefficient of restitution is not required.
2.3.9	Define *power*.	1	
2.3.10	Define and apply the concept of *efficiency*.	2	
2.3.11	Solve problems involving momentum, work, energy and power.	3	

2.4Uniform circular motion

2 hours

This topic links with sub-topics 6.3 and 9.4.

	Assessment statement	Obj	Teacher’s notes
2.4.1	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.	1	
2.4.2	Apply the expression for centripetal acceleration.	2	
2.4.3	Identify the force producing circular motion in various situations.	2	Examples include gravitational force acting on the Moon and friction acting sideways on the tyres of a car turning a corner.
2.4.4	Solve problems involving circular motion.	3	Problems on banked motion (aircraft and vehicles going round banked tracks) will not be included.

Topic 3: Thermal physics (7 hours)

3.1Thermal concepts

2 hours

	Assessment statement	Obj	Teacher’s notes
3.1.1	State that temperature determines the direction of thermal energy transfer between two objects.	1	Students should be familiar with the concept of thermal equilibrium.
3.1.2	State the relation between the Kelvin and Celsius scales of temperature.	1	$T/\text{K} = t/°\text{C} + 273$ is sufficient.
3.1.3	State that the internal energy of a substance is the total potential energy and random kinetic	1	Students should know that the kinetic energy of the molecules arises from their random/translational/rotational motion and that the

	energy of the molecules of the substance.		potential energy of the molecules arises from the forces between the molecules.
3.1.4	Explain and distinguish between the macroscopic concepts of temperature, internal energy and thermal energy (heat).	3	Students should understand that the term thermal energy refers to the non-mechanical transfer of energy between a system and its surroundings. In this respect it is just as incorrect to refer to the "thermal energy in a body" as it would be to refer to the "work in a body".
3.1.5	Define the *mole* and *molar mass*.	1	
3.1.6	Define the *Avogadro constant*.	1	

3.2Thermal properties of matter

5 hours

	Assessment statement	Obj	Teacher's notes
Specific heat capacity, phase changes and latent heat			
3.2.1	Define *specific heat capacity* and *thermal capacity*.	1	
3.2.2	Solve problems involving specific heat capacities and thermal capacities.	3	
3.2.3	Explain the physical differences between the solid, liquid and gaseous phases in terms of molecular structure and particle motion.	3	Only a simple model is required.
3.2.4	Describe and explain the process of phase changes in terms of molecular behaviour.	3	Students should be familiar with the terms melting, freezing, evaporating, boiling and condensing, and should be able to describe each in terms of the changes in molecular potential and random kinetic energies of molecules.
3.2.5	Explain in terms of molecular behaviour why temperature does not change during a phase change.	3	
3.2.6	Distinguish between evaporation and boiling.	2	
3.2.7	Define *specific latent heat*.	1	
3.2.8	Solve problems involving specific latent heats.	3	Problems may include specific heat calculations.
Kinetic model of an ideal gas **Aim 7:** There are many computer simulations of the behaviour of gases. **TOK:** The use of modelling in science may be introduced here.			
3.2.9	Define *pressure*.	1	
3.2.10	State the assumptions of the kinetic model of an ideal gas.	1	
3.2.11	State that temperature is a measure of the average random kinetic energy of the molecules of an ideal gas.	1	
3.2.12	Explain the macroscopic behaviour of an ideal gas in terms of a molecular model.	3	Only qualitative explanations are required. Students should, for example, be able to explain how a change in volume results in a change in the frequency of particle collisions with the container and how this relates to a change in pressure and/or temperature.

Topic 4: Oscillations and waves (10 hours)

4.1Kinematics of simple harmonic motion (SHM)

2 hours

Aim 7: Many computer simulations of SHM are available.

	Assessment statement	Obj	Teacher's notes
4.1.1	Describe examples of oscillations.	2	
4.1.2	Define the terms *displacement*, *amplitude*,*frequency*, *period* and *phase difference*.	1	The connection between frequency and period should be known.
4.1.3	Define *simple harmonic motion* (*SHM*) and state the defining equation as $a = -\omega^2 x$.	1	Students are expected to understand the significance of the negative sign in the equation and to recall the connection between ω and T.
4.1.4	Solve problems using the defining equation for SHM.	3	
4.1.5	Apply the equations $v = v_0 \sin \omega t$, $v = v_0 \cos \omega t$, $v = \pm\omega\sqrt{(x_0^2 - x^2)}$, $x = x_0 \cos \omega t$ and $x = x_0 \sin \omega t$ as solutions to the defining equation for SHM.	2	
4.1.6	Solve problems, both graphically and by calculation, for acceleration, velocity and displacement during SHM.	3	

4.2Energy changes during simple harmonic motion (SHM)

1 hour

	Assessment statement	Obj	Teacher's notes
4.2.1	Describe the interchange between kinetic energy and potential energy during SHM.	2	
4.2.2	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.	2	
4.2.3	Solve problems, both graphically and by calculation, involving energy changes during SHM.	3	

4.3Forced oscillations and resonance

3 hours

	Assessment statement	Obj	Teacher's notes
4.3.1	State what is meant by damping.	1	It is sufficient for students to know that damping involves a force that is always in the opposite direction to the direction of motion of the oscillating particle and that the force is a dissipative force.
4.3.2	Describe examples of damped oscillations.	2	Reference should be made to the degree of damping and the importance of critical damping. A detailed

			account of degrees of damping is not required.
4.3.3	State what is meant by natural frequency of vibration and forced oscillations.	1	
4.3.4	Describe graphically the variation with forced frequency of the amplitude of vibration of an object close to its natural frequency of vibration.	2	Students should be able to describe qualitatively factors that affect the frequency response and sharpness of the curve.
4.3.5	State what is meant by resonance.	1	
4.3.6	Describe examples of resonance where the effect is useful and where it should be avoided.	2	Examples may include quartz oscillators, microwave generators and vibrations in machinery.

4.4Wave characteristics

2 hours

	Assessment statement	Obj	Teacher's notes
4.4.1	Describe a wave pulse and a continuous progressive (travelling) wave.	2	Students should be able to distinguish between oscillations and wave motion, and appreciate that, in many examples, the oscillations of the particles are simple harmonic.
4.4.2	State that progressive (travelling) waves transfer energy.	1	Students should understand that there is no net motion of the medium through which the wave travels.
4.4.3	Describe and give examples of transverse and of longitudinal waves.	2	Students should describe the waves in terms of the direction of oscillation of particles in the wave relative to the direction of transfer of energy by the wave. Students should know that sound waves are longitudinal, that light waves are transverse and that transverse waves cannot be propagated in gases.
4.4.4	Describe waves in two dimensions, including the concepts of wavefronts and of rays.	2	
4.4.5	Describe the terms crest, trough, compression and rarefaction.	2	
4.4.6	Define the terms *displacement*, *amplitude*,*frequency*, *period*, *wavelength*, *wave speed* and*intensity*.	1	Students should know that intensity $\propto$ amplitude^2.
4.4.7	Draw and explain displacement–time graphs and displacement–position graphs for transverse and for longitudinal waves.	3	
4.4.8	Derive and apply the relationship between wave speed, wavelength and frequency.	3	
4.4.9	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.	1	

4.5Wave properties

2 hours

	Assessment statement	Obj	Teacher's notes
4.5.1	Describe the reflection and transmission of waves at a boundary between two media.	2	This should include the sketching of incident, reflected and transmitted waves.
4.5.2	State and apply Snell's law.	2	Students should be able to define refractive index in terms of the ratio of the speeds of the wave in the two media and also in terms of the angles of incidence and refraction.
4.5.3	Explain and discuss qualitatively the diffraction of waves at apertures and obstacles.	3	The effect of wavelength compared to aperture or obstacle dimensions should be discussed.
4.5.4	Describe examples of diffraction.	2	
4.5.5	State the principle of superposition and explain what is meant by constructive interference and by destructive interference.	3	
4.5.6	State and apply the conditions for constructive and for destructive interference in terms of path difference and phase difference.	2	
4.5.7	Apply the principle of superposition to determine the resultant of two waves.	2	

(Topic 5 is coming……)

Topic 6: Fields and forces, cont. (7 hours)

In this topic, the similarities and differences between the fields should be brought to the attention of students.

TOK: The concept of fields in science is well worth exploring.

6.1 – 6.2 Are in a separate file.

6.3Magnetic force and field

2 hours

	Assessment statement	Obj	Teacher's notes
6.3.1	State that moving charges give rise to magnetic fields.	1	
6.3.2	Draw magnetic field patterns due to currents.	1	These include the fields due to currents in a straight wire, a flat circular coil and a solenoid.
6.3.3	Determine the direction of the force on a current-carrying conductor in a magnetic field.	3	Different rules may be used to determine the force direction. Knowledge of any particular rule is not required.
6.3.4	Determine the direction of the force on a charge moving in a magnetic field.	3	
6.3.5	Define the *magnitude* and *direction* of a magnetic field.	1	
6.3.6	Solve problems involving magnetic forces, fields and currents.	3	

Topic 7: Atomic and nuclear physics (9 hours)

Aim 7: There are opportunities throughout this topic to look at databases, use spreadsheets, explore simulations and perform data-logging experiments.

7.1The atom

2 hours

	Assessment statement	Obj	Teacher's notes
Atomic structure			
7.1.1	Describe a model of the atom that features a small nucleus surrounded by electrons.	2	Students should be able to describe a simple model involving electrons kept in orbit around the nucleus as a result of the electrostatic attraction between the electrons and the nucleus.
7.1.2	Outline the evidence that supports a nuclear model of the atom.	2	A qualitative description of the Geiger–Marsden experiment and an interpretation of the results are all that is required.
7.1.3	Outline one limitation of the simple model of the nuclear atom.	2	
7.1.4	Outline evidence for the existence of atomic energy levels.	2	Students should be familiar with emission and absorption spectra, but the details of atomic models are not required. Students should understand that light is not a continuous wave but is emitted as "packets" or "photons" of energy, each of energy hf.

Nuclear structure			
7.1.5	Explain the terms nuclide, isotope and nucleon.	3	
7.1.6	Define *nucleon number A*, *proton number Z*and *neutron number N*.	1	
7.1.7	Describe the interactions in a nucleus.	2	Students need only know about the Coulomb interaction between protons and the strong, short-range nuclear interaction between nucleons.

7.2Radioactive decay

3 hours

	Assessment statement	Obj	Teacher's notes
Radioactivity			
7.2.1	Describe the phenomenon of natural radioactive decay.	2	The inclusion of the antineutrino in β^- decay is required.
7.2.2	Describe the properties of alpha (α) and beta (β) particles and gamma (γ) radiation.	2	
7.2.3	Describe the ionizing properties of alpha (α) and beta (β) particles and gamma (γ) radiation.	2	
7.2.4	Outline the biological effects of ionizing radiation.	2	Students should be familiar with the direct and indirect effects of radiation on structures within cells. A simple account of short-term and long-term effects of radiation on the body is required. **Aim 8:** There are moral, social and environmental aspects to consider here. **TOK:** Correlation and cause, and risk assessment, can also be looked at.
7.2.5	Explain why some nuclei are stable while others are unstable.	3	An explanation in terms of relative numbers of protons and neutrons and the forces involved is all that is required.
Half-life			
7.2.6	State that radioactive decay is a random and spontaneous process and that the rate of decay decreases exponentially with time.	1	Exponential decay need not be treated analytically. It is sufficient to know that any quantity that reduces to half its initial value in a constant time decays exponentially. The nature of the decay is independent of the initial amount.
7.2.7	Define the term *radioactive half-life*.	1	
7.2.8	Determine the half-life of a nuclide from a decay curve.	3	
7.2.9	Solve radioactive decay problems involving integral numbers of half-lives.	3	

7.3Nuclear reactions, fission and fusion

4 hours

	Assessment statement	Obj	Teacher's notes
Nuclear reactions			
7.3.1	Describe and give an example of an artificial (induced) transmutation.	2	
7.3.2	Construct and complete nuclear equations.	3	
7.3.3	Define the term *unified atomic mass unit*.	1	Students must be familiar with the units MeV c^{-2} and GeV c^{-2} for mass.
7.3.4	Apply the Einstein mass–energy equivalence relationship.	2	
7.3.5	Define the concepts of *mass defect*, *binding energy* and *binding energy per nucleon*.	1	
7.3.6	Draw and annotate a graph showing the variation with nucleon number of the binding energy per nucleon.	2	Students should be familiar with binding energies plotted as positive quantities.
7.3.7	Solve problems involving mass defect and binding energy.	3	
Fission and fusion			
7.3.8	Describe the processes of nuclear fission and nuclear fusion.	2	
7.3.9	Apply the graph in 7.3.6 to account for the energy release in the processes of fission and fusion.	2	
7.3.10	State that nuclear fusion is the main source of the Sun's energy.	1	
7.3.11	Solve problems involving fission and fusion reactions.	3	

Topic 8: Energy, power and climate change (18 hours)

Aim 8 and the international dimension feature strongly in all the sub-topics.

8.1Energy degradation and power generation

2 hours

Aim 7: Computer simulations of Sankey diagrams feature here.

	Assessment statement	Obj	Teacher's notes
8.1.1	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.	1	
8.1.2	Explain what is meant by degraded energy.	3	Students should understand that, in any process that involves energy transformations, the energy that is transferred to the surroundings (thermal energy) is

			no longer available to perform useful work.
8.1.3	Construct and analyse energy flow diagrams (Sankey diagrams) and identify where the energy is degraded.	3	It is expected that students will be able to construct flow diagrams for various systems including those described in sub-topics 8.3 and 8.4.
8.1.4	Outline the principal mechanisms involved in the production of electrical power.	2	Students should know that electrical energy may be produced by rotating coils in a magnetic field. In sub-topics 8.2 and 8.3 students look in more detail at energy sources used to provide the energy to rotate the coils.

8.2World energy sources

2 hours

Aim 7: Databases of energy statistics on a global and national scale can be explored here. Moral, environmental and economic aspects may be considered.

	Assessment statement	Obj	Teacher's notes
8.2.1	Identify different world energy sources.	2	Students should be able to recognize those sources associated with CO_2 emission. Students should also appreciate that, in most instances, the Sun is the prime energy source for world energy.
8.2.2	Outline and distinguish between renewable and non-renewable energy sources.	2	
8.2.3	Define the *energy density* of a fuel.	1	Energy density is measured in J kg^{-1}.
8.2.4	Discuss how choice of fuel is influenced by its energy density.	3	The values of energy density of different fuels will be provided.
8.2.5	State the relative proportions of world use of the different energy sources that are available.	1	Only approximate values are needed.
8.2.6	Discuss the relative advantages and disadvantages of various energy sources.	3	The discussion applies to all the sources identified in sub-topics 8.2, 8.3 and 8.4.

8.3Fossil fuel power production

1 hour

	Assessment statement	Obj	Teacher's notes
8.3.1	Outline the historical and geographical reasons for the widespread use of fossil fuels.	2	Students should appreciate that industrialization led to a higher rate of energy usage, leading to industry being developed near to large deposits of fossil fuels.
8.3.2	Discuss the energy density of fossil fuels with respect to the demands of power stations.	3	Students should be able to estimate the rate of fuel consumption by power stations.
8.3.3	Discuss the relative advantages and disadvantages associated with the transportation and storage of fossil fuels.	3	
8.3.4	State the overall efficiency of power stations fuelled by different fossil fuels.	1	Only approximate values are required.
8.3.5	Describe the environmental problems associated with the recovery of fossil fuels and their use in power stations.	2	

8.4Non-fossil fuel power production

7 hours

Aim 7: Computer simulations may be shown modelling nuclear power stations and nuclear processes in general.

	Assessment statement	Obj	Teacher's notes
Nuclear power			
8.4.1	Describe how neutrons produced in a fission reaction may be used to initiate further fission reactions (chain reaction).	2	Students should know that only low-energy neutrons (≈ 1 eV) favour nuclear fission. They should also know about critical mass.
8.4.2	Distinguish between controlled nuclear fission (power production) and uncontrolled nuclear fission (nuclear weapons).	2	Students should be aware of the moral and ethical issues associated with nuclear weapons.
8.4.3	Describe what is meant by fuel enrichment.	2	
8.4.4	Describe the main energy transformations that take place in a nuclear power station.	2	
8.4.5	Discuss the role of the moderator and the control rods in the production of controlled fission in a thermal fission reactor.	3	
8.4.6	Discuss the role of the heat exchanger in a fission reactor.	3	
8.4.7	Describe how neutron capture by a nucleus of uranium-238 (^{238}U) results in the production of a nucleus of plutonium-239 (^{239}Pu).	2	
8.4.8	Describe the importance of plutonium-239 (^{239}Pu) as a nuclear fuel.	2	It is sufficient for students to know that plutonium-239 (^{239}Pu) is used as a fuel in other types of reactors.
8.4.9	Discuss safety issues and risks associated with the production of nuclear power.	3	Such issues involve: the possibility of thermal meltdown and how it might arise problems associated with nuclear waste problems associated with the mining of uranium the possibility that a nuclear power programme may be used as a means to produce nuclear weapons.
8.4.10	Outline the problems associated with producing nuclear power using nuclear fusion.	2	It is sufficient that students appreciate the problem of maintaining and confining a high-temperature, high-density plasma.
8.4.11	Solve problems on the production of nuclear power.	3	
Solar power			
8.4.12	Distinguish between a photovoltaic cell and a solar heating panel.	2	Students should be able to describe the energy transfers involved and outline appropriate uses of these devices.
8.4.13	Outline reasons for seasonal and regional variations in the solar power incident per unit area of the Earth's surface.	2	
8.4.14	Solve problems involving specific applications	3	

	of photovoltaic cells and solar heating panels.		
Hydroelectric power			
8.4.15	Distinguish between different hydroelectric schemes.	2	Students should know that the different schemes are based on: water storage in lakes tidal water storage pump storage.
8.4.16	Describe the main energy transformations that take place in hydroelectric schemes.	2	
8.4.17	Solve problems involving hydroelectric schemes.	3	
Wind power			
8.4.18	Outline the basic features of a wind generator.	2	A conventional horizontal-axis machine is sufficient.
8.4.19	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.	3	
8.4.20	Solve problems involving wind power.	3	
Wave power			
8.4.21	Describe the principle of operation of an oscillating water column (OWC) ocean-wave energy converter.	2	Students should be aware that energy from a water wave can be extracted in a variety of different ways, but only a description of the OWC is required.
8.4.22	Determine the power per unit length of a wavefront, assuming a rectangular profile for the wave.	3	
8.4.23	Solve problems involving wave power.	3	

8.5Greenhouse effect

3 hours

Aim 7: Computer simulation, spreadsheets and databases have a significant role here.

	Assessment statement	Obj	Teacher's notes
Solar radiation			
8.5.1	Calculate the intensity of the Sun's radiation incident on a planet.	2	
8.5.2	Define *albedo*.	1	
8.5.3	State factors that determine a planet's albedo.	1	Students should know that the Earth's albedo varies daily and is dependent on season (cloud formations) and latitude. Oceans have a low value but snow a high value. The global annual mean albedo is 0.3 (30%) on Earth.
The greenhouse effect			

8.5.4	Describe the greenhouse effect.	2	
8.5.5	Identify the main greenhouse gases and their sources.	2	The gases to be considered are CH_4, H_2O, CO_2 and N_2O. It is sufficient for students to know that each has natural and man-made origins.
8.5.6	Explain the molecular mechanisms by which greenhouse gases absorb infrared radiation.	3	Students should be aware of the role played by resonance. The natural frequency of oscillation of the molecules of greenhouse gases is in the infrared region.
8.5.7	Analyse absorption graphs to compare the relative effects of different greenhouse gases.	3	Students should be familiar with, but will not be expected to remember, specific details of graphs showing infrared transmittance through a gas.
8.5.8	Outline the nature of black-body radiation.	2	Students should know that black-body radiation is the radiation emitted by a “perfect” emitter.
8.5.9	Draw and annotate a graph of the emission spectra of black bodies at different temperatures.	2	
8.5.10	State the Stefan–Boltzmann law and apply it to compare emission rates from different surfaces.	2	
8.5.11	Apply the concept of emissivity to compare the emission rates from the different surfaces.	2	
8.5.12	Define *surface heat capacity* C_s.	1	Surface heat capacity is the energy required to raise the temperature of unit area of a planet’s surface by one degree, and is measured in J m^{-2} K^{-1}.
8.5.13	Solve problems on the greenhouse effect and the heating of planets using a simple energy balance climate model.	3	Students should appreciate that the change of a planet’s temperature over a period of time is given by: (incoming radiation intensity – outgoing radiation intensity) × time / surface heat capacity. Students should be aware of limitations of the model and suggest how it may be improved. **Aim 7:** A spreadsheet should be used to show a simple climate model. Computer simulations could be used to show more complex models (see OCC for details). **TOK:** The use and importance of computer modelling can be explained as a powerful means by which knowledge may be gained.

8.6Global warming

3 hours

Int: The importance of the international dimension in scientific research to solve global problems can be demonstrated here.

	Assessment statement	Obj	Teacher’s notes
Global warming			
8.6.1	Describe some possible models of global warming.	2	Students must be aware that a range of models has been suggested to explain global warming, including changes in the composition of greenhouse gases in the atmosphere, increased solar flare activity, cyclical changes in the Earth’s orbit and volcanic activity.
8.6.2	State what is meant by the enhanced greenhouse effect.	1	It is sufficient for students to be aware that enhancement of the greenhouse effect is caused by human activities.

8.6.3	Identify the increased combustion of fossil fuels as the likely major cause of the enhanced greenhouse effect.	2	Students should be aware that, although debatable, the generally accepted view of most scientists is that human activities, mainly related to burning of fossil fuels, have released extra carbon dioxide into the atmosphere.
8.6.4	Describe the evidence that links global warming to increased levels of greenhouse gases.	2	For example, international ice core research produces evidence of atmospheric composition and mean global temperatures over thousands of years (ice cores up to 420,000 years have been drilled in the Russian Antarctic base, Vostok).
8.6.5	Outline some of the mechanisms that may increase the rate of global warming.	2	Students should know that: global warming reduces ice/snow cover, which in turn changes the albedo, to increase rate of heat absorption temperature increase reduces the solubility of CO_2 in the sea and increases atmospheric concentrations deforestation reduces carbon fixation.
8.6.6	Define *coefficient of volume expansion*.	1	Students should know that the coefficient of volume expansion is the fractional change in volume per degree change in temperature.
8.6.7	State that one possible effect of the enhanced greenhouse effect is a rise in mean sea-level.	1	
8.6.8	Outline possible reasons for a predicted rise in mean sea-level.	2	Students should be aware that precise predictions are difficult to make due to factors such as: anomalous expansion of water different effects of ice melting on sea water compared to ice melting on land.
8.6.9	Identify climate change as an outcome of the enhanced greenhouse effect.	2	
8.6.10	Solve problems related to the enhanced greenhouse effect.	3	Problems could involve volume expansion, specific heat capacity and latent heat.
8.6.11	Identify some possible solutions to reduce the enhanced greenhouse effect.	2	Students should be aware of the following: greater efficiency of power production replacing the use of coal and oil with natural gas use of combined heating and power systems (CHP) increased use of renewable energy sources and nuclear power carbon dioxide capture and storage use of hybrid vehicles.
8.6.12	Discuss international efforts to reduce the enhanced greenhouse effect.	3	These should include, for example: Intergovernmental Panel on Climate Change (IPCC) Kyoto Protocol Asia-Pacific Partnership on Clean Development and Climate (APPCDC).

Option A: Sight and wave phenomena (15 hours)

These options are available at SL only.

A2–A6 are identical to 11.1–11.5.

B1–B2 are identical to 13.1–13.2.

C1–C2 are identical to 14.1–14.2.

C3–C4 are identical to F5–F6.

D1–D3 are identical to H1–H3.

D4 and D5 are identical to J1 and J3.

Aim 7: Computer simulations could be very helpful in illustrating the different ideas in this option.

A1The eye and sight

3 hours

	Assessment statement	Obj	Teacher's notes
A.1.1	Describe the basic structure of the human eye.	2	The structure should be limited to those features affecting the physical operation of the eye.
A.1.2	State and explain the process of depth of vision and accommodation.	3	The near point and the far point of the eye for normal vision are also included.
A.1.3	State that the retina contains rods and cones, and describe the variation in density across the surface of the retina.	2	
A.1.4	Describe the function of the rods and of the cones in photopic and scotopic vision.	2	Students should be able to sketch and interpret spectral response graphs and give an explanation for colour blindness.
A.1.5	Describe colour mixing of light by addition and subtraction.	2	Students should be able to "identify" primary and secondary colours.
A.1.6	Discuss the effect of light and dark, and colour, on the perception of objects.	3	Students should consider architectural effects of light and shadow (for example, deep shadow gives the impression of massiveness). Glow can be used to give an impression of "warmth" (for example, blue tints are cold) or to change the perceived size of a room (for example, light-coloured ceilings heighten the room). **TOK:** This can contribute to a discussion on perception.

Wave phenomena: (A2–A6 are identical to 11.1–11.5).

A2Standing (stationary) waves

2 hours

	Assessment statement	Obj	Teacher's notes
A.2.1	Describe the nature of standing (stationary) waves.	2	Students should consider energy transfer, amplitude and phase.
A.2.2	Explain the formation of one-dimensional standing waves.	3	Students should understand what is meant by nodes and antinodes.
A.2.3	Discuss the modes of vibration of strings and air in open and in closed pipes.	3	The lowest-frequency mode is known either as the fundamental or as the first harmonic. The term overtone will not be used.
A.2.4	Compare standing waves and travelling waves.	3	
A.2.5	Solve problems involving standing waves.	3	

A3Doppler effect

2 hours

	Assessment statement	Obj	Teacher's notes
A.3.1	Describe what is meant by the Doppler effect.	2	
A.3.2	Explain the Doppler effect by reference to wavefront diagrams for moving-detector and moving-source situations.	3	
A.3.3	Apply the Doppler effect equations for sound.	2	
A.3.4	Solve problems on the Doppler effect for sound.	3	Problems will not include situations where both source and detector are moving.
A.3.5	Solve problems on the Doppler effect for electromagnetic waves using the approximation $\Delta f = \frac{v}{c} f$.	3	Students should appreciate that the approximation may be used only when $v << c$.
A.3.6	Outline an example in which the Doppler effect is used to measure speed.	2	Suitable examples include blood-flow measurements and the measurement of vehicle speeds.

A4Diffraction

1 hour

	Assessment statement	Obj	Teacher's notes
Diffraction at a single slit			
A.4.1	Sketch the variation with angle of diffraction of the relative intensity of light diffracted at a single slit.	3	
A.4.2	Derive the formula $\theta = \frac{\lambda}{b}$ for the position of the first minimum of the diffraction pattern produced at a single slit.	3	
A.4.3	Solve problems involving single-slit diffraction.	3	

A5Resolution

4 hours

	Assessment statement	Obj	Teacher's notes
A.5.1	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.	3	Students should sketch the variation where the diffraction patterns are well resolved, just resolved and not resolved.
A.5.2	State the Rayleigh criterion for images of two sources to be just resolved.	1	Students should know that the criterion for a circular aperture is $\theta = 1.22\frac{\lambda}{b}$.
A.5.3	Describe the significance of resolution in the development of devices such as CDs and DVDs, the electron microscope and radio telescopes.	2	
A.5.4	Solve problems involving resolution.	3	Problems could involve the human eye and optical

			instruments.

A6Polarization

3 hours

	Assessment statement	Obj	Teacher's notes
A.6.1	Describe what is meant by polarized light.	2	
A.6.2	Describe polarization by reflection.	2	This may be illustrated using light or microwaves. The use of polarized sunglasses should be included.
A.6.3	State and apply Brewster's law.	2	
A.6.4	Explain the terms polarizer and analyser.	3	
A.6.5	Calculate the intensity of a transmitted beam of polarized light using Malus' law.	2	
A.6.6	Describe what is meant by an optically active substance.	2	Students should be aware that such substances rotate the plane of polarization.
A.6.7	Describe the use of polarization in the determination of the concentration of certain solutions.	2	
A.6.8	Outline qualitatively how polarization may be used in stress analysis.	2	
A.6.9	Outline qualitatively the action of liquid-crystal displays (LCDs).	2	**Aim 8:** The use of LCD screens in a wide variety of different applications/devices can be mentioned.
A.6.10	Solve problems involving the polarization of light.	3	

Option E: Astrophysics (15/22 hours)

SL students study the core of these options and HL students study the whole option (the core and the extension material).

The European Space Agency web site contains material specifically written for this option (see OCC for details).

Aim 7: This option allows great scope for the use of ICT. Databases of astronomical data may be assessed, and simulations depicting astronomical processes may be used in teaching and learning. Spreadsheets may be used to model astronomical events. The web sites of large space organizations contain much useful material.

Aim 8: The ethical implications of the cost of space research may be discussed.

Int: These web sites can also be used to illustrate the international nature of collaboration and research in terms of, for example, telescopes and spacecraft missions.

TOK: This option also allows for much discussion of scientific theories (on the nature and origin of the universe) and how those theories are developed and accepted or abandoned.

Core material: E1–E4 are core material for SL and HL (15 hours).

Extension material: E5–E6 are extension material for HL only (7 hours).

E1Introduction to the universe

2 hours

	Assessment statement	Obj	Teacher's notes
The solar system and beyond			
E.1.1	Outline the general structure of the solar system.	2	Students should know that the planets orbit the Sun in ellipses and moons orbit planets. (Details of Kepler's laws are not required.) Students should also know the names of the planets, their approximate comparative sizes and comparative distances from the Sun, the nature of comets, and the nature and position of the asteroid belt.
E.1.2	Distinguish between a stellar cluster and a constellation.	2	
E.1.3	Define the *light year.*	1	
E.1.4	Compare the relative distances between stars within a galaxy and between galaxies, in terms of order of magnitude.	3	
E.1.5	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.	3	This is the basic background for stellar parallax. Other observations, for example, seasons and the motion of planets, are not expected.

E2Stellar radiation and stellar types

4 hours

	Assessment statement	Obj	Teacher's notes
Energy source			
E.2.1	State that fusion is the main energy source of stars.	1	Students should know that the basic process is one in which hydrogen is converted into helium. They do not need to know about the fusion of elements with higher proton numbers.
E.2.2	Explain that, in a stable star (for example, our Sun), there is an equilibrium between radiation pressure and gravitational pressure.	3	
Luminosity			
E.2.3	Define the *luminosity* of a star.	1	
E.2.4	Define *apparent brightness* and state how it is measured.	1	
Wien's law and the Stefan–Boltzmann law			
E.2.5	Apply the Stefan–Boltzmann law to compare the luminosities of different stars.	2	
E.2.6	State Wien's (displacement) law and apply it to explain the connection between the colour and temperature of stars.	2	
Stellar spectra			

E.2.7	Explain how atomic spectra may be used to deduce chemical and physical data for stars.	3	Students must have a qualitative appreciation of the Doppler effect as applied to light, including the terms red-shift and blue-shift.
E.2.8	Describe the overall classification system of spectral classes.	2	Students need to refer only to the principal spectral classes (OBAFGKM).
Types of star			
E.2.9	Describe the different types of star.	2	Students need to refer only to single and binary stars, Cepheids, red giants, red supergiants and white dwarfs. Knowledge of different types of Cepheids is not required.
E.2.10	Discuss the characteristics of spectroscopic and eclipsing binary stars.	3	
The Hertzsprung–Russell diagram			
E.2.11	Identify the general regions of star types on a Hertzsprung–Russell (HR) diagram.	2	Main sequence, red giant, red supergiant, white dwarf and Cepheid stars should be shown, with scales of luminosity and/or absolute magnitude, spectral class and/or surface temperature indicated. Students should be aware that the scale is not linear. Students should know that the mass of main sequence stars is dependent on position on the HR diagram.

E3Stellar distances

5 hours

	Assessment statement	Obj	Teacher's notes
Parallax method			
E.3.1	Define the *parsec*.	1	
E.3.2	Describe the stellar parallax method of determining the distance to a star.	2	
E.3.3	Explain why the method of stellar parallax is limited to measuring stellar distances less than several hundred parsecs.	3	
E.3.4	Solve problems involving stellar parallax.	3	
Absolute and apparent magnitudes			
E.3.5	Describe the apparent magnitude scale.	2	Students should know that apparent magnitude depends on luminosity and the distance to a star. They should also know that a magnitude 1 star is 100 times brighter than a magnitude 6 star.
E.3.6	Define *absolute magnitude*.	1	
E.3.7	Solve problems involving apparent magnitude, absolute magnitude and distance.	3	
E.3.8	Solve problems involving apparent brightness and apparent magnitude.	3	
Spectroscopic parallax			
E.3.9	State that the luminosity of a star may be estimated from its spectrum.	1	

E.3.10	Explain how stellar distance may be determined using apparent brightness and luminosity.	3	
E.3.11	State that the method of spectroscopic parallax is limited to measuring stellar distances less than about 10 Mpc.	1	
E.3.12	Solve problems involving stellar distances, apparent brightness and luminosity.	3	
Cepheid variables			
E.3.13	Outline the nature of a Cepheid variable.	2	Students should know that a Cepheid variable is a star in which the outer layers undergo a periodic expansion and contraction, which produces a periodic variation in its luminosity.
E.3.14	State the relationship between period and absolute magnitude for Cepheid variables.	1	
E.3.15	Explain how Cepheid variables may be used as “standard candles”.	3	It is sufficient for students to know that, if a Cepheid variable is located in a particular galaxy, then the distance to the galaxy may be determined.
E.3.16	Determine the distance to a Cepheid variable using the luminosity–period relationship.	3	

E4Cosmology

4 hours

	Assessment statement	Obj	Teacher’s notes
Olbers’ paradox			
E.4.1	Describe Newton’s model of the universe.	2	Students should know that Newton assumed an infinite (in space and time), uniform and static universe.
E.4.2	Explain Olbers’ paradox.	3	Students should be able to show quantitatively, using the inverse square law of luminosity, that Newton’s model of the universe leads to a sky that should never be dark.
The Big Bang model			
E.4.3	Suggest that the red-shift of light from galaxies indicates that the universe is expanding.	3	
E.4.4	Describe both space and time as originating with the Big Bang.	2	Students should appreciate that the universe is not expanding into a void.
E.4.5	Describe the discovery of cosmic microwave background (CMB) radiation by Penzias and Wilson.	2	
E.4.6	Explain how cosmic radiation in the microwave region is consistent with the Big Bang model.	3	A simple explanation in terms of the universe “cooling down” is all that is required.
E.4.7	Suggest how the Big Bang model provides a resolution to Olbers’ paradox.	3	

The development of the universe			
E.4.8	Distinguish between the terms open, flat and closed when used to describe the development of the universe.	2	
E.4.9	Define the term *critical density* by reference to a flat model of the development of the universe.	1	
E.4.10	Discuss how the density of the universe determines the development of the universe.	3	
E.4.11	Discuss problems associated with determining the density of the universe.	3	This statement is included to give the students a flavour for the ongoing and complex current nature of research. They should be able to discuss relevant observations and possible explanations. They should recognize that, in common with many other aspects of our universe, much about the phenomena is currently not well understood. Teachers should include dark matter, MACHOs and WIMPs.
E.4.12	State that current scientific evidence suggests that the universe is open.	1	
E.4.13	Discuss an example of the international nature of recent astrophysics research.	3	It is sufficient for students to outline any astrophysics project that is funded by more than one country.
E.4.14	Evaluate arguments related to investing significant resources into researching the nature of the universe.	3	Students should be able to demonstrate their ability to understand the issues involved in deciding priorities for scientific research as well as being able to express their own opinions coherently.