Syllabus outline

Syllabus component	Recommended teaching hours	
	SL	HL
Core	**95**	
1. Measurements and uncertainties	5	
2. Mechanics	22	
3. Thermal physics	11	
4. Waves	15	
5. Electricity and magnetism	15	
6. Circular motion and gravitation	5	
7. Atomic, nuclear and particle physics	14	
8. Energy production	8	
Additional higher level (AHL)		**60**
9. Wave phenomena		17
10. Fields		11
11. Electromagnetic induction		16
12. Quantum and nuclear physics		16
Option	**15**	**25**
A. Relativity	15	25
B. Engineering physics	15	25
C. Imaging	15	25
D. Astrophysics	15	25
Practical scheme of work	**40**	**60**
Practical activities	20	40
Individual investigation (internal assessment – IA)	10	10
Group 4 project	10	10
Total teaching hours	**150**	**240**

The recommended teaching time is 240 hours to complete HL courses and 150 hours to complete SL courses as stated in the document *General regulations: Diploma Programme* for students and their legal guardians (page 4, article 8.2).

Syllabus content

Recommended teaching hours

Core	**95 hours**
Topic 1: Measurements and uncertainties	**5**
1.1 – Measurements in physics	
1.2 – Uncertainties and errors	
1.3 – Vectors and scalars	
Topic 2: Mechanics	**22**
2.1 – Motion	
2.2 – Forces	
2.3 – Work, energy and power	
2.4 – Momentum and impulse	
Topic 3: Thermal physics	**11**
3.1 – Thermal concepts	
3.2 – Modelling a gas	
Topic 4: Waves	**15**
4.1 – Oscillations	
4.2 – Travelling waves	
4.3 – Wave characteristics	
4.4 – Wave behaviour	
4.5 – Standing waves	
Topic 5: Electricity and magnetism	**15**
5.1 – Electric fields	
5.2 – Heating effect of electric currents	
5.3 – Electric cells	
5.4 – Magnetic effects of electric currents	

Topic 6: Circular motion and gravitation	**5**
6.1 – Circular motion	
6.2 – Newton's law of gravitation	
Topic 7: Atomic, nuclear and particle physics	**14**
7.1 – Discrete energy and radioactivity	
7.2 – Nuclear reactions	
7.3 – The structure of matter	
Topic 8: Energy production	**8**
8.1 – Energy sources	
8.2 – Thermal energy transfer	
Additional higher level (AHL)	**60 hours**
Topic 9: Wave phenomena	**17**
9.1 – Simple harmonic motion	
9.2 – Single-slit diffraction	
9.3 – Interference	
9.4 – Resolution	
9.5 – Doppler effect	
Topic 10: Fields	**11**
10.1 – Describing fields	
10.2 – Fields at work	
Topic 11: Electromagnetic induction	**16**
11.1 – Electromagnetic induction	
11.2 – Power generation and transmission	
11.3 – Capacitance	
Topic 12: Quantum and nuclear physics	**16**
12.1 – The interaction of matter with radiation	
12.2 – Nuclear physics	

Options

15 hours (SL)/25 hours (HL)

A: Relativity

Core topics

A.1 – The beginnings of relativity

A.2 – Lorentz transformations

A.3 – Spacetime diagrams

Additional higher level topics

A.4 – Relativistic mechanics (HL only)

A.5 – General relativity (HL only)

B: Engineering physics

Core topics

B.1 – Rigid bodies and rotational dynamics

B.2 – Thermodynamics

Additional higher level topics

B.3 – Fluids and fluid dynamics (HL only)

B.4 – Forced vibrations and resonance (HL only)

Option C: Imaging

Core topics

C.1 – Introduction to imaging

C.2 – Imaging instrumentation

C.3 – Fibre optics

Additional higher level topics

C.4 – Medical imaging (HL only)

Option D: Astrophysics

Core topics

D.1 – Stellar quantities

D.2 – Stellar characteristics and stellar evolution

D.3 – Cosmology

Additional higher level topics

D.4 – Stellar processes (HL only)

D.5 – Further cosmology (HL only)

Topic 1: Measurement and uncertainties

5 hours

Essential idea: Since 1948, the Système International d'Unités (SI) has been used as the preferred language of science and technology across the globe and reflects current best measurement practice.

1.1 – Measurements in physics

Nature of science:

Common terminology: Since the 18th century, scientists have sought to establish common systems of measurements to facilitate international collaboration across science disciplines and ensure replication and comparability of experimental findings. (1.6)

Improvement in instrumentation: An improvement in apparatus and instrumentation, such as using the transition of cesium-133 atoms for atomic clocks, has led to more refined definitions of standard units. (1.8)

Certainty: Although scientists are perceived as working towards finding "exact" answers, the unavoidable uncertainty in any measurement always exists. (3.6)

Understandings:

- Fundamental and derived SI units
- Scientific notation and metric multipliers
- Significant figures
- Orders of magnitude
- Estimation

International-mindedness:

- Scientific collaboration is able to be truly global without the restrictions of national borders or language due to the agreed standards for data representation

Theory of knowledge:

- What has influenced the common language used in science? To what extent does having a common standard approach to measurement facilitate the sharing of knowledge in physics?

1.1 – Measurements in physics	
Applications and skills: • Using SI units in the correct format for all required measurements, final answers to calculations and presentation of raw and processed data • Using scientific notation and metric multipliers • Quoting and comparing ratios, values and approximations to the nearest order of magnitude • Estimating quantities to an appropriate number of significant figures **Guidance:** • SI unit usage and information can be found at the website of *Bureau International des Poids et Mesures* • Students will not need to know the definition of SI units except where explicitly stated in the relevant topics in this guide • Candela is not a required SI unit for this course • Guidance on any use of non-SI units such as eV, MeV c^{-2}, ly and pc will be provided in the relevant topics in this guide • Further guidance on how scientific notation and significant figures are used in examinations can be found in the *Teacher support material* **Data booklet reference:** • Metric (SI) multipliers can be found on page 5 of the physics data booklet	**Utilization:** • This topic is able to be integrated into any topic taught at the start of the course and is important to all topics • Students studying more than one group 4 subject will be able to use these skills across all subjects • See *Mathematical studies SL* sub-topics *1.2–1.4* **Aims:** • **Aim 2 and 3:** this is an essential area of knowledge that allows scientists to collaborate across the globe • **Aim 4 and 5:** a common approach to expressing results of analysis, evaluation and synthesis of scientific information enables greater sharing and collaboration

Essential idea: Scientists aim towards designing experiments that can give a "true value" from their measurements, but due to the limited precision in measuring devices, they often quote their results with some form of uncertainty.

1.2 – Uncertainties and errors

Nature of science:

Uncertainties: "All scientific knowledge is uncertain… if you have made up your mind already, you might not solve it. When the scientist tells you he does not know the answer, he is an ignorant man. When he tells you he has a hunch about how it is going to work, he is uncertain about it. When he is pretty sure of how it is going to work, and he tells you, 'This is the way it's going to work, I'll bet,' he still is in some doubt. And it is of paramount importance, in order to make progress, that we recognize this ignorance and this doubt. Because we have the doubt, we then propose looking in new directions for new ideas." (3.4)

Feynman, Richard P. 1998. *The Meaning of It All: Thoughts of a Citizen-Scientist*. Reading, Massachusetts, USA. Perseus. P 13.

Understandings:

- Random and systematic errors
- Absolute, fractional and percentage uncertainties
- Error bars
- Uncertainty of gradient and intercepts

Applications and skills:

- Explaining how random and systematic errors can be identified and reduced
- Collecting data that include absolute and/or fractional uncertainties and stating these as an uncertainty range (expressed as: best estimate ± uncertainty range)
- Propagating uncertainties through calculations involving addition, subtraction, multiplication, division and raising to a power
- Determining the uncertainty in gradients and intercepts

Theory of knowledge:

- "One aim of the physical sciences has been to give an exact picture of the material world. One achievement of physics in the twentieth century has been to prove that this aim is unattainable." – Jacob Bronowski. Can scientists ever be truly certain of their discoveries?

Utilization:

- Students studying more than one group 4 subject will be able to use these skills across all subjects

1.2 – Uncertainties and errors

Guidance:

- Analysis of uncertainties will not be expected for trigonometric or logarithmic functions in examinations
- Further guidance on how uncertainties, error bars and lines of best fit are used in examinations can be found in the *Teacher support material*

Data booklet reference:

- If $y = a \pm b$

  then $\Delta y = \Delta a + \Delta b$
- If $y = \frac{ab}{c}$

  then $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$
- If $y = a^n$

  then $\frac{\Delta y}{y} = \left| n \frac{\Delta a}{a} \right|$

Aims:

- **Aim 4:** it is important that students see scientific errors and uncertainties not only as the range of possible answers but as an integral part of the scientific process
- **Aim 9:** the process of using uncertainties in classical physics can be compared to the view of uncertainties in modern (and particularly quantum) physics

Essential idea: Some quantities have direction and magnitude, others have magnitude only, and this understanding is the key to correct manipulation of quantities. This sub-topic will have broad applications across multiple fields within physics and other sciences.

1.3 – Vectors and scalars

Nature of science:

Models: First mentioned explicitly in a scientific paper in 1846, scalars and vectors reflected the work of scientists and mathematicians across the globe for over 300 years on representing measurements in three-dimensional space. (1.10)

Understandings:

- Vector and scalar quantities
- Combination and resolution of vectors

Applications and skills:

- Solving vector problems graphically and algebraically

Guidance:

- Resolution of vectors will be limited to two perpendicular directions
- Problems will be limited to addition and subtraction of vectors and the multiplication and division of vectors by scalars

International-mindedness:

- Vector notation forms the basis of mapping across the globe

Theory of knowledge:

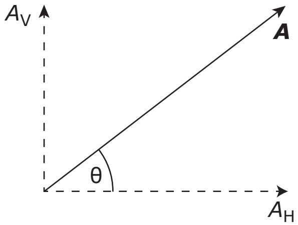
- What is the nature of certainty and proof in mathematics?

Utilization:

- Navigation and surveying (see *Geography SL/HL* syllabus: *Geographic skills*)
- Force and field strength (see *Physics* sub-topics *2.2*, *5.1*, *6.1* and *10.1*)
- Vectors (see *Mathematics HL* sub-topic *4.1*; Mathematics *SL* sub-topic *4.1*)

1.3 – Vectors and scalars

Data booklet reference:



- $A_H = A\cos\theta$
- $A_v = A\sin\theta$

Aims:

- **Aim 2 and 3:** this is a fundamental aspect of scientific language that allows for spatial representation and manipulation of abstract concepts

Topic 2: Mechanics

22 hours

Essential idea: Motion may be described and analysed by the use of graphs and equations.

2.1 – Motion

Nature of science:

Observations: The ideas of motion are fundamental to many areas of physics, providing a link to the consideration of forces and their implication. The kinematic equations for uniform acceleration were developed through careful observations of the natural world. (1.8)

Understandings:

- Distance and displacement
- Speed and velocity
- Acceleration
- Graphs describing motion
- Equations of motion for uniform acceleration
- Projectile motion
- Fluid resistance and terminal speed

Applications and skills:

- Determining instantaneous and average values for velocity, speed and acceleration
- Solving problems using equations of motion for uniform acceleration
- Sketching and interpreting motion graphs
- Determining the acceleration of free-fall experimentally
- Analysing projectile motion, including the resolution of vertical and horizontal components of acceleration, velocity and displacement
- Qualitatively describing the effect of fluid resistance on falling objects or projectiles, including reaching terminal speed

International-mindedness:

- International cooperation is needed for tracking shipping, land-based transport, aircraft and objects in space

Theory of knowledge:

- The independence of horizontal and vertical motion in projectile motion seems to be counter-intuitive. How do scientists work around their intuitions? How do scientists make use of their intuitions?

Utilization:

- Diving, parachuting and similar activities where fluid resistance affects motion
- The accurate use of ballistics requires careful analysis
- Biomechanics (see *Sports, exercise and health science SL* sub-topic *4.3*)
- Quadratic functions (see *Mathematics HL* sub-topic *2.6*; *Mathematics SL* sub-topic *2.4*; *Mathematical studies SL* sub-topic *6.3*)
- The kinematic equations are treated in calculus form in *Mathematics HL* sub-topic *6.6* and *Mathematics SL* sub-topic *6.6*

2.1 – Motion	
Guidance: • Calculations will be restricted to those neglecting air resistance • Projectile motion will only involve problems using a constant value of *g* close to the surface of the Earth • The equation of the path of a projectile will not be required **Data booklet reference:** • $v = u + at$ • $s = ut + \frac{1}{2}at^2$ • $v^2 = u^2 + 2as$ • $s = \frac{(v+u)t}{2}$	**Aims:** • **Aim 2:** much of the development of classical physics has been built on the advances in kinematics • **Aim 6:** experiments, including use of data logging, could include (but are not limited to): determination of *g*, estimating speed using travel timetables, analysing projectile motion, and investigating motion through a fluid • **Aim 7:** technology has allowed for more accurate and precise measurements of motion, including video analysis of real-life projectiles and modelling/simulations of terminal velocity

Essential idea: Classical physics requires a force to change a state of motion, as suggested by Newton in his laws of motion.

2.2 – Forces

Nature of science:

Using mathematics: Isaac Newton provided the basis for much of our understanding of forces and motion by formalizing the previous work of scientists through the application of mathematics by inventing calculus to assist with this. (2.4)

Intuition: The tale of the falling apple describes simply one of the many flashes of intuition that went into the publication of *Philosophiæ Naturalis Principia Mathematica* in 1687. (1.5)

Understandings:

- Objects as point particles
- Free-body diagrams
- Translational equilibrium
- Newton's laws of motion
- Solid friction

Applications and skills:

- Representing forces as vectors
- Sketching and interpreting free-body diagrams
- Describing the consequences of Newton's first law for translational equilibrium
- Using Newton's second law quantitatively and qualitatively
- Identifying force pairs in the context of Newton's third law
- Solving problems involving forces and determining resultant force
- Describing solid friction (static and dynamic) by coefficients of friction

Theory of knowledge:

- Classical physics believed that the whole of the future of the universe could be predicted from knowledge of the present state. To what extent can knowledge of the present give us knowledge of the future?

Utilization:

- Motion of charged particles in fields (see *Physics* sub-topics *5.4*, *6.1*, *11.1*, *12.2*)
- Application of friction in circular motion (see *Physics* sub-topic *6.1*)
- Construction (considering ancient and modern approaches to safety, longevity and consideration of local weather and geological influences)
- Biomechanics (see *Sports, exercise and health science SL* sub-topic *4.3*)

2.2 – Forces	
Guidance: • Students should label forces using commonly accepted names or symbols (for example: *weight* or *force of gravity* or *mg*) • Free-body diagrams should show scaled vector lengths acting from the point of application • Examples and questions will be limited to constant mass • *mg* should be identified as weight • Calculations relating to the determination of resultant forces will be restricted to one- and two-dimensional situations **Data booklet reference:** • $F = ma$ • $F_f \leq \mu_s R$ • $F_f \leq \mu_d R$	**Aims:** • **Aims 2 and 3:** Newton's work is often described by the quote from a letter he wrote to his rival, Robert Hooke, 11 years before the publication of *Philosophiæ Naturalis Principia Mathematica*, which states: "*What Descartes did was a good step. You have added much several ways, and especially in taking the colours of thin plates into philosophical consideration. If I have seen a little further it is by standing on the shoulders of Giants*." It should be remembered that this quote is also inspired, this time by writers who had been using versions of it for at least 500 years before Newton's time. • **Aim 6:** experiments could include (but are not limited to): verification of Newton's second law; investigating forces in equilibrium; determination of the effects of friction

Essential idea: The fundamental concept of energy lays the basis upon which much of science is built.

2.3 – Work, energy and power

Nature of science:

Theories: Many phenomena can be fundamentally understood through application of the theory of conservation of energy. Over time, scientists have utilized this theory both to explain natural phenomena and, more importantly, to predict the outcome of previously unknown interactions. The concept of energy has evolved as a result of recognition of the relationship between mass and energy. (2.2)

Understandings:

- Kinetic energy
- Gravitational potential energy
- Elastic potential energy
- Work done as energy transfer
- Power as rate of energy transfer
- Principle of conservation of energy
- Efficiency

Applications and skills:

- Discussing the conservation of total energy within energy transformations
- Sketching and interpreting force–distance graphs
- Determining work done including cases where a resistive force acts
- Solving problems involving power
- Quantitatively describing efficiency in energy transfers

Guidance:

- Cases where the line of action of the force and the displacement are not parallel should be considered
- Examples should include force–distance graphs for variable forces

Theory of knowledge:

- To what extent is scientific knowledge based on fundamental concepts such as energy? What happens to scientific knowledge when our understanding of such fundamental concepts changes or evolves?

Utilization:

- Energy is also covered in other group 4 subjects (for example, see: *Biology* topics *2*, *4* and *8*; *Chemistry* topics *5*, *15*, and *C*; *Sports, exercise and health science* topics *3, A.2, C.3* and *D.3*; *Environmental systems and societies* topics *1, 2,* and *3*)
- Energy conversions are essential for electrical energy generation (see *Physics* topic *5* and sub-topic *8.1*)
- Energy changes occurring in simple harmonic motion (see *Physics* sub-topics *4.1* and *9.1*)

2.3 – Work, energy and power	
Data booklet reference: • $W = Fs\cos\theta$ • $E_K = \frac{1}{2}mv^2$ • $E_P = \frac{1}{2}k\,\Delta x^2$ • $\Delta E_P = mg\Delta h$ • power $= Fv$ • Efficiency $= \frac{\text{useful work out}}{\text{total work in}} = \frac{\text{useful power out}}{\text{total power in}}$	**Aims:** • **Aim 6:** experiments could include (but are not limited to): relationship of kinetic and gravitational potential energy for a falling mass; power and efficiency of mechanical objects; comparison of different situations involving elastic potential energy • **Aim 8:** by linking this sub-topic with topic 8, students should be aware of the importance of efficiency and its impact of conserving the fuel used for energy production

Essential idea: Conservation of momentum is an example of a law that is never violated.

2.4 – Momentum and impulse

Nature of science:

The concept of momentum and the principle of momentum conservation can be used to analyse and predict the outcome of a wide range of physical interactions, from macroscopic motion to microscopic collisions. (1.9)

Understandings / Applications and skills	International-mindedness / Theory of knowledge / Utilization
Understandings: • Newton's second law expressed in terms of rate of change of momentum • Impulse and force–time graphs • Conservation of linear momentum • Elastic collisions, inelastic collisions and explosions **Applications and skills:** • Applying conservation of momentum in simple isolated systems including (but not limited to) collisions, explosions, or water jets • Using Newton's second law quantitatively and qualitatively in cases where mass is not constant • Sketching and interpreting force–time graphs • Determining impulse in various contexts including (but not limited to) car safety and sports • Qualitatively and quantitatively comparing situations involving elastic collisions, inelastic collisions and explosions	**International-mindedness:** • Automobile passive safety standards have been adopted across the globe based on research conducted in many countries **Theory of knowledge:** • Do conservation laws restrict or enable further development in physics? **Utilization:** • Jet engines and rockets **Martial arts** • Particle theory and collisions (see *Physics* sub-topic *3.1*)

2.4 – Momentum and impulse

Guidance:

- Students should be aware that $F = ma$ is equivalent of $F = \frac{\Delta p}{\Delta t}$ only when mass is constant
- Solving simultaneous equations involving conservation of momentum and energy in collisions will not be required
- Calculations relating to collisions and explosions will be restricted to one-dimensional situations
- A comparison between energy involved in inelastic collisions (in which kinetic energy is not conserved) and the conservation of (total) energy should be made

Data booklet reference:

- $p = mv$
- $F = \frac{\Delta p}{\Delta t}$
- $E_K = \frac{p^2}{2m}$
- Impulse $= F\Delta t = \Delta p$

Aims:

- **Aim 3:** conservation laws in science disciplines have played a major role in outlining the limits within which scientific theories are developed
- **Aim 6:** experiments could include (but are not limited to): analysis of collisions with respect to energy transfer; impulse investigations to determine velocity, force, time, or mass; determination of amount of transformed energy in inelastic collisions
- **Aim 7:** technology has allowed for more accurate and precise measurements of force and momentum, including video analysis of real-life collisions and modelling/simulations of molecular collisions

Topic 3: Thermal physics

11 hours

Essential idea: Thermal physics deftly demonstrates the links between the macroscopic measurements essential to many scientific models with the microscopic properties that underlie these models.

3.1 – Thermal concepts

Nature of science:

Evidence through experimentation: Scientists from the 17th and 18th centuries were working without the knowledge of atomic structure and sometimes developed theories that were later found to be incorrect, such as phlogiston and perpetual motion capabilities. Our current understanding relies on statistical mechanics providing a basis for our use and understanding of energy transfer in science. (1.8)

Understandings:

- Molecular theory of solids, liquids and gases
- Temperature and absolute temperature
- Internal energy
- Specific heat capacity
- Phase change
- Specific latent heat

Applications and skills:

- Describing temperature change in terms of internal energy
- Using Kelvin and Celsius temperature scales and converting between them
- Applying the calorimetric techniques of specific heat capacity or specific latent heat experimentally
- Describing phase change in terms of molecular behaviour
- Sketching and interpreting phase change graphs
- Calculating energy changes involving specific heat capacity and specific latent heat of fusion and vaporization

International-mindedness:

- The topic of thermal physics is a good example of the use of international systems of measurement that allow scientists to collaborate effectively

Theory of knowledge:

- Observation through sense perception plays a key role in making measurements. Does sense perception play different roles in different areas of knowledge?

Utilization:

- Pressure gauges, barometers and manometers are a good way to present aspects of this sub-topic
- Higher level students, especially those studying option B, can be shown links to thermodynamics (see *Physics* topic *9* and option sub-topic *B.4*)
- Particulate nature of matter (see *Chemistry* sub-topic *1.3*) and measuring energy changes (see *Chemistry* sub-topic *5.1*)
- Water (see *Biology* sub-topic *2.2*)

3.1 – Thermal concepts	
Guidance: • Internal energy is taken to be the total intermolecular potential energy + the total random kinetic energy of the molecules • Phase change graphs may have axes of temperature versus time or temperature versus energy • The effects of cooling should be understood qualitatively but cooling correction calculations are not required **Data booklet reference:** • $Q = mc\Delta T$ • $Q = mL$	**Aims:** • **Aim 3:** an understanding of thermal concepts is a fundamental aspect of many areas of science • **Aim 6:** experiments could include (but are not limited to): transfer of energy due to temperature difference; calorimetric investigations; energy involved in phase changes

Essential idea: The properties of ideal gases allow scientists to make predictions of the behaviour of real gases.

3.2 – Modelling a gas

Nature of science:

Collaboration: Scientists in the 19th century made valuable progress on the modern theories that form the basis of thermodynamics, making important links with other sciences, especially chemistry. The scientific method was in evidence with contrasting but complementary statements of some laws derived by different scientists. Empirical and theoretical thinking both have their place in science and this is evident in the comparison between the unattainable ideal gas and real gases. (4.1)

Understandings:

- Pressure
- Equation of state for an ideal gas
- Kinetic model of an ideal gas
- Mole, molar mass and the Avogadro constant
- Differences between real and ideal gases

Applications and skills:

- Solving problems using the equation of state for an ideal gas and gas laws
- Sketching and interpreting changes of state of an ideal gas on pressure–volume, pressure–temperature and volume–temperature diagrams
- Investigating at least one gas law experimentally

Guidance:

- Students should be aware of the assumptions that underpin the molecular kinetic theory of ideal gases
- Gas laws are limited to constant volume, constant temperature, constant pressure and the ideal gas law
- Students should understand that a real gas approximates to an ideal gas at conditions of low pressure, moderate temperature and low density

Theory of knowledge:

- When does modelling of "ideal" situations become "good enough" to count as knowledge?

Utilization:

- Transport of gases in liquid form or at high pressures/densities is common practice across the globe. Behaviour of real gases under extreme conditions needs to be carefully considered in these situations.
- Consideration of thermodynamic processes is essential to many areas of chemistry (see *Chemistry* sub-topic *1.3*)
- Respiration processes (see *Biology* sub-topic *D.6*)

Aims:

- **Aim 3:** this is a good topic to make comparisons between empirical and theoretical thinking in science
- **Aim 6:** experiments could include (but are not limited to): verification of gas laws; calculation of the Avogadro constant; virtual investigation of gas law parameters not possible within a school laboratory setting

3.2 – Modelling a gas	
Data booklet reference: • $p = \frac{F}{A}$ • $n = \frac{N}{N_A}$ • $pV = nRT$ • $\bar{E}_K = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T$	

Topic 4: Waves

15 hours

Essential idea: A study of oscillations underpins many areas of physics with simple harmonic motion (shm), a fundamental oscillation that appears in various natural phenomena.

4.1 – Oscillations

Nature of science:

Models: Oscillations play a great part in our lives, from the tides to the motion of the swinging pendulum that once governed our perception of time. General principles govern this area of physics, from water waves in the deep ocean or the oscillations of a car suspension system. This introduction to the topic reminds us that not all oscillations are isochronous. However, the simple harmonic oscillator is of great importance to physicists because all periodic oscillations can be described through the mathematics of simple harmonic motion. (1.10)

Understandings:

- Simple harmonic oscillations
- Time period, frequency, amplitude, displacement and phase difference
- Conditions for simple harmonic motion

Applications and skills:

- Qualitatively describing the energy changes taking place during one cycle of an oscillation
- Sketching and interpreting graphs of simple harmonic motion examples

International-mindedness:

- Oscillations are used to define the time systems on which nations agree so that the world can be kept in synchronization. This impacts most areas of our lives including the provision of electricity, travel and location-determining devices and all microelectronics.

Theory of knowledge:

- The harmonic oscillator is a paradigm for modelling where a simple equation is used to describe a complex phenomenon. How do scientists know when a simple model is not detailed enough for their requirements?

4.1 – Oscillations	
Guidance: • Graphs describing simple harmonic motion should include displacement–time, velocity–time, acceleration–time and acceleration–displacement • Students are expected to understand the significance of the negative sign in the relationship: $a \propto -x$ **Data booklet reference:** • $T = \frac{1}{f}$	**Utilization:** • Isochronous oscillations can be used to measure time • Many systems can approximate simple harmonic motion: mass on a spring, fluid in U-tube, models of icebergs oscillating vertically in the ocean, and motion of a sphere rolling in a concave mirror • Simple harmonic motion is frequently found in the context of mechanics (see *Physics* topic 2) **Aims:** • **Aim 6:** experiments could include (but are not limited to): mass on a spring; simple pendulum; motion on a curved air track • **Aim 7:** IT skills can be used to model the simple harmonic motion defining equation; this gives valuable insight into the meaning of the equation itself

Essential idea: There are many forms of waves available to be studied. A common characteristic of all travelling waves is that they carry energy, but generally the medium through which they travel will not be permanently disturbed.

4.2 – Travelling waves

Nature of science:

Patterns, trends and discrepancies: Scientists have discovered common features of wave motion through careful observations of the natural world, looking for patterns, trends and discrepancies and asking further questions based on these findings. (3.1)

Understandings:

- Travelling waves
- Wavelength, frequency, period and wave speed
- Transverse and longitudinal waves
- The nature of electromagnetic waves
- The nature of sound waves

Applications and skills:

- Explaining the motion of particles of a medium when a wave passes through it for both transverse and longitudinal cases
- Sketching and interpreting displacement–distance graphs and displacement–time graphs for transverse and longitudinal waves
- Solving problems involving wave speed, frequency and wavelength
- Investigating the speed of sound experimentally

Guidance:

- Students will be expected to derive $c = f\lambda$
- Students should be aware of the order of magnitude of the wavelengths of radio, microwave, infra-red, visible, ultraviolet, X-ray and gamma rays

Data booklet reference:

- $c = f\lambda$

International-mindedness:

- Electromagnetic waves are used extensively for national and international communication

Theory of knowledge:

- Scientists often transfer their perception of tangible and visible concepts to explain similar non-visible concepts, such as in wave theory. How do scientists explain concepts that have no tangible or visible quality?

Utilization:

- Communication using both sound (locally) and electromagnetic waves (near and far) involve wave theory
- Emission spectra are analysed by comparison to the electromagnetic wave spectrum (see *Chemistry* topic *2* and *Physics* sub-topic *12.1*)
- Sight (see *Biology* sub-topic *A.2*)

Aims:

- **Aim 2:** there is a common body of knowledge and techniques involved in wave theory that is applicable across many areas of physics
- **Aim 4:** there are opportunities for the analysis of data to arrive at some of the models in this section from first principles
- **Aim 6:** experiments could include (but are not limited to): speed of waves in different media; detection of electromagnetic waves from various sources; use of echo methods (or similar) for determining wave speed, wavelength, distance, or medium elasticity and/or density

Essential idea: All waves can be described by the same sets of mathematical ideas. Detailed knowledge of one area leads to the possibility of prediction in another.

4.3 – Wave characteristics

Nature of science:

Imagination: It is speculated that polarization had been utilized by the Vikings through their use of Iceland Spar over 1300 years ago for navigation (prior to the introduction of the magnetic compass). Scientists across Europe in the 17th–19th centuries continued to contribute to wave theory by building on the theories and models proposed as our understanding developed. (1.4)

Understandings:

- Wavefronts and rays
- Amplitude and intensity
- Superposition
- Polarization

Applications and skills:

- Sketching and interpreting diagrams involving wavefronts and rays
- Solving problems involving amplitude, intensity and the inverse square law
- Sketching and interpreting the superposition of pulses and waves
- Describing methods of polarization
- Sketching and interpreting diagrams illustrating polarized, reflected and transmitted beams
- Solving problems involving Malus's law

Guidance:

- Students will be expected to calculate the resultant of two waves or pulses both graphically and algebraically
- Methods of polarization will be restricted to the use of polarizing filters and reflection from a non-metallic plane surface

Data booklet reference:

- $I \propto A^2$
- $I \propto x^{-2}$
- $I = I_0 \cos^2 \theta$

Theory of knowledge:

- Wavefronts and rays are visualizations that help our understanding of reality, characteristic of modelling in the physical sciences. How does the methodology used in the natural sciences differ from the methodology used in the human sciences?
- How much detail does a model need to contain to accurately represent reality?

Utilization:

- A number of modern technologies, such as LCD displays, rely on polarization for their operation

Aims:

- **Aim 3:** these universal behaviours of waves are applied in later sections of the course in more advanced topics, allowing students to generalize the various types of waves
- **Aim 6:** experiments could include (but are not limited to): observation of polarization under different conditions, including the use of microwaves; superposition of waves; representation of wave types using physical models (eg slinky demonstrations)
- **Aim 7:** use of computer modelling enables students to observe wave motion in three dimensions as well as being able to more accurately adjust wave characteristics in superposition demonstrations

Essential idea: Waves interact with media and each other in a number of ways that can be unexpected and useful.

4.4 – Wave behaviour

Nature of science:

Competing theories: The conflicting work of Huygens and Newton on their theories of light and the related debate between Fresnel, Arago and Poisson are demonstrations of two theories that were valid yet flawed and incomplete. This is an historical example of the progress of science that led to the acceptance of the duality of the nature of light. (1.9)

Understandings:

- Reflection and refraction
- Snell's law, critical angle and total internal reflection
- Diffraction through a single-slit and around objects
- Interference patterns
- Double-slit interference
- Path difference

Applications and skills:

- Sketching and interpreting incident, reflected and transmitted waves at boundaries between media
- Solving problems involving reflection at a plane interface
- Solving problems involving Snell's law, critical angle and total internal reflection
- Determining refractive index experimentally
- Qualitatively describing the diffraction pattern formed when plane waves are incident normally on a single-slit
- Quantitatively describing double-slit interference intensity patterns

International-mindedness:

- Characteristic wave behaviour has been used in many cultures throughout human history, often tying closely to myths and legends that formed the basis for early scientific studies

Theory of knowledge:

- Huygens and Newton proposed two competing theories of the behaviour of light. How does the scientific community decide between competing theories?

Utilization:

- A satellite footprint on Earth is governed by the diffraction at the dish on the satellite
- Applications of the refraction and reflection of light range from the simple plane mirror through the medical endoscope and beyond. Many of these applications have enabled us to improve and extend our sense of vision
- The simple idea of the cancellation of two coherent light rays reflecting from two surfaces leads to data storage in compact discs and their successors
- The physical explanation of the rainbow involves refraction and total internal reflection. The bright and dark bands inside the rainbow, supernumeraries, can be explained only by the wave nature of light and diffraction

4.4 – Wave behaviour	
Guidance: • Quantitative descriptions of refractive index are limited to light rays passing between two or more transparent media. If more than two media, only parallel interfaces will be considered • Students will not be expected to derive the double-slit equation • Students should have the opportunity to observe diffraction and interference patterns arising from more than one type of wave **Data booklet reference:** • $\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$ • $s = \frac{\lambda D}{d}$ • Constructive interference: path difference = $n\lambda$ • Destructive interference: path difference = $\left(n + \frac{1}{2}\right)\lambda$	**Aims:** • **Aim 1:** the historical aspects of this topic are still relevant science and provide valuable insight into the work of earlier scientists • **Aim 6:** experiments could include (but are not limited to): determination of refractive index and application of Snell’s law; determining conditions under which total internal reflection may occur; examination of diffraction patterns through apertures and around obstacles; investigation of the double-slit experiment • **Aim 8:** the increasing use of digital data and its storage density has implications on individual privacy through the permanence of a digital footprint

Essential idea: When travelling waves meet they can superpose to form standing waves in which energy may not be transferred.

4.5 – Standing waves

Nature of science:

Common reasoning process: From the time of Pythagoras onwards the connections between the formation of standing waves on strings and in pipes have been modelled mathematically and linked to the observations of the oscillating systems. In the case of sound in air and light, the system can be visualized in order to recognize the underlying processes occurring in the standing waves. (1.6)

Understandings:

- The nature of standing waves
- Boundary conditions
- Nodes and antinodes

Applications and skills:

- Describing the nature and formation of standing waves in terms of superposition
- Distinguishing between standing and travelling waves
- Observing, sketching and interpreting standing wave patterns in strings and pipes
- Solving problems involving the frequency of a harmonic, length of the standing wave and the speed of the wave

Guidance:

- Students will be expected to consider the formation of standing waves from the superposition of no more than two waves
- Boundary conditions for strings are: two fixed boundaries; fixed and free boundary; two free boundaries

International-mindedness:

- The art of music, which has its scientific basis in these ideas, is universal to all cultures, past and present. Many musical instruments rely heavily on the generation and manipulation of standing waves

Theory of knowledge:

- There are close links between standing waves in strings and Schrodinger's theory for the probability amplitude of electrons in the atom. Application to superstring theory requires standing wave patterns in 11 dimensions. What is the role of reason and imagination in enabling scientists to visualize scenarios that are beyond our physical capabilities?

Utilization:

- Students studying music should be encouraged to bring their own experiences of this art form to the physics classroom

4.5 – Standing waves	
• Boundary conditions for pipes are: two closed boundaries; closed and open boundary; two open boundaries • For standing waves in air, explanations will not be required in terms of pressure nodes and pressure antinodes • The lowest frequency mode of a standing wave is known as the first harmonic • The terms *fundamental* and *overtone* will not be used in examination questions	**Aims:** • **Aim 3:** students are able to both physically observe and qualitatively measure the locations of nodes and antinodes, following the investigative techniques of early scientists and musicians • **Aim 6:** experiments could include (but are not limited to): observation of standing wave patterns in physical objects (eg slinky springs); prediction of harmonic locations in an air tube in water; determining the frequency of tuning forks; observing or measuring vibrating violin/guitar strings • **Aim 8:** the international dimension of the application of standing waves is important in music

Topic 5: Electricity and magnetism

15 hours

Essential idea: When charges move an electric current is created.

5.1 – Electric fields

Nature of science:

Modelling: Electrical theory demonstrates the scientific thought involved in the development of a microscopic model (behaviour of charge carriers) from macroscopic observation. The historical development and refinement of these scientific ideas when the microscopic properties were unknown and unobservable is testament to the deep thinking shown by the scientists of the time. (1.10)

Understandings:

- Charge
- Electric field
- Coulomb's law
- Electric current
- Direct current (dc)
- Potential difference

Applications and skills:

- Identifying two forms of charge and the direction of the forces between them
- Solving problems involving electric fields and Coulomb's law
- Calculating work done in an electric field in both joules and electronvolts
- Identifying sign and nature of charge carriers in a metal
- Identifying drift speed of charge carriers
- Solving problems using the drift speed equation
- Solving problems involving current, potential difference and charge

International-mindedness:

- Electricity and its benefits have an unparalleled power to transform society

Theory of knowledge:

- Early scientists identified positive charges as the charge carriers in metals; however, the discovery of the electron led to the introduction of "conventional" current direction. Was this a suitable solution to a major shift in thinking? What role do paradigm shifts play in the progression of scientific knowledge?

Utilization:

- Transferring energy from one place to another (see *Chemistry* option *C* and *Physics* topic 11)
- Impact on the environment from electricity generation (see *Physics* topic *8* and *Chemistry* option sub-topic *C2*)
- The comparison between the treatment of electric fields and gravitational fields (see *Physics* topic *10*)

5.1 – Electric fields	
Guidance: • Students will be expected to apply Coulomb's law for a range of permittivity values **Data booklet reference:** • $I = \frac{\Delta q}{\Delta t}$ • $F = k\frac{q_1 q_2}{r^2}$ • $k = \frac{1}{4\pi\varepsilon_0}$ • $V = \frac{W}{q}$ • $E = \frac{F}{q}$ • $I = nAvq$	**Aims:** • **Aim 2:** electrical theory lies at the heart of much modern science and engineering • **Aim 3:** advances in electrical theory have brought immense change to all societies • **Aim 6:** experiments could include (but are not limited to): demonstrations showing the effect of an electric field (eg. using semolina); simulations involving the placement of one or more point charges and determining the resultant field • **Aim 7:** use of computer simulations would enable students to measure microscopic interactions that are typically very difficult in a school laboratory situation

Essential idea: One of the earliest uses for electricity was to produce light and heat. This technology continues to have a major impact on the lives of people around the world.

5.2 – Heating effect of electric currents

Nature of science:

Peer review: Although Ohm and Barlow published their findings on the nature of electric current around the same time, little credence was given to Ohm. Barlow's incorrect law was not initially criticized or investigated further. This is a reflection of the nature of academia of the time, with physics in Germany being largely non-mathematical and Barlow held in high respect in England. It indicates the need for the publication and peer review of research findings in recognized scientific journals. (4.4)

Understandings:

- Circuit diagrams
- Kirchhoff's circuit laws
- Heating effect of current and its consequences
- Resistance expressed as $R = \frac{V}{I}$
- Ohm's law
- Resistivity
- Power dissipation

Applications and skills:

- Drawing and interpreting circuit diagrams
- Identifying ohmic and non-ohmic conductors through a consideration of the *V/I* characteristic graph
- Solving problems involving potential difference, current, charge, Kirchhoff's circuit laws, power, resistance and resistivity
- Investigating combinations of resistors in parallel and series circuits
- Describing ideal and non-ideal ammeters and voltmeters
- Describing practical uses of potential divider circuits, including the advantages of a potential divider over a series resistor in controlling a simple circuit
- Investigating one or more of the factors that affect resistance experimentally

International-mindedness:

- A set of universal symbols is needed so that physicists in different cultures can readily communicate ideas in science and engineering

Theory of knowledge:

- Sense perception in early electrical investigations was key to classifying the effect of various power sources; however, this is fraught with possible irreversible consequences for the scientists involved. Can we still ethically and safely use sense perception in science research?

Utilization:

- Although there are nearly limitless ways that we use electrical circuits, heating and lighting are two of the most widespread
- Sensitive devices can employ detectors capable of measuring small variations in potential difference and/or current, requiring carefully planned circuits and high precision components

5.2 – Heating effect of electric currents

Guidance:

- The filament lamp should be described as a non-ohmic device; a metal wire at a constant temperature is an ohmic device
- The use of non-ideal voltmeters is confined to voltmeters with a constant but finite resistance
- The use of non-ideal ammeters is confined to ammeters with a constant but non-zero resistance
- Application of Kirchhoff's circuit laws will be limited to circuits with a maximum number of two source-carrying loops

Data book reference:

- Kirchoff's circuit laws:
  - $\Sigma V = 0$ (loop)
  - $\Sigma I = 0$ (junction)
- $R = \frac{V}{I}$
- $P = VI = I^2R = \frac{V^2}{R}$
- $R_{total} = R_1 + R_2 + \cdots$
- $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$
- $\rho = \frac{RA}{L}$
- *Refer to electrical symbols on page 4 of the physics data booklet*

Aims:

- **Aim 2:** electrical theory and its approach to macro and micro effects characterizes much of the physical approach taken in the analysis of the universe
- **Aim 3:** electrical techniques, both practical and theoretical, provide a relatively simple opportunity for students to develop a feeling for the arguments of physics
- **Aim 6:** experiments could include (but are not limited to): use of a hot-wire ammeter as an historically important device; comparison of resistivity of a variety of conductors such as a wire at constant temperature, a filament lamp, or a graphite pencil; determination of thickness of a pencil mark on paper; investigation of ohmic and non-ohmic conductor characteristics; using a resistive wire wound and taped around the reservoir of a thermometer to relate wire resistance to current in the wire and temperature of wire
- **Aim 7:** there are many software and online options for constructing simple and complex circuits quickly to investigate the effect of using different components within a circuit

Essential idea: Electric cells allow us to store energy in a chemical form.

5.3 – Electric cells

Nature of science:

Long-term risks: Scientists need to balance the research into electric cells that can store energy with greater energy density to provide longer device lifetimes with the long-term risks associated with the disposal of the chemicals involved when batteries are discarded. (4.8)

Understandings:

- Cells
- Internal resistance
- Secondary cells
- Terminal potential difference
- Electromotive force (emf)

Applications and skills:

- Investigating practical electric cells (both primary and secondary)
- Describing the discharge characteristic of a simple cell (variation of terminal potential difference with time)
- Identifying the direction of current flow required to recharge a cell
- Determining internal resistance experimentally
- Solving problems involving emf, internal resistance and other electrical quantities

Guidance:

- Students should recognize that the terminal potential difference of a typical practical electric cell loses its initial value quickly, has a stable and constant value for most of its lifetime, followed by a rapid decrease to zero as the cell discharges completely

Data booklet reference:

- $\varepsilon = I(R + r)$

International-mindedness:

- Battery storage is important to society for use in areas such as portable devices, transportation options and back-up power supplies for medical facilities

Theory of knowledge:

- Battery storage is seen as useful to society despite the potential environmental issues surrounding their disposal. Should scientists be held morally responsible for the long-term consequences of their inventions and discoveries?

Utilization:

- The chemistry of electric cells (see *Chemistry* sub-topics *9.2* and *C.6*)

Aims:

- **Aim 6:** experiments could include (but are not limited to): investigation of simple electrolytic cells using various materials for the cathode, anode and electrolyte; software-based investigations of electrical cell design; comparison of the life expectancy of various batteries
- **Aim 8:** although cell technology can supply electricity without direct contribution from national grid systems (and the inherent carbon output issues), safe disposal of batteries and the chemicals they use can introduce land and water pollution problems
- **Aim 10:** improvements in cell technology has been through collaboration with chemists

Essential idea: The effect scientists call magnetism arises when one charge moves in the vicinity of another moving charge.

5.4 – Magnetic effects of electric currents

Nature of science:

Models and visualization: Magnetic field lines provide a powerful visualization of a magnetic field. Historically, the field lines helped scientists and engineers to understand a link that begins with the influence of one moving charge on another and leads onto relativity. (1.10)

Understandings:

- Magnetic fields
- Magnetic force

Applications and skills:

- Determining the direction of force on a charge moving in a magnetic field
- Determining the direction of force on a current-carrying conductor in a magnetic field
- Sketching and interpreting magnetic field patterns
- Determining the direction of the magnetic field based on current direction
- Solving problems involving magnetic forces, fields, current and charges

Guidance:

- Magnetic field patterns will be restricted to long straight conductors, solenoids, and bar magnets

Data booklet reference:

- $F = qvB \sin\theta$
- $F = BIL \sin\theta$

International-mindedness:

- The investigation of magnetism is one of the oldest studies by man and was used extensively by voyagers in the Mediterranean and beyond thousands of years ago

Theory of knowledge:

- Field patterns provide a visualization of a complex phenomenon, essential to an understanding of this topic. Why might it be useful to regard knowledge in a similar way, using the metaphor of knowledge as a map – a simplified representation of reality?

Utilization:

- Only comparatively recently has the magnetic compass been superseded by different technologies after hundreds of years of our dependence on it
- Modern medical scanners rely heavily on the strong, uniform magnetic fields produced by devices that utilize superconductors
- Particle accelerators such as the Large Hadron Collider at CERN rely on a variety of precise magnets for aligning the particle beams

Aims:

- **Aims 2 and 9:** visualizations frequently provide us with insights into the action of magnetic fields; however, the visualizations themselves have their own limitations
- **Aim 7:** computer-based simulations enable the visualization of electromagnetic fields in three-dimensional space

Topic 6: Circular motion and gravitation

5 hours

Essential idea: A force applied perpendicular to its displacement can result in circular motion.

6.1 – Circular motion

Nature of science:

Observable universe: Observations and subsequent deductions led to the realization that the force must act radially inwards in all cases of circular motion. (1.1)

Understandings:

- Period, frequency, angular displacement and angular velocity
- Centripetal force
- Centripetal acceleration

Applications and skills:

- Identifying the forces providing the centripetal forces such as tension, friction, gravitational, electrical, or magnetic
- Solving problems involving centripetal force, centripetal acceleration, period, frequency, angular displacement, linear speed and angular velocity
- Qualitatively and quantitatively describing examples of circular motion including cases of vertical and horizontal circular motion

Guidance:

- Banking will be considered qualitatively only

Data booklet reference:

- $v = \omega r$
- $a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$
- $F = \frac{mv^2}{r} = m\omega^2 r$

International-mindedness:

- International collaboration is needed in establishing effective rocket launch sites to benefit space programs

Theory of knowledge:

- Foucault's pendulum gives a simple observable proof of the rotation of the earth, which is largely unobservable. How can we have knowledge of things that are unobservable?

Utilization:

- Motion of charged particles in magnetic fields (see *Physics* sub-topic *5.4*)
- Mass spectrometry (see *Chemistry* sub-topics *2.1* and *11.3*)
- Playground and amusement park rides often use the principles of circular motion in their design

Aims:

- **Aim 6:** experiments could include (but are not limited to): mass on a string; observation and quantification of loop-the-loop experiences; friction of a mass on a turntable
- **Aim 7:** technology has allowed for more accurate and precise measurements of circular motion, including data loggers for force measurements and video analysis of objects moving in circular motion

Essential idea: The Newtonian idea of gravitational force acting between two spherical bodies and the laws of mechanics create a model that can be used to calculate the motion of planets.

6.2 – Newton's law of gravitation

Nature of science:

Laws: Newton's law of gravitation and the laws of mechanics are the foundation for deterministic classical physics. These can be used to make predictions but do not explain why the observed phenomena exist. (2.4)

Understandings:

- Newton's law of gravitation
- Gravitational field strength

Applications and skills:

- Describing the relationship between gravitational force and centripetal force
- Applying Newton's law of gravitation to the motion of an object in circular orbit around a point mass
- Solving problems involving gravitational force, gravitational field strength, orbital speed and orbital period
- Determining the resultant gravitational field strength due to two bodies

Guidance:

- Newton's law of gravitation should be extended to spherical masses of uniform density by assuming that their mass is concentrated at their centre
- Gravitational field strength at a point is the force per unit mass experienced by a small point mass at that point
- Calculations of the resultant gravitational field strength due to two bodies will be restricted to points along the straight line joining the bodies

Data booklet reference:

- $F = G\frac{Mm}{r^2}$
- $g = \frac{F}{m}$
- $g = G\frac{M}{r^2}$

Theory of knowledge:

- The laws of mechanics along with the law of gravitation create the deterministic nature of classical physics. Are classical physics and modern physics compatible? Do other areas of knowledge also have a similar division between classical and modern in their historical development?

Utilization:

- The law of gravitation is essential in describing the motion of satellites, planets, moons and entire galaxies
- Comparison to Coulomb's law (see *Physics* sub-topic *5.1*)

Aims:

- **Aim 4:** the theory of gravitation when combined and synthesized with the rest of the laws of mechanics allows detailed predictions about the future position and motion of planets

Topic 7: Atomic, nuclear and particle physics — 14 hours

Essential idea: In the microscopic world energy is discrete.

7.1 – Discrete energy and radioactivity	
Nature of science: Accidental discovery: Radioactivity was discovered by accident when Becquerel developed photographic film that had accidentally been exposed to radiation from radioactive rocks. The marks on the photographic film seen by Becquerel probably would not lead to anything further for most people. What Becquerel did was to correlate the presence of the marks with the presence of the radioactive rocks and investigate the situation further. (1.4)	
Understandings: • Discrete energy and discrete energy levels • Transitions between energy levels • Radioactive decay • Fundamental forces and their properties • Alpha particles, beta particles and gamma rays • Half-life • Absorption characteristics of decay particles • Isotopes • Background radiation	**International-mindedness:** • The geopolitics of the past 60+ years have been greatly influenced by the existence of nuclear weapons **Theory of knowledge:** • The role of luck/serendipity in successful scientific discovery is almost inevitably accompanied by a scientifically curious mind that will pursue the outcome of the "lucky" event. To what extent might scientific discoveries that have been described as being the result of luck actually be better described as being the result of reason or intuition?

7.1 – Discrete energy and radioactivity

Applications and skills:

- Describing the emission and absorption spectrum of common gases
- Solving problems involving atomic spectra, including calculating the wavelength of photons emitted during atomic transitions
- Completing decay equations for alpha and beta decay
- Determining the half-life of a nuclide from a decay curve
- Investigating half-life experimentally (or by simulation)

Guidance:

- Students will be required to solve problems on radioactive decay involving only integral numbers of half-lives
- Students will be expected to include the neutrino and antineutrino in beta decay equations

Data booklet reference:

- $E = hf$
- $\lambda = \frac{hc}{E}$

Utilization:

- Knowledge of radioactivity, radioactive substances and the radioactive decay law are crucial in modern nuclear medicine
- How to deal with the radioactive output of nuclear decay is important in the debate over nuclear power stations (see *Physics* sub-topic *8.1*)
- Carbon dating is used in providing evidence for evolution (see *Biology* sub-topic *5.1*)
- Exponential functions (see *Mathematical studies SL* sub-topic *6.4*; *Mathematics HL* sub-topic *2.4*)

Aims:

- **Aim 8:** the use of radioactive materials poses environmental dangers that must be addressed at all stages of research
- **Aim 9:** the use of radioactive materials requires the development of safe experimental practices and methods for handling radioactive materials

Essential idea: Energy can be released in nuclear decays and reactions as a result of the relationship between mass and energy.

7.2 – Nuclear reactions

Nature of science:

Patterns, trends and discrepancies: Graphs of binding energy per nucleon and of neutron number versus proton number reveal unmistakable patterns. This allows scientists to make predictions of isotope characteristics based on these graphs. (3.1)

Understandings:

- The unified atomic mass unit
- Mass defect and nuclear binding energy
- Nuclear fission and nuclear fusion

Applications and skills:

- Solving problems involving mass defect and binding energy
- Solving problems involving the energy released in radioactive decay, nuclear fission and nuclear fusion
- Sketching and interpreting the general shape of the curve of average binding energy per nucleon against nucleon number

Theory of knowledge:

- The acceptance that mass and energy are equivalent was a major paradigm shift in physics. How have other paradigm shifts changed the direction of science? Have there been similar paradigm shifts in other areas of knowledge?

Utilization:

- Our understanding of the energetics of the nucleus has led to ways to produce electricity from nuclei but also to the development of very destructive weapons
- The chemistry of nuclear reactions (see *Chemistry* option sub-topics *C.3* and *C.7*)

7.2 – Nuclear reactions	
Guidance: • Students must be able to calculate changes in terms of mass or binding energy • Binding energy may be defined in terms of energy required to completely separate the nucleons or the energy released when a nucleus is formed from its nucleons **Data booklet reference:** • $\Delta E = \Delta m\, c^2$	**Aims:** • **Aim 5:** some of the issues raised by the use of nuclear power transcend national boundaries and require the collaboration of scientists from many different nations • **Aim 8:** the development of nuclear power and nuclear weapons raises very serious moral and ethical questions: who should be allowed to possess nuclear power and nuclear weapons and who should make these decisions? There also serious environmental issues associated with the nuclear waste of nuclear power plants.

Essential idea: It is believed that all the matter around us is made up of fundamental particles called quarks and leptons. It is known that matter has a hierarchical structure with quarks making up nucleons, nucleons making up nuclei, nuclei and electrons making up atoms and atoms making up molecules. In this hierarchical structure, the smallest scale is seen for quarks and leptons (10^{-18}m).

7.3 – The structure of matter

Nature of science:

Predictions: Our present understanding of matter is called the Standard Model, consisting of six quarks and six leptons. Quarks were postulated on a completely mathematical basis in order to explain patterns in properties of particles. (1.9)

Collaboration: It was much later that large-scale collaborative experimentation led to the discovery of the predicted fundamental particles. (4.3)

Understandings:

- Quarks, leptons and their antiparticles
- Hadrons, baryons and mesons
- The conservation laws of charge, baryon number, lepton number and strangeness
- The nature and range of the strong nuclear force, weak nuclear force and electromagnetic force
- Exchange particles
- Feynman diagrams
- Confinement
- The Higgs boson

Applications and skills:

- Describing the Rutherford-Geiger-Marsden experiment that led to the discovery of the nucleus
- Applying conservation laws in particle reactions
- Describing protons and neutrons in terms of quarks
- Comparing the interaction strengths of the fundamental forces, including gravity
- Describing the mediation of the fundamental forces through exchange particles

International-mindedness:

- Research into particle physics requires ever-increasing funding, leading to debates in governments and international research organizations on the fair allocation of precious financial resources

Theory of knowledge:

- Does the belief in the existence of fundamental particles mean that it is justifiable to see physics as being more important than other areas of knowledge?

Utilization:

- An understanding of particle physics is needed to determine the final fate of the universe (see *Physics* option sub-topics *D.3* and *D.4*)

Aims:

- **Aim 1:** the research that deals with the fundamental structure of matter is international in nature and is a challenging and stimulating adventure for those who take part
- **Aim 4:** particle physics involves the analysis and evaluation of very large amounts of data
- **Aim 6:** students could investigate the scattering angle of alpha particles as a function of the aiming error, or the minimum distance of approach as a function of the initial kinetic energy of the alpha particle

7.3 – The structure of matter	
• Sketching and interpreting simple Feynman diagrams • Describing why free quarks are not observed **Guidance**: • A qualitative description of the standard model is required **Data booklet reference:**	• **Aim 8:** scientific and government organizations are asked if the funding for particle physics research could be spent on other research or social needs

Charge	Quarks			Baryon number
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$

All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1

Charge	Leptons		
–1	e	μ	τ
0	ν_e	ν_μ	ν_τ

All leptons have a lepton number of 1 and antileptons have a lepton number of –1

	Gravitational	Weak	Electromagnetic	Strong
Particles experiencing	All	Quarks, leptons	Charged	Quarks, gluons
Particles mediating	Graviton	W^+, W^-, Z^0	γ	Gluons

Topic 8: Energy production

8 hours

Essential idea: The constant need for new energy sources implies decisions that may have a serious effect on the environment. The finite quantity of fossil fuels and their implication in global warming has led to the development of alternative sources of energy. This continues to be an area of rapidly changing technological innovation.

8.1 – Energy sources

Nature of science:

Risks and problem-solving: Since early times mankind understood the vital role of harnessing energy and large-scale production of electricity has impacted all levels of society. Processes where energy is transformed require holistic approaches that involve many areas of knowledge. Research and development of alternative energy sources has lacked support in some countries for economic and political reasons. Scientists, however, have continued to collaborate and share new technologies that can reduce our dependence on non-renewable energy sources. (4.8)

Understandings:

- Specific energy and energy density of fuel sources
- Sankey diagrams
- Primary energy sources
- Electricity as a secondary and versatile form of energy
- Renewable and non-renewable energy sources

Applications and skills:

- Solving specific energy and energy density problems
- Sketching and interpreting Sankey diagrams
- Describing the basic features of fossil fuel power stations, nuclear power stations, wind generators, pumped storage hydroelectric systems and solar power cells
- Solving problems relevant to energy transformations in the context of these generating systems

International-mindedness:

- The production of energy from fossil fuels has a clear impact on the world we live in and therefore involves global thinking. The geographic concentrations of fossil fuels have led to political conflict and economic inequalities. The production of energy through alternative energy resources demands new levels of international collaboration.

Theory of knowledge:

- The use of nuclear energy inspires a range of emotional responses from scientists and society. How can accurate scientific risk assessment be undertaken in emotionally charged areas?

Utilization:

- Generators for electrical production and engines for motion have revolutionized the world (see *Physics* sub-topics *5.4* and *11.2*)
- The engineering behind alternative energy sources is influenced by different areas of physics (see *Physics* sub-topics *3.2*, *5.4* and *B.2*)

8.1 – Energy sources

- Discussing safety issues and risks associated with the production of nuclear power
- Describing the differences between photovoltaic cells and solar heating panels

Guidance:

- Specific energy has units of J kg^{-1}; energy density has units of J m^{-3}
- The description of the basic features of nuclear power stations must include the use of control rods, moderators and heat exchangers
- Derivation of the wind generator equation is not required but an awareness of relevant assumptions and limitations is required
- Students are expected to be aware of new and developing technologies which may become important during the life of this guide

Data booklet reference:

- $\text{Power} = \dfrac{\text{energy}}{\text{time}}$
- $\text{Power} = \dfrac{1}{2} A \rho v^3$

- Energy density (see *Chemistry* sub-topic *C.1*)
- Carbon recycling (see *Biology* sub-topic *4.3*)

Aims:

- **Aim 4:** the production of power involves many different scientific disciplines and requires the evaluation and synthesis of scientific information
- **Aim 8:** the production of energy has wide economic, environmental, moral and ethical dimensions

Essential idea: For simplified modelling purposes the Earth can be treated as a black-body radiator and the atmosphere treated as a grey-body.

8.2 – Thermal energy transfer

Nature of science:

Simple and complex modelling: The kinetic theory of gases is a simple mathematical model that produces a good approximation of the behaviour of real gases. Scientists are also attempting to model the Earth's climate, which is a far more complex system. Advances in data availability and the ability to include more processes in the models together with continued testing and scientific debate on the various models will improve the ability to predict climate change more accurately. (1.12)

Understandings:

- Conduction, convection and thermal radiation
- Black-body radiation
- Albedo and emissivity
- The solar constant
- The greenhouse effect
- Energy balance in the Earth surface–atmosphere system

Applications and skills:

- Sketching and interpreting graphs showing the variation of intensity with wavelength for bodies emitting thermal radiation at different temperatures
- Solving problems involving the Stefan–Boltzmann law and Wien's displacement law
- Describing the effects of the Earth's atmosphere on the mean surface temperature
- Solving problems involving albedo, emissivity, solar constant and the Earth's average temperature

International-mindedness:

- The concern over the possible impact of climate change has resulted in an abundance of international press coverage, many political discussions within and between nations, and the consideration of people, corporations, and the environment when deciding on future plans for our planet. IB graduates should be aware of the science behind many of these scenarios.

Theory of knowledge:

- The debate about global warming illustrates the difficulties that arise when scientists cannot always agree on the interpretation of the data, especially as the solution would involve large-scale action through international government cooperation. When scientists disagree, how do we decide between competing theories?

8.2 – Thermal energy transfer

Guidance:

- Discussion of conduction and convection will be qualitative only
- Discussion of conduction is limited to intermolecular and electron collisions
- Discussion of convection is limited to simple gas or liquid transfer via density differences
- The absorption of infrared radiation by greenhouse gases should be described in terms of the molecular energy levels and the subsequent emission of radiation in all directions
- The greenhouse gases to be considered are CH_4, H_2O, CO_2 and N_2O. It is sufficient for students to know that each has both natural and man-made origins.
- Earth's albedo varies daily and is dependent on season (cloud formations) and latitude. The global annual mean albedo will be taken to be 0.3 (30%) for Earth.

Data booklet reference:

- $P = e\sigma AT^4$
- $\lambda_{max}(\text{metres}) = \frac{2.90 \times 10^{-3}}{T(\text{kelvin})}$
- $I = \frac{\text{power}}{A}$
- $\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$

Utilization:

- Climate models and the variation in detail/processes included
- Environmental chemistry (see *Chemistry* option topic *C*)
- Climate change (see *Biology* sub-topic *4.4* and *Environmental systems and societies* topics *5* and *6*)
- The normal distribution curve is explored in *Mathematical studies SL* sub-topic *4.1*

Aims:

- **Aim 4:** this topic gives students the opportunity to understand the wide range of scientific analysis behind climate change issues
- **Aim 6:** simulations of energy exchange in the Earth surface–atmosphere system
- **Aim 8:** while science has the ability to analyse and possibly help solve climate change issues, students should be aware of the impact of science on the initiation of conditions that allowed climate change due to human contributions to occur. Students should also be aware of the way science can be used to promote the interests of one side of the debate on climate change (or, conversely, to hinder debate).

Topic 9: Wave phenomena

17 hours

Essential idea: The solution of the harmonic oscillator can be framed around the variation of kinetic and potential energy in the system.

9.1 – Simple harmonic motion

Nature of science:

Insights: The equation for simple harmonic motion (SHM) can be solved analytically and numerically. Physicists use such solutions to help them to visualize the behaviour of the oscillator. The use of the equations is very powerful as any oscillation can be described in terms of a combination of harmonic oscillators. Numerical modelling of oscillators is important in the design of electrical circuits. (1.11)

Understandings and applications	Utilization
Understandings: • The defining equation of SHM • Energy changes **Applications and skills:** • Solving problems involving acceleration, velocity and displacement during simple harmonic motion, both graphically and algebraically • Describing the interchange of kinetic and potential energy during simple harmonic motion • Solving problems involving energy transfer during simple harmonic motion, both graphically and algebraically **Guidance** • Contexts for this sub-topic include the simple pendulum and a mass-spring system	**Utilization:** • Fourier analysis allows us to describe all periodic oscillations in terms of simple harmonic oscillators. The mathematics of simple harmonic motion is crucial to any areas of science and technology where oscillations occur • The interchange of energies in oscillation is important in electrical phenomena • Quadratic functions (see *Mathematics HL* sub-topic *2.6*; *Mathematics SL* sub-topic *2.4*; *Mathematical studies SL* sub-topic *6.3*) • Trigonometric functions (see *Mathematics SL* sub-topic *3.4*)

9.1 – Simple harmonic motion

Data booklet reference:	Aims:
• $\omega = \frac{2\pi}{T}$ • $a = -\omega^2 x$ • $x = x_0 \sin \omega t$; $x = x_0 \cos \omega t$ • $v = \omega x_0 \cos \omega t$; $v = -\omega x_0 \sin \omega t$ • $v = \pm\omega\sqrt{(x_0^2 - x^2)}$ • $E_K = \frac{1}{2} m\omega^2 (x_0^2 - x^2)$ • $E_T = \frac{1}{2} m\omega^2 x_0^2$ • Pendulum: $T = 2\pi\sqrt{\frac{l}{g}}$ • Mass – spring: $T = 2\pi\sqrt{\frac{m}{k}}$	• **Aim 4:** students can use this topic to develop their ability to synthesize complex and diverse scientific information • **Aim 6:** experiments could include (but are not limited to): investigation of simple or torsional pendulums; measuring the vibrations of a tuning fork; further extensions of the experiments conducted in sub-topic 4.1. By using the force law, a student can, with iteration, determine the behaviour of an object under simple harmonic motion. The iterative approach (numerical solution), with given initial conditions, applies basic uniform acceleration equations in successive small time increments. At each increment, final values become the following initial conditions. • **Aim 7:** the observation of simple harmonic motion and the variables affected can be easily followed in computer simulations

Essential idea: Single-slit diffraction occurs when a wave is incident upon a slit of approximately the same size as the wavelength.

9.2 – Single-slit diffraction

Nature of science:

Development of theories: When light passes through an aperture the summation of all parts of the wave leads to an intensity pattern that is far removed from the geometrical shadow that simple theory predicts. (1.9)

Understandings:

- The nature of single-slit diffraction

Applications and skills:

- Describing the effect of slit width on the diffraction pattern
- Determining the position of first interference minimum
- Qualitatively describing single-slit diffraction patterns produced from white light and from a range of monochromatic light frequencies

Guidance:

- Only rectangular slits need to be considered
- Diffraction around an object (rather than through a slit) does not need to be considered in this sub-topic (see *Physics* sub-topic *4.4*)

Theory of knowledge:

- Are explanations in science different from explanations in other areas of knowledge such as history?

Utilization:

- X-ray diffraction is an important tool of the crystallographer and the material scientist

Aims:

- **Aim 2:** this topic provides a body of knowledge that characterizes the way that science is subject to modification with time
- **Aim 6:** experiments can be combined with those from sub-topics 4.4 and 9.3

9.2 – Single-slit diffraction	
• Students will be expected to be aware of the approximate ratios of successive intensity maxima for single-slit interference patterns • Calculations will be limited to a determination of the position of the first minimum for single-slit interference patterns using the approximation equation **Data booklet reference:** • $\theta = \frac{\lambda}{b}$	

Essential idea: Interference patterns from multiple slits and thin films produce accurately repeatable patterns.

9.3 – Interference

Nature of science:

Curiosity: Observed patterns of iridescence in animals, such as the shimmer of peacock feathers, led scientists to develop the theory of thin film interference. (1.5)

Serendipity: The first laboratory production of thin films was accidental. (1.5)

Understandings:

- Young's double-slit experiment
- Modulation of two-slit interference pattern by one-slit diffraction effect
- Multiple slit and diffraction grating interference patterns
- Thin film interference

Applications and skills:

- Qualitatively describing two-slit interference patterns, including modulation by one-slit diffraction effect
- Investigating Young's double-slit experimentally
- Sketching and interpreting intensity graphs of double-slit interference patterns
- Solving problems involving the diffraction grating equation
- Describing conditions necessary for constructive and destructive interference from thin films, including phase change at interface and effect of refractive index
- Solving problems involving interference from thin films

Theory of knowledge:

- Most two-slit interference descriptions can be made without reference to the one-slit modulation effect. To what level can scientists ignore parts of a model for simplicity and clarity?

Utilization:

- Compact discs are a commercial example of the use of diffraction gratings
- Thin films are used to produce anti-reflection coatings

Aims:

- **Aim 4:** two scientific concepts (diffraction and interference) come together in this sub-topic, allowing students to analyse and synthesize a wider range of scientific information
- **Aim 6:** experiments could include (but are not limited to): observing the use of diffraction gratings in spectroscopes; analysis of thin soap films; sound wave and microwave interference pattern analysis
- **Aim 9:** the ray approach to the description of thin film interference is only an approximation. Students should recognize the limitations of such a visualization

9.3 – Interference	
Guidance: • Students should be introduced to interference patterns from a variety of coherent sources such as (but not limited to) electromagnetic waves, sound and simulated demonstrations • Diffraction grating patterns are restricted to those formed at normal incidence • The treatment of thin film interference is confined to parallel-sided films at normal incidence • The constructive interference and destructive interference formulae listed below and in the data booklet apply to specific cases of phase changes at interfaces and are not generally true **Data booklet reference:** • $n\lambda = d \sin \theta$ • Constructive interference: $2dn = \left(m + \frac{1}{2}\right)\lambda$ • Destructive interference: $2dn = m\lambda$	

Essential idea: Resolution places an absolute limit on the extent to which an optical or other system can separate images of objects.

9.4 – Resolution

Nature of science:

Improved technology: The Rayleigh criterion is the limit of resolution. Continuing advancement in technology such as large diameter dishes or lenses or the use of smaller wavelength lasers pushes the limits of what we can resolve. (1.8)

Understandings:

- The size of a diffracting aperture
- The resolution of simple monochromatic two-source systems

Applications and skills:

- Solving problems involving the Rayleigh criterion for light emitted by two sources diffracted at a single slit
- Resolvance of diffraction gratings

Guidance:

- Proof of the diffraction grating resolvance equation is not required

Data booklet reference:

- $\theta = 1.22\frac{\lambda}{b}$
- $R = \frac{\lambda}{\Delta\lambda} = mN$

International-mindedness:

- Satellite use for commercial and political purposes is dictated by the resolution capabilities of the satellite

Theory of knowledge:

- The resolution limits set by Dawes and Rayleigh are capable of being surpassed by the construction of high quality telescopes. Are we capable of breaking other limits of scientific knowledge with our advancing technology?

Utilization:

- An optical or other reception system must be able to resolve the intended images. This has implications for satellite transmissions, radio astronomy and many other applications in physics and technology (see *Physics* option *C*)
- Storage media such as compact discs (and their variants) and CCD sensors rely on resolution limits to store and reproduce media accurately

Aims:

- **Aim 3:** this sub-topic helps bridge the gap between wave theory and real-life applications
- **Aim 8:** the need for communication between national communities via satellites raises the awareness of the social and economic implications of technology

Essential idea: The Doppler effect describes the phenomenon of wavelength/frequency shift when relative motion occurs.

9.5 – Doppler effect

Nature of science:

Technology: Although originally based on physical observations of the pitch of fast moving sources of sound, the Doppler effect has an important role in many different areas such as evidence for the expansion of the universe and generating images used in weather reports and in medicine. (5.5)

Understandings:

- The Doppler effect for sound waves and light waves

Applications and skills:

- Sketching and interpreting the Doppler effect when there is relative motion between source and observer
- Describing situations where the Doppler effect can be utilized
- Solving problems involving the change in frequency or wavelength observed due to the Doppler effect to determine the velocity of the source/observer

Guidance:

- For electromagnetic waves, the approximate equation should be used for all calculations
- Situations to be discussed should include the use of Doppler effect in radars and in medical physics, and its significance for the red-shift in the light spectra of receding galaxies

Data booklet reference:

- Moving source: $f' = f\left(\frac{v}{v \pm u_s}\right)$
- Moving observer: $f' = f\left(\frac{v \pm u_0}{v}\right)$
- $\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$

International-mindedness:

- Radar usage is affected by the Doppler effect and must be considered for applications using this technology

Theory of knowledge:

- How important is sense perception in explaining scientific ideas such as the Doppler effect?

Utilization:

- Astronomy relies on the analysis of the Doppler effect when dealing with fast moving objects (see *Physics* option *D*)

Aims:

- **Aim 2:** the Doppler effect needs to be considered in various applications of technology that utilize wave theory
- **Aim 6:** spectral data and images of receding galaxies are available from professional astronomical observatories for analysis
- **Aim 7:** computer simulations of the Doppler effect allow students to visualize complex and mostly unobservable situations

Topic 10: Fields

11 hours

Essential idea: Electric charges and masses each influence the space around them and that influence can be represented through the concept of fields.

10.1 – Describing fields

Nature of science:

Paradigm shift: The move from direct, observable actions being responsible for influence on an object to acceptance of a field's "action at a distance" required a paradigm shift in the world of science. (2.3)

Understandings:

- Gravitational fields
- Electrostatic fields
- Electric potential and gravitational potential
- Field lines
- Equipotential surfaces

Applications and skills:

- Representing sources of mass and charge, lines of electric and gravitational force, and field patterns using an appropriate symbolism
- Mapping fields using potential
- Describing the connection between equipotential surfaces and field lines

Theory of knowledge:

- Although gravitational and electrostatic forces decrease with the square of distance and will only become zero at infinite separation, from a practical standpoint they become negligible at much smaller distances. How do scientists decide when an effect is so small that it can be ignored?

Utilization:

- Knowledge of vector analysis is useful for this sub-topic (see *Physics* sub-topic *1.3*)

Aims:

- **Aim 9:** models developed for electric and gravitational fields using lines of forces allow predictions to be made but have limitations in terms of the finite width of a line

10.1 – Describing fields

Guidance:

- Electrostatic fields are restricted to the radial fields around point or spherical charges, the field between two point charges and the uniform fields between charged parallel plates
- Gravitational fields are restricted to the radial fields around point or spherical masses and the (assumed) uniform field close to the surface of massive celestial bodies and planetary bodies
- Students should recognize that no work is done in moving charge or mass on an equipotential surface

Data booklet reference:

- $W = q\Delta V_e$
- $W = m\Delta V_g$

Essential idea: Similar approaches can be taken in analysing electrical and gravitational potential problems.

10.2 – Fields at work

Nature of science:

Communication of scientific explanations: The ability to apply field theory to the unobservable (charges) and the massively scaled (motion of satellites) required scientists to develop new ways to investigate, analyse and report findings to a general public used to scientific discoveries based on tangible and discernible evidence. (5.1)

Understandings:

- Potential and potential energy
- Potential gradient
- Potential difference
- Escape speed
- Orbital motion, orbital speed and orbital energy
- Forces and inverse-square law behaviour

Applications and skills:

- Determining the potential energy of a point mass and the potential energy of a point charge
- Solving problems involving potential energy
- Determining the potential inside a charged sphere
- Solving problems involving the speed required for an object to go into orbit around a planet and for an object to escape the gravitational field of a planet
- Solving problems involving orbital energy of charged particles in circular orbital motion and masses in circular orbital motion
- Solving problems involving forces on charges and masses in radial and uniform fields

Utilization:

- The global positioning system depends on complete understanding of satellite motion
- Geostationary/polar satellites
- The acceleration of charged particles in particle accelerators and in many medical imaging devices depends on the presence of electric fields (see *Physics* option sub-topic *C.4*)

Aims:

- **Aim 2:** Newton's law of gravitation and Coulomb's law form part of the structure known as "classical physics". This body of knowledge has provided the methods and tools of analysis up to the advent of the theory of relativity and the quantum theory
- **Aim 4:** the theories of gravitation and electrostatic interactions allows for a great synthesis in the description of a large number of phenomena

10.2 – Fields at work	
Guidance: • Orbital motion of a satellite around a planet is restricted to a consideration of circular orbits (links to 6.1 and 6.2) • Both uniform and radial fields need to be considered • Students should recognize that lines of force can be two-dimensional representations of three-dimensional fields • Students should assume that the electric field everywhere between parallel plates is uniform with edge effects occurring beyond the limits of the plates. **Data booklet reference:**	

$V_g = -\frac{GM}{r}$	$V_e = \frac{kq}{r}$
$g = -\frac{\Delta V_g}{\Delta r}$	$E = -\frac{\Delta V_e}{\Delta r}$
$E_P = mV_g = -\frac{GMm}{r}$	$E_P = qV_e = \frac{kq_1q_2}{r}$
$F_G = G\frac{m_1m_2}{r^2}$	$F_E = k\frac{q_1q_2}{r^2}$

- $V_{esc} = \sqrt{\frac{2GM}{r}}$
- $V_{orbit} = \sqrt{\frac{GM}{r}}$

Topic 11: Electromagnetic induction

16 hours

Essential idea: The majority of electricity generated throughout the world is generated by machines that were designed to operate using the principles of electromagnetic induction.

11.1 – Electromagnetic induction

Nature of science:

Experimentation: In 1831 Michael Faraday, using primitive equipment, observed a minute pulse of current in one coil of wire only when the current in a second coil of wire was switched on or off but nothing while a constant current was established. Faraday's observation of these small transient currents led him to perform experiments that led to his law of electromagnetic induction. (1.8)

Understandings:

- Electromotive force (emf)
- Magnetic flux and magnetic flux linkage
- Faraday's law of induction
- Lenz's law

Applications and skills:

- Describing the production of an induced emf by a changing magnetic flux and within a uniform magnetic field
- Solving problems involving magnetic flux, magnetic flux linkage and Faraday's law
- Explaining Lenz's law through the conservation of energy

Theory of knowledge:

- Terminology used in electromagnetic field theory is extensive and can confuse people who are not directly involved. What effect can lack of clarity in terminology have on communicating scientific concepts to the public?

Utilization:

- Applications of electromagnetic induction can be found in many places including transformers, electromagnetic braking, geophones used in seismology, and metal detectors

Aims:

- **Aim 2:** the simple principles of electromagnetic induction are a powerful aspect of the physicist's or technologist's armoury when designing systems that transfer energy from one form to another

11.1 – Electromagnetic induction

Guidance:

- Quantitative treatments will be expected for straight conductors moving at right angles to magnetic fields and rectangular coils moving in and out of fields and rotating in fields
- Qualitative treatments only will be expected for fixed coils in a changing magnetic field and ac generators

Data booklet reference:

- $\Phi = BA\cos\theta$
- $\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$
- $\varepsilon = Bv\ell$
- $\varepsilon = Bv\ell N$

Essential idea: Generation and transmission of alternating current (ac) electricity has transformed the world.

11.2 – Power generation and transmission

Nature of science:

Bias: In the late 19th century Edison was a proponent of direct current electrical energy transmission while Westinghouse and Tesla favoured alternating current transmission. The so called "battle of currents" had a significant impact on today's society. (3.5)

Understandings:

- Alternating current (ac) generators
- Average power and root mean square (rms) values of current and voltage
- Transformers
- Diode bridges
- Half-wave and full-wave rectification

Applications and skills:

- Explaining the operation of a basic ac generator, including the effect of changing the generator frequency
- Solving problems involving the average power in an ac circuit
- Solving problems involving step-up and step-down transformers
- Describing the use of transformers in ac electrical power distribution
- Investigating a diode bridge rectification circuit experimentally
- Qualitatively describing the effect of adding a capacitor to a diode bridge rectification circuit

Guidance:

- Calculations will be restricted to ideal transformers but students should be aware of some of the reasons why real transformers are not ideal (for example: flux leakage, joule heating, eddy current heating, magnetic hysteresis)
- Proof of the relationship between the peak and rms values will not be expected

International-mindedness:

- The ability to maintain a reliable power grid has been the aim of all governments since the widespread use of electricity started

Theory of knowledge:

- There is continued debate of the effect of electromagnetic waves on the health of humans, especially children. Is it justifiable to make use of scientific advances even if we do not know what their long-term consequences may be?

Aims:

- **Aim 6:** experiments could include (but are not limited to): construction of a basic ac generator; investigation of variation of input and output coils on a transformer; observing Wheatstone and Wien bridge circuits
- **Aim 7:** construction and observation of the adjustments made in very large electricity distribution systems are best carried out using computer-modelling software and websites
- **Aim 9:** power transmission is modelled using perfectly efficient systems but no such system truly exists. Although the model is imperfect, it renders the maximum power transmission. Recognition of, and accounting for, the differences between the "perfect" system and the practical system is one of the main functions of professional scientists

11.2 – Power generation and transmission

Data booklet reference:

- $I_{rms} = \dfrac{I_0}{\sqrt{2}}$
- $V_{rms} = \dfrac{V_0}{\sqrt{2}}$
- $R = \dfrac{V_0}{I_0} = \dfrac{V_{rms}}{I_{rms}}$
- $P_{max} = I_0 V_0$
- $\overline{P} = \dfrac{1}{2} I_0 V_0$
- $\dfrac{\varepsilon_p}{\varepsilon_s} = \dfrac{N_p}{N_s} = \dfrac{I_s}{I_p}$

Essential idea: Capacitors can be used to store electrical energy for later use.

11.3 – Capacitance

Nature of science:

Relationships: Examples of exponential growth and decay pervade the whole of science. It is a clear example of the way that scientists use mathematics to model reality. This topic can be used to create links between physics topics but also to uses in chemistry, biology, medicine and economics. (3.1)

Understandings:

- Capacitance
- Dielectric materials
- Capacitors in series and parallel
- Resistor-capacitor (RC) series circuits
- Time constant

Applications and skills:

- Describing the effect of different dielectric materials on capacitance
- Solving problems involving parallel-plate capacitors
- Investigating combinations of capacitors in series or parallel circuits
- Determining the energy stored in a charged capacitor
- Describing the nature of the exponential discharge of a capacitor
- Solving problems involving the discharge of a capacitor through a fixed resistor
- Solving problems involving the time constant of an RC circuit for charge, voltage and current

International-mindedness:

- Lightning is a phenomenon that has fascinated physicists from Pliny through Newton to Franklin. The charged clouds form one plate of a capacitor with other clouds or Earth forming the second plate. The frequency of lightning strikes varies globally, being particularly prevalent in equatorial regions. The impact of lightning strikes is significant, with many humans and animals being killed annually and huge financial costs to industry from damage to buildings, communication and power transmission systems, and delays or the need to reroute air transport.

Utilization:

- The charge and discharge of capacitors obeys rules that have parallels in other branches of physics including radioactivity (see *Physics* sub-topic *7.1*)

Aims:

- **Aim 3:** the treatment of exponential growth and decay by graphical and algebraic methods offers both the visual and rigorous approach so often characteristic of science and technology
- **Aim 6:** experiments could include (but are not limited to): investigating basic RC circuits; using a capacitor in a bridge circuit; examining other types of capacitors; verifying time constant

11.3 – Capacitance

Guidance: • Only single parallel-plate capacitors providing a uniform electric field, in series with a load, need to be considered (edge effect will be neglected) • Problems involving the discharge of capacitors through fixed resistors need to be treated both graphically and algebraically • Problems involving the charging of a capacitor will only be treated graphically • Derivation of the charge, voltage and current equations as a function of time is not required **Data booklet reference:** • $C = \frac{q}{V}$ • $C_{\text{parallel}} = C_1 + C_2 + \cdots$ • $\frac{1}{C_{\text{series}}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$ • $C = \varepsilon \frac{A}{d}$ • $E = \frac{1}{2} C V^2$ • $\tau = RC$ • $q = q_0 e^{-\frac{t}{\tau}}$ • $I = I_0 e^{-\frac{t}{\tau}}$ • $V = V_0 e^{-\frac{t}{\tau}}$	

Topic 12: Quantum and nuclear physics 16 hours

Essential idea: The microscopic quantum world offers a range of phenomena, the interpretation and explanation of which require new ideas and concepts not found in the classical world.

12.1 – The interaction of matter with radiation

Nature of science:

Observations: Much of the work towards a quantum theory of atoms was guided by the need to explain the observed patterns in atomic spectra. The first quantum model of matter is the Bohr model for hydrogen. (1.8)

Paradigm shift: The acceptance of the wave–particle duality paradox for light and particles required scientists in many fields to view research from new perspectives. (2.3)

Understandings:

- Photons
- The photoelectric effect
- Matter waves
- Pair production and pair annihilation
- Quantization of angular momentum in the Bohr model for hydrogen
- The wave function
- The uncertainty principle for energy and time and position and momentum
- Tunnelling, potential barrier and factors affecting tunnelling probability

Theory of knowledge:

- The duality of matter and tunnelling are cases where the laws of classical physics are violated. To what extent have advances in technology enabled paradigm shifts in science?

Utilization:

- The electron microscope and the tunnelling electron microscope rely on the findings from studies in quantum physics
- Probability is treated in a mathematical sense in *Mathematical studies SL* sub-topics *3.6–3.7*

12.1 – The interaction of matter with radiation

Applications and skills:

- Discussing the photoelectric effect experiment and explaining which features of the experiment cannot be explained by the classical wave theory of light
- Solving photoelectric problems both graphically and algebraically
- Discussing experimental evidence for matter waves, including an experiment in which the wave nature of electrons is evident
- Stating order of magnitude estimates from the uncertainty principle

Guidance:

- The order of magnitude estimates from the uncertainty principle may include (but is not limited to) estimates of the energy of the ground state of an atom, the impossibility of an electron existing within a nucleus, and the lifetime of an electron in an excited energy state
- Tunnelling to be treated qualitatively using the idea of continuity of wave functions

Data booklet reference:

- $E = hf$
- $E_{max} = hf - \Phi$
- $E = -\frac{13.6}{n^2} eV$
- $mvr = \frac{nh}{2\pi}$
- $P(r) = |\Psi|^2 \Delta V$
- $\Delta x \Delta p \geq \frac{h}{4\pi}$
- $\Delta E \Delta t \geq \frac{h}{4\pi}$

Aims:

- **Aim 1:** study of quantum phenomena introduces students to an exciting new world that is not experienced at the macroscopic level. The study of tunneling is a novel phenomenon not observed in macroscopic physics.
- **Aim 6:** the photoelectric effect can be investigated using LEDs
- **Aim 9:** the Bohr model is very successful with hydrogen but not of any use for other elements

Essential idea: The idea of discreteness that we met in the atomic world continues to exist in the nuclear world as well.

12.2 – Nuclear physics

Nature of science:

Theoretical advances and inspiration: Progress in atomic, nuclear and particle physics often came from theoretical advances and strokes of inspiration.

Advances in instrumentation: New ways of detecting subatomic particles due to advances in electronic technology were also crucial.

Modern computing power: Finally, the analysis of the data gathered in modern particle detectors in particle accelerator experiments would be impossible without modern computing power. (1.8)

Understandings:

- Rutherford scattering and nuclear radius
- Nuclear energy levels
- The neutrino
- The law of radioactive decay and the decay constant

Applications and skills:

- Describing a scattering experiment including location of minimum intensity for the diffracted particles based on their de Broglie wavelength
- Explaining deviations from Rutherford scattering in high energy experiments
- Describing experimental evidence for nuclear energy levels
- Solving problems involving the radioactive decay law for arbitrary time intervals
- Explaining the methods for measuring short and long half-lives

Theory of knowledge:

- Much of the knowledge about subatomic particles is based on the models one uses to interpret the data from experiments. How can we be sure that we are discovering an "independent truth" not influenced by our models? Is there such a thing as a single truth?

Utilization:

- Knowledge of radioactivity, radioactive substances and the radioactive decay law are crucial in modern nuclear medicine (see *Physics* option sub-topic *C.4*)

Aims:

- **Aim 2:** detection of the neutrino demonstrates the continuing growing body of knowledge scientists are gathering in this area of study

12.2 – Nuclear physics	
Guidance: • Students should be aware that nuclear densities are approximately the same for all nuclei and that the only macroscopic objects with the same density as nuclei are neutron stars • The small angle approximation is usually not appropriate to use to determine the location of the minimum intensity **Data booklet reference:** • $R = R_0 A^{1/3}$ • $N = N_0 e^{-\lambda t}$ • $A = \lambda N_0 e^{-\lambda t}$ • $\sin\theta \approx \frac{\lambda}{D}$	

Core topics

15 hours

Essential idea: Einstein's study of electromagnetism revealed inconsistencies between the theory of Maxwell and Newton's mechanics. He recognized that both theories could not be reconciled and so choosing to trust Maxwell's theory of electromagnetism he was forced to change long-cherished ideas about space and time in mechanics.

A.1 – The beginnings of relativity

Nature of science:

Paradigm shift: The fundamental fact that the speed of light is constant for all inertial observers has far-reaching consequences about our understanding of space and time. Ideas about space and time that went unchallenged for more than 2,000 years were shown to be false. The extension of the principle of relativity to accelerated frames of reference leads to the revolutionary idea of general relativity that the mass and energy that spacetime contains determines the geometry of spacetime. (2.3)

Understandings:

- Reference frames
- Galilean relativity and Newton's postulates concerning time and space
- Maxwell and the constancy of the speed of light
- Forces on a charge or current

Applications and skills:

- Using the Galilean transformation equations
- Determining whether a force on a charge or current is electric or magnetic in a given frame of reference
- Determining the nature of the fields observed by different observers

Theory of knowledge:

- When scientists claim a new direction in thinking requires a paradigm shift in how we observe the universe, how do we ensure their claims are valid?

Aims:

- **Aim 3:** this sub-topic is the cornerstone of developments that followed in relativity and modern physics

A.1 – The beginnings of relativity	
Guidance: • Maxwell's equations do not need to be described • Qualitative treatment of electric and magnetic fields as measured by observers in relative motion. Examples will include a charge moving in a magnetic field or two charged particles moving with parallel velocities. Students will be asked to analyse these motions from the point of view of observers at rest with respect to the particles and observers at rest with respect to the magnetic field. **Data booklet reference:** • $x' = x - vt$ • $u' = u - v$	

Essential idea: Observers in relative uniform motion disagree on the numerical values of space and time coordinates for events, but agree with the numerical value of the speed of light in a vacuum. The Lorentz transformation equations relate the values in one reference frame to those in another. These equations replace the Galilean transformation equations that fail for speeds close to that of light.

A.2 – Lorentz transformations

Nature of science:

Pure science: Einstein based his theory of relativity on two postulates and deduced the rest by mathematical analysis. The first postulate integrates all of the laws of physics including the laws of electromagnetism, not only Newton's laws of mechanics. (1.2)

Understandings:

- The two postulates of special relativity
- Clock synchronization
- The Lorentz transformations
- Velocity addition
- Invariant quantities (spacetime interval, proper time, proper length and rest mass)
- Time dilation
- Length contraction
- The muon decay experiment

Applications and skills:

- Using the Lorentz transformations to describe how different measurements of space and time by two observers can be converted into the measurements observed in either frame of reference
- Using the Lorentz transformation equations to determine the position and time coordinates of various events
- Using the Lorentz transformation equations to show that if two events are simultaneous for one observer but happen at different points in space, then the events are not simultaneous for an observer in a different reference frame
- Solving problems involving velocity addition
- Deriving the time dilation and length contraction equations using the Lorentz equations

Utilization:

- Once a very esoteric part of physics, relativity ideas about space and time are needed in order to produce accurate global positioning systems (GPS)

Aims:

- **Aim 2:** the Lorentz transformation formulae provide a consistent body of knowledge that can be used to compare the description of motion by one observer to the description of another observer in relative motion to the first
- **Aim 3:** these formulae can be applied to a varied set of conditions and situations
- **Aim 9:** the introduction of relativity pushed the limits of Galilean thoughts on space and motion

A.2 – Lorentz transformations	
• Solving problems involving time dilation and length contraction • Solving problems involving the muon decay experiment **Guidance:** • Problems will be limited to one dimension • Derivation of the Lorentz transformation equations will not be examined • Muon decay experiments can be used as evidence for both time dilation and length contraction **Data booklet reference:** • $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ • $x' = \gamma(x - vt)$; $\Delta x' = \gamma(\Delta x - v\Delta t)$ • $t' = \gamma\left(t - \frac{vx}{c^2}\right)$; $\Delta t' = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right)$ • $u' = \frac{u - v}{1 - \frac{uv}{c^2}}$ • $\Delta t = \gamma \Delta t_0$ • $L = \frac{L_0}{\gamma}$ • $(ct')^2 - (x')^2 = (ct)^2 - (x)^2$	

Essential idea: Spacetime diagrams are a very clear and illustrative way to show graphically how different observers in relative motion to each other have measurements that differ from each other.

A.3 – Spacetime diagrams

Nature of science:

Visualization of models: The visualization of the description of events in terms of spacetime diagrams is an enormous advance in understanding the concept of spacetime. (1.10)

Understandings:

- Spacetime diagrams
- Worldlines
- The twin paradox

Applications and skills:

- Representing events on a spacetime diagram as points
- Representing the positions of a moving particle on a spacetime diagram by a curve (the worldline)
- Representing more than one inertial reference frame on the same spacetime diagram
- Determining the angle between a worldline for specific speed and the time axis on a spacetime diagram
- Solving problems on simultaneity and kinematics using spacetime diagrams
- Representing time dilation and length contraction on spacetime diagrams
- Describing the twin paradox
- Resolving of the twin paradox through spacetime diagrams

Theory of knowledge:

- Can paradoxes be solved by reason alone, or do they require the utilization of other ways of knowing?

Aims:

- **Aim 4:** spacetime diagrams allow one to analyse problems in relativity more reliably

A.3 – Spacetime diagrams	
Guidance: • Examination questions will refer to spacetime diagrams; these are also known as Minkowski diagrams • Quantitative questions involving spacetime diagrams will be limited to constant velocity • Spacetime diagrams can have *t* or *ct* on the vertical axis • Examination questions may use units in which $c = 1$ **Data booklet reference:** • $\theta = \tan^{-1}\left(\frac{v}{c}\right)$	

Additional higher level option topics

10 hours

Essential idea: The relativity of space and time requires new definitions for energy and momentum in order to preserve the conserved nature of these laws.

A.4 – Relativistic mechanics

Nature of science:

Paradigm shift: Einstein realized that the law of conservation of momentum could not be maintained as a law of physics. He therefore deduced that in order for momentum to be conserved under all conditions, the definition of momentum had to change and along with it the definitions of other mechanics quantities such as kinetic energy and total energy of a particle. This was a major paradigm shift. (2.3)

Understandings:

- Total energy and rest energy
- Relativistic momentum
- Particle acceleration
- Electric charge as an invariant quantity
- Photons
- MeV c^{-2} as the unit of mass and MeV c^{-1} as the unit of momentum

Applications and skills:

- Describing the laws of conservation of momentum and conservation of energy within special relativity
- Determining the potential difference necessary to accelerate a particle to a given speed or energy
- Solving problems involving relativistic energy and momentum conservation in collisions and particle decays

Theory of knowledge:

- In what ways do laws in the natural sciences differ from laws in economics?

Utilization:

- The laws of relativistic mechanics are routinely used in order to manage the operation of nuclear power plants, particle accelerators and particle detectors

Aims:

- **Aim 4:** relativistic mechanics synthesizes knowledge on the behaviour of matter at speeds close to the speed of light
- **Aim 9:** the theory of relativity imposes one severe limitation: nothing can exceed the speed of light

A.4 – Relativistic mechanics

Guidance:

- Applications will involve relativistic decays such as calculating the wavelengths of photons in the decay of a moving pion $[\pi^{o} \rightarrow 2\gamma]$
- The symbol m_0 refers to the *invariant rest mass* of a particle
- The concept of a relativistic mass that varies with speed will not be used
- Problems will be limited to one dimension

Data booklet reference:

- $E = \gamma m_0 c^2$
- $E_0 = m_0 c^2$
- $E_K = (\gamma - 1) m_0 c^2$
- $p = \gamma m_0 \upsilon$
- $E^2 = p^2 c^2 + {m_0}^2 c^4$
- $qV = \Delta E_K$

Essential idea: General relativity is applied to bring together fundamental concepts of mass, space and time in order to describe the fate of the universe.

A.5 – General relativity

Nature of science:

Creative and critical thinking: Einstein's great achievement, the general theory of relativity, is based on intuition, creative thinking and imagination, namely to connect the geometry of spacetime (through its curvature) to the mass and energy content of spacetime. For years it was thought that nothing could escape a black hole and this is true but only for classical black holes. When quantum theory is taken into account a black hole radiates like a black body. This unexpected result revealed other equally unexpected connections between black holes and thermodynamics. (1.4)

Understandings:

- The equivalence principle
- The bending of light
- Gravitational redshift and the Pound–Rebka–Snider experiment
- Schwarzschild black holes
- Event horizons
- Time dilation near a black hole
- Applications of general relativity to the universe as a whole

Applications and skills:

- Using the equivalence principle to deduce and explain light bending near massive objects
- Using the equivalence principle to deduce and explain gravitational time dilation
- Calculating gravitational frequency shifts
- Describing an experiment in which gravitational redshift is observed and measured
- Calculating the Schwarzschild radius of a black hole
- Applying the formula for gravitational time dilation near the event horizon of a black hole

Theory of knowledge:

- Although Einstein self-described the cosmological constant as his "greatest blunder", the 2011 Nobel Prize was won by scientists who had proved it to be valid through their studies on dark energy. What other examples are there of initially doubted claims being proven correct later in history?

Utilization:

- For the global positioning system to be so accurate, general relativity must be taken into account in calculating the details of the satellite's orbit
- The development of the general theory of relativity has been used to explain the very large-scale behaviour of the universe as a whole with far-reaching implications about the future development and fate of the universe

Aims:

- **Aim 2:** the general theory of relativity is a great synthesis of ideas that are required to describe the large-scale structure of the universe
- **Aim 9:** it must be appreciated that the magnificent Newtonian structure had serious limitations when it came to the description of very detailed aspects of planetary motion

A.5 – General relativity	
Guidance: • Students should recognize the equivalence principle in terms of accelerating reference frames and freely falling frames **Data booklet reference:** • $\frac{\Delta f}{f} = \frac{g\Delta h}{c^2}$ • $R_s = \frac{2GM}{c^2}$ • $\Delta t = \frac{\Delta t_0}{\sqrt{1 - \frac{R_S}{r}}}$	

Core topics

15 hours

Essential idea: The basic laws of mechanics have an extension when equivalent principles are applied to rotation. Actual objects have dimensions and they require the expansion of the point particle model to consider the possibility of different points on an object having different states of motion and/or different velocities.

B.1 – Rigid bodies and rotational dynamics

Nature of science:

Modelling: The use of models has different purposes and has allowed scientists to identify, simplify and analyse a problem within a given context to tackle it successfully. The extension of the point particle model to actually consider the dimensions of an object led to many groundbreaking developments in engineering. (1.2)

Understandings:

- Torque
- Moment of inertia
- Rotational and translational equilibrium
- Angular acceleration
- Equations of rotational motion for uniform angular acceleration
- Newton's second law applied to angular motion
- Conservation of angular momentum

Applications and skills:

- Calculating torque for single forces and couples
- Solving problems involving moment of inertia, torque and angular acceleration
- Solving problems in which objects are in both rotational and translational equilibrium

Theory of knowledge:

- Models are always valid within a context and they are modified, expanded or replaced when that context is altered or considered differently. Are there examples of unchanging models in the natural sciences or in any other areas of knowledge?

Utilization:

- Structural design and civil engineering rely on the knowledge of how objects can move in all situations

Aims:

- **Aim 7:** technology has allowed for computer simulations that accurately model the complicated outcomes of actions on bodies

B.1 – Rigid bodies and rotational dynamics	
• Solving problems using rotational quantities analogous to linear quantities • Sketching and interpreting graphs of rotational motion • Solving problems involving rolling without slipping **Guidance:** • Analysis will be limited to basic geometric shapes • The equation for the moment of inertia of a specific shape will be provided when necessary • Graphs will be limited to angular displacement–time, angular velocity–time and torque–time **Data booklet reference:** • $\Gamma = Fr\sin\theta$ • $I = \Sigma mr^2$ • $\Gamma = I\alpha$ • $\omega = 2\pi f$ • $\omega_f = \omega_i + \alpha t$ • $\omega_f^2 = \omega_i^2 + 2\alpha\theta$ • $\theta = \omega_i t + \frac{1}{2}\alpha t^2$ • $L = I\omega$ • $E_{K_{rot}} = \frac{1}{2}I\omega^2$	

Essential idea: The first law of thermodynamics relates the change in internal energy of a system to the energy transferred and the work done. The entropy of the universe tends to a maximum.

B.2 – Thermodynamics	
Nature of science: Variety of perspectives: With three alternative and equivalent statements of the second law of thermodynamics, this area of physics demonstrates the collaboration and testing involved in confirming abstract notions such as this. (4.1)	
Understandings: • The first law of thermodynamics • The second law of thermodynamics • Entropy • Cyclic processes and *pV* diagrams • Isovolumetric, isobaric, isothermal and adiabatic processes • Carnot cycle • Thermal efficiency **Applications and skills:** • Describing the first law of thermodynamics as a statement of conservation of energy • Explaining sign convention used when stating the first law of thermodynamics a $Q = \Delta U + W$ • Solving problems involving the first law of thermodynamics • Describing the second law of thermodynamics in Clausius form, Kelvin form and as a consequence of entropy	**International-mindedness:** • The development of this topic was the subject of intense debate between scientists of many countries in the 19th century **Utilization:** • This work leads directly to the concept of the heat engines that play such a large role in modern society • The possibility of the heat death of the universe is based on ever-increasing entropy • Chemistry of entropy (see *Chemistry* sub-topic *15.2*) **Aims:** • **Aim 5:** development of the second law demonstrates the collaboration involved in scientific pursuits • **Aim 10:** the relationships and similarities between scientific disciplines are particularly apparent here

B.2 – Thermodynamics	
• Describing examples of processes in terms of entropy change • Solving problems involving entropy changes • Sketching and interpreting cyclic processes • Solving problems for adiabatic processes for monatomic gases using $pV^{\frac{5}{3}} = \text{constant}$ • Solving problems involving thermal efficiency **Guidance:** • If cycles other than the Carnot cycle are used quantitatively, full details will be provided • Only graphical analysis will be required for determination of work done on a *pV* diagram when pressure is not constant **Data booklet reference:** • $Q = \Delta U + W$ • $U = \frac{3}{2}nRT$ • $\Delta S = \frac{\Delta Q}{T}$ • $pV^{\frac{5}{3}} = \text{constant}$ (for monatomic gases) • $W = p\Delta V$ • $\eta = \frac{\text{useful work done}}{\text{energy input}}$ • $\eta_{\text{Carnot}} = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}$	

Additional higher level option topics

10 hours

Essential idea: Fluids cannot be modelled as point particles. Their distinguishable response to compression from solids creates a set of characteristics that require an in-depth study.

B.3 – Fluids and fluid dynamics

Nature of science:

Human understandings: Understanding and modelling fluid flow has been important in many technological developments such as designs of turbines, aerodynamics of cars and aircraft, and measurement of blood flow. (1.1)

Understandings:

- Density and pressure
- Buoyancy and Archimedes' principle
- Pascal's principle
- Hydrostatic equilibrium
- The ideal fluid
- Streamlines
- The continuity equation
- The Bernoulli equation and the Bernoulli effect
- Stokes' law and viscosity
- Laminar and turbulent flow and the Reynolds number

Applications and skills:

- Determining buoyancy forces using Archimedes' principle
- Solving problems involving pressure, density and Pascal's principle
- Solving problems using the Bernoulli equation and the continuity equation

International-mindedness:

- Water sources for dams and irrigation rely on the knowledge of fluid flow. These resources can cross national boundaries leading to sharing of water or disputes over ownership and use.

Theory of knowledge:

- The mythology behind the anecdote of Archimedes' "Eureka!" moment of discovery demonstrates one of the many ways scientific knowledge has been transmitted throughout the ages. What role can mythology and anecdotes play in passing on scientific knowledge? What role might they play in passing on scientific knowledge within indigenous knowledge systems?

Utilization:

- Hydroelectric power stations
- Aerodynamic design of aircraft and vehicles
- Fluid mechanics is essential in understanding blood flow in arteries
- Biomechanics (see *Sports, exercise and health science SL* sub-topic *4.3*)

B.3 – Fluids and fluid dynamics	
• Explaining situations involving the Bernoulli effect • Describing the frictional drag force exerted on small spherical objects in laminar fluid flow • Solving problems involving Stokes' law • Determining the Reynolds number in simple situations **Guidance:** • Ideal fluids will be taken to mean fluids that are incompressible and non-viscous and have steady flows • Applications of the Bernoulli equation will involve (but not be limited to) flow out of a container, determining the speed of a plane (pitot tubes), and venturi tubes • Proof of the Bernoulli equation will not be required for examination purposes • Laminar and turbulent flow will only be considered in simple situations • Values of $R < 10^3$ will be taken to represent conditions for laminar flow **Data booklet reference:** • $B = \rho_f V_f g$ • $P = P_0 + \rho_f gd$ • $Av = \text{constant}$ • $\frac{1}{2}\rho v^2 + \rho gz + p = \text{constant}$ • $F_D = 6\pi\eta rv$ • $R = \frac{vr\rho}{\eta}$	**Aims:** • **Aim 2:** fluid dynamics is an essential part of any university physics or engineering course • **Aim 7:** the complexity of fluid dynamics makes it an ideal topic to be visualized through computer software

Essential idea: In the real world, damping occurs in oscillators and has implications that need to be considered.

B.4 – Forced vibrations and resonance	
Nature of science: Risk assessment: The ideas of resonance and forced oscillation have application in many areas of engineering ranging from electrical oscillation to the safe design of civil structures. In large-scale civil structures, modelling all possible effects is essential before construction. (4.8)	
Understandings: • Natural frequency of vibration • *Q* factor and damping • Periodic stimulus and the driving frequency • Resonance **Applications and skills:** • Qualitatively and quantitatively describing examples of under-, over- and critically-damped oscillations	**International-mindedness:** • Communication through radio and television signals is based on resonance of the broadcast signals **Utilization:** • Science and technology meet head-on when the real behaviour of damped oscillating systems is modelled

B.4 – Forced vibrations and resonance	
• Graphically describing the variation of the amplitude of vibration with driving frequency of an object close to its natural frequency of vibration • Describing the phase relationship between driving frequency and forced oscillations • Solving problems involving *Q* factor • Describing the useful and destructive effects of resonance **Guidance:** • Only amplitude resonance is required **Data booklet reference:** • $Q = 2\pi \frac{\text{energy stored}}{\text{energy dissipated per cycle}}$ • $Q = 2\pi \times \text{resonant frequency} \times \frac{\text{energy stored}}{\text{power loss}}$	**Aims:** • **Aim 6:** experiments could include (but are not limited to): observation of sand on a vibrating surface of varying frequencies; investigation of the effect of increasing damping on an oscillating system, such as a tuning fork; observing the use of a driving frequency on forced oscillations • **Aim 7:** to investigate the use of resonance in electrical circuits, atoms/molecules, or with radio/television communications is best achieved through software modelling examples

Core topics

15 hours

Essential idea: The progress of a wave can be modelled via the ray or the wavefront. The change in wave speed when moving between media changes the shape of the wave.

C.1 – Introduction to imaging

Nature of science:

Deductive logic: The use of virtual images is essential for our analysis of lenses and mirrors. (1.6)

Understandings:

- Thin lenses
- Converging and diverging lenses
- Converging and diverging mirrors
- Ray diagrams
- Real and virtual images
- Linear and angular magnification
- Spherical and chromatic aberrations

Applications and skills:

- Describing how a curved transparent interface modifies the shape of an incident wavefront
- Identifying the principal axis, focal point and focal length of a simple converging or diverging lens on a scaled diagram
- Solving problems involving not more than two lenses by constructing scaled ray diagrams

International-mindedness:

- Optics is an ancient study encompassing development made in the early Greco-Roman and medieval Islamic worlds

Theory of knowledge:

- Could sign convention, using the symbols of positive and negative, emotionally influence scientists?

Utilization:

- Microscopes and telescopes
- Eyeglasses and contact lenses

Aims:

- **Aim 3:** the theories of optics, originating with human curiosity of our own senses, continue to be of great value in leading to new and useful technology
- **Aim 6:** experiments could include (but are not limited to): magnification determination using an optical bench; investigating real and virtual images formed by lenses; observing aberrations

C.1 – Introduction to imaging	
• Solving problems involving not more than two curved mirrors by constructing scaled ray diagrams • Solving problems involving the thin lens equation, linear magnification and angular magnification • Explaining spherical and chromatic aberrations and describing ways to reduce their effects on images **Guidance:** • Students should treat the passage of light through lenses from the standpoint of both rays and wavefronts • Curved mirrors are limited to spherical and parabolic converging mirrors and spherical diverging mirrors • Only thin lenses are to be considered in this topic • The lens-maker's formula is not required • Sign convention used in examinations will be based on real being positive (the "real-is-positive" convention) **Data booklet reference:** • $\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$ • $P=\frac{1}{f}$ • $m=\frac{h_i}{h_o}=-\frac{v}{u}$ • $M=\frac{\theta_i}{\theta_o}$ • $M_{\text{near point}}=\frac{D}{f}+1;\ M_{\text{infinity}}=\frac{D}{f}$	

Essential idea: Optical microscopes and telescopes utilize similar physical properties of lenses and mirrors. Analysis of the universe is performed both optically and by using radio telescopes to investigate different regions of the electromagnetic spectrum.

C.2 – Imaging instrumentation

Nature of science:

Improved instrumentation: The optical telescope has been in use for over 500 years. It has enabled humankind to observe and hypothesize about the universe. More recently, radio telescopes have been developed to investigate the electromagnetic radiation beyond the visible region. Telescopes (both visual and radio) are now placed away from the Earth's surface to avoid the image degradation caused by the atmosphere, while corrective optics are used to enhance images collected at the Earth's surface. Many satellites have been launched with sensors capable of recording vast amounts of data in the infrared, ultraviolet, X-ray and other electromagnetic spectrum ranges. (1.8)

Understandings:

- Optical compound microscopes
- Simple optical astronomical refracting telescopes
- Simple optical astronomical reflecting telescopes
- Single-dish radio telescopes
- Radio interferometry telescopes
- Satellite-borne telescopes

Applications and skills:

- Constructing and interpreting ray diagrams of optical compound microscopes at normal adjustment
- Solving problems involving the angular magnification and resolution of optical compound microscopes
- Investigating the optical compound microscope experimentally
- Constructing or completing ray diagrams of simple optical astronomical refracting telescopes at normal adjustment

International-mindedness:

- The use of the radio interferometry telescope crosses cultures with collaboration between scientists from many countries to produce arrays of interferometers that span the continents

Theory of knowledge:

- However advanced the technology, microscopes and telescopes always involve sense perception. Can technology be used effectively to extend or correct our senses?

Utilization:

- Cell observation (see *Biology* sub-topic *1.2*)
- The information that the astronomical telescopes gather continues to allow us to improve our understanding of the universe
- Resolution is covered for other sources in *Physics* sub-topic *9.4*

C.2 – Imaging instrumentation	
• Solving problems involving the angular magnification of simple optical astronomical telescopes • Investigating the performance of a simple optical astronomical refracting telescope experimentally • Describing the comparative performance of Earth-based telescopes and satellite-borne telescopes **Guidance:** • Simple optical astronomical reflecting telescope design is limited to Newtonian and Cassegrain mounting • Radio interferometer telescopes should be approximated as a dish of diameter equal to the maximum separation of the antennae • Radio interferometry telescopes refer to array telescopes **Data booklet reference:** • $M = \frac{f_o}{f_e}$	**Aims:** • **Aim 3:** images from microscopes and telescopes both in the school laboratory and obtained via the internet enable students to apply their knowledge of these techniques • **Aim 5:** research astronomy and astrophysics is an example of the need for collaboration between teams of scientists from different countries and continents • **Aim 6:** local amateur or professional astronomical organizations can be useful for arranging demonstrations of the night sky

Essential idea: Total internal reflection allows light or infrared radiation to travel along a transparent fibre. However, the performance of a fibre can be degraded by dispersion and attenuation effects.

<table>
<tr><th colspan="2">C.3 – Fibre optics</th></tr>
<tr><td colspan="2">Nature of science:
Applied science: Advances in communication links using fibre optics have led to a global network of optical fibres that has transformed global communications by voice, video and data. (1.2)</td></tr>
<tr><td>Understandings:
• Structure of optic fibres
• Step-index fibres and graded-index fibres
• Total internal reflection and critical angle
• Waveguide and material dispersion in optic fibres
• Attenuation and the decibel (dB) scale
Applications and skills:
• Solving problems involving total internal reflection and critical angle in the context of fibre optics
• Describing how waveguide and material dispersion can lead to attenuation and how this can be accounted for
• Solving problems involving attenuation
• Describing the advantages of fibre optics over twisted pair and coaxial cables</td><td>International-mindedness:
• The under-sea optic fibres are a vital part of the communication between continents
Utilization:
• Will a communication limit be reached as we cannot move information faster than the speed of light?
Aims:
• Aim 1: this is a global technology that embraces and drives increases in communication speeds
• Aim 9: the dispersion effects illustrate the inherent limitations that can be part of a technology</td></tr>
</table>

C.3 – Fibre optics	
Guidance: • Quantitative descriptions of attenuation are required and include attenuation per unit length • The term *waveguide dispersion* will be used in examinations. Waveguide dispersion is sometimes known as *modal dispersion*. **Data booklet reference:** • $n = \frac{1}{\sin c}$ • $\text{attenuation} = 10 \log \frac{I}{I_0}$	

Additional higher level option topics

10 hours

Essential idea: The body can be imaged using radiation generated from both outside and inside. Imaging has enabled medical practitioners to improve diagnosis with fewer invasive procedures.

C.4 – Medical imaging

Nature of science:

Risk analysis: The doctor's role is to minimize patient risk in medical diagnosis and procedures based on an assessment of the overall benefit to the patient. Arguments involving probability are used in considering the attenuation of radiation transmitted through the body. (4.8)

Understandings:

- Detection and recording of X-ray images in medical contexts
- Generation and detection of ultrasound in medical contexts
- Medical imaging techniques (magnetic resonance imaging) involving nuclear magnetic resonance (NMR)

Applications and skills:

- Explaining features of X-ray imaging, including attenuation coefficient, half-value thickness, linear/mass absorption coefficients and techniques for improvements of sharpness and contrast
- Solving X-ray attenuation problems
- Solving problems involving ultrasound acoustic impedance, speed of ultrasound through tissue and air and relative intensity levels

International-mindedness:

- There is constant dialogue between research clinicians in different countries to communicate new methods and treatments for the good of patients everywhere
- Organizations such as *Médecins Sans Frontières* provide valuable medical skills in parts of the world where medical help is required

Theory of knowledge:

- "It's not what you look at that matters, it's what you see." – Henry David Thoreau. To what extent do you agree with this comment on the impact of factors such as expectation on perception?

Utilization:

- Scanning the human brain (see *Biology* sub-topic *A.4*)

C.4 – Medical imaging	
• Explaining features of medical ultrasound techniques, including choice of frequency, use of gel and the difference between A and B scans • Explaining the use of gradient fields in NMR • Explaining the origin of the relaxation of proton spin and consequent emission of signal in NMR • Discussing the advantages and disadvantages of ultrasound and NMR scanning methods, including a simple assessment of risk in these medical procedures **Guidance:** • Students will be expected to compute final beam intensity after passage through multiple layers of tissue. Only parallel plane interfaces will be treated. **Data booklet reference:** • $L_I = 10 \log \frac{I_1}{I_0}$ • $I = I_0 e^{-\mu x}$ • $\mu x_{\frac{1}{2}} = \ln 2$ • $Z = \rho c$	**Aims**: • **Aim 4:** there are many opportunities for students to analyse and evaluate scientific information • **Aim 8:** the social impact of these scientific techniques for the benefit of humankind cannot be over-emphasized • **Aim 10:** medicine and physics meet in the hi-tech world of scanning and treatment. Modern doctors rely on technology that arises from developments in the physical sciences.

Core topics

15 hours

Essential idea: One of the most difficult problems in astronomy is coming to terms with the vast distances between stars and galaxies and devising accurate methods for measuring them.

<table>
<tr><td colspan="2">D.1 – Stellar quantities</td></tr>
<tr><td colspan="2">Nature of science:
Reality: The systematic measurement of distance and brightness of stars and galaxies has led to an understanding of the universe on a scale that is difficult to imagine and comprehend. (1.1)</td></tr>
<tr><td>Understandings:
• Objects in the universe
• The nature of stars
• Astronomical distances
• Stellar parallax and its limitations
• Luminosity and apparent brightness
Applications and skills:
• Identifying objects in the universe
• Qualitatively describing the equilibrium between pressure and gravitation in stars
• Using the astronomical unit (AU), light year (ly) and parsec (pc)
• Describing the method to determine distance to stars through stellar parallax
• Solving problems involving luminosity, apparent brightness and distance</td>
<td>Theory of knowledge:
• The vast distances between stars and galaxies are difficult to comprehend or imagine. Are other ways of knowing more useful than imagination for gaining knowledge in astronomy?
Utilization:
• Similar parallax techniques can be used to accurately measure distances here on Earth
Aims:
• Aim 1: creativity is required to analyse objects that are such vast distances from us
• Aim 6: local amateur or professional astronomical organizations can be useful for arranging viewing evenings
• Aim 9: as we are able to observe further into the universe, we reach the limits of our current technology to make accurate measurements</td></tr>
</table>

D.1 – Stellar quantities	
Guidance: • For this course, objects in the universe include planets, comets, stars (single and binary), planetary systems, constellations, stellar clusters (open and globular), nebulae, galaxies, clusters of galaxies and super clusters of galaxies • Students are expected to have an awareness of the vast changes in distance scale from planetary systems through to super clusters of galaxies and the universe as a whole **Data booklet reference:** • $d\,(\text{parsec}) = \frac{1}{p\,(\text{arc–second})}$ • $L = \sigma A T^4$ • $b = \frac{L}{4\pi d^2}$	

Essential idea: A simple diagram that plots the luminosity versus the surface temperature of stars reveals unusually detailed patterns that help understand the inner workings of stars. Stars follow well-defined patterns from the moment they are created out of collapsing interstellar gas, to their lives on the main sequence and to their eventual death.

D.2 – Stellar characteristics and stellar evolution

Nature of science:

Evidence: The simple light spectra of a gas on Earth can be compared to the light spectra of distant stars. This has allowed us to determine the velocity, composition and structure of stars and confirmed hypotheses about the expansion of the universe. (1.11)

Understandings:

- Stellar spectra
- Hertzsprung–Russell (HR) diagram
- Mass–luminosity relation for main sequence stars
- Cepheid variables
- Stellar evolution on HR diagrams
- Red giants, white dwarfs, neutron stars and black holes
- Chandrasekhar and Oppenheimer–Volkoff limits

Applications and skills:

- Explaining how surface temperature may be obtained from a star's spectrum
- Explaining how the chemical composition of a star may be determined from the star's spectrum
- Sketching and interpreting HR diagrams
- Identifying the main regions of the HR diagram and describing the main properties of stars in these regions
- Applying the mass–luminosity relation
- Describing the reason for the variation of Cepheid variables
- Determining distance using data on Cepheid variables
- Sketching and interpreting evolutionary paths of stars on an HR diagram
- Describing the evolution of stars off the main sequence
- Describing the role of mass in stellar evolution

Theory of knowledge:

- The information revealed through spectra needs a trained mind to be interpreted. What is the role of interpretation in gaining knowledge in the natural sciences? How does this differ from the role of interpretation in other areas of knowledge?

Utilization:

- An understanding of how similar stars to our Sun have aged and evolved assists in our predictions of our fate on Earth

Aims:

- **Aim 4:** analysis of star spectra provides many opportunities for evaluation and synthesis
- **Aim 6:** software-based analysis is available for students to participate in astrophysics research

D.2 – Stellar characteristics and stellar evolution	
Guidance: • Regions of the HR diagram are restricted to the main sequence, white dwarfs, red giants, super giants and the instability strip (variable stars), as well as lines of constant radius • HR diagrams will be labelled with luminosity on the vertical axis and temperature on the horizontal axis • Only one specific exponent (3.5) will be used in the mass–luminosity relation • References to electron and neutron degeneracy pressures need to be made **Data booklet reference:** • $\lambda_{max} T = 2.9 \times 10^{-3}$ m K • $L \propto M^{3.5}$	

Essential idea: The Hot Big Bang model is a theory that describes the origin and expansion of the universe and is supported by extensive experimental evidence.

D.3 – Cosmology

Nature of science:

Occam's Razor: The Big Bang model was purely speculative until it was confirmed by the discovery of the cosmic microwave background radiation. The model, while correctly describing many aspects of the universe as we observe it today, still cannot explain what happened at time zero. (2.7)

Understandings:

- The Big Bang model
- Cosmic microwave background (CMB) radiation
- Hubble's law
- The accelerating universe and redshift (*z*)
- The cosmic scale factor (*R*)

Applications and skills:

- Describing both space and time as originating with the Big Bang
- Describing the characteristics of the CMB radiation
- Explaining how the CMB radiation is evidence for a Hot Big Bang
- Solving problems involving *z*, *R* and Hubble's law
- Estimating the age of the universe by assuming a constant expansion rate

International-mindedness:

- Contributions from scientists from many nations made the analysis of the cosmic microwave background radiation possible

Utilization:

- Doppler effect (see *Physics* sub-topic *9.5*)

Aims:

- **Aim 1:** scientific explanation of black holes requires a heightened level of creativity
- **Aim 9:** our limit of understanding is guided by our ability to observe within our universe

D.3 – Cosmology

Guidance:

- CMB radiation will be considered to be isotropic with $T \approx 2.76\text{K}$
- For CMB radiation a simple explanation in terms of the universe cooling down or distances (and hence wavelengths) being stretched out is all that is required
- A qualitative description of the role of type Ia supernovae as providing evidence for an accelerating universe is required

Data booklet reference:

- $z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$
- $z = \frac{R}{R_0} - 1$
- $v = H_0 d$
- $T \approx \frac{1}{H_0}$

Additional higher level option topics

10 hours

Essential idea: The laws of nuclear physics applied to nuclear fusion processes inside stars determine the production of all elements up to iron.

D.4 – Stellar processes	
Nature of science: Observation and deduction: Observations of stellar spectra showed the existence of different elements in stars. Deductions from nuclear fusion theory were able to explain this. (1.8)	
Understandings: • The Jeans criterion • Nuclear fusion • Nucleosynthesis off the main sequence • Type Ia and II supernovae **Applications and skills:** • Applying the Jeans criterion to star formation • Describing the different types of nuclear fusion reactions taking place off the main sequence • Applying the mass–luminosity relation to compare lifetimes on the main sequence relative to that of our Sun • Describing the formation of elements in stars that are heavier than iron including the required increases in temperature • Qualitatively describe the s and r processes for neutron capture • Distinguishing between type Ia and II supernovae	**Aims:** • **Aim 10:** analysis of nucleosynthesis involves the work of chemists

D.4 – Stellar processes	
Guidance: • Only an elementary application of the Jeans criterion is required, ie collapse of an interstellar cloud may begin if $M > M_j$ • Students should be aware of the use of type Ia supernovae as standard candles	

Essential idea: The modern field of cosmology uses advanced experimental and observational techniques to collect data with an unprecedented degree of precision and as a result very surprising and detailed conclusions about the structure of the universe have been reached.

D.5 – Further cosmology

Nature of science:

Cognitive bias: According to everybody's expectations the rate of expansion of the universe should be slowing down because of gravity. The detailed results from the 1998 (and subsequent) observations on distant supernovae showed that the opposite was in fact true. The accelerated expansion of the universe, whereas experimentally verified, is still an unexplained phenomenon. (3.5)

Understandings:

- The cosmological principle
- Rotation curves and the mass of galaxies
- Dark matter
- Fluctuations in the CMB
- The cosmological origin of redshift
- Critical density
- Dark energy

Applications and skills:

- Describing the cosmological principle and its role in models of the universe
- Describing rotation curves as evidence for dark matter
- Deriving rotational velocity from Newtonian gravitation
- Describing and interpreting the observed anisotropies in the CMB
- Deriving critical density from Newtonian gravitation
- Sketching and interpreting graphs showing the variation of the cosmic scale factor with time
- Describing qualitatively the cosmic scale factor in models with and without dark energy

International-mindedness:

- This is a highly collaborative field of research involving scientists from all over the world

Theory of knowledge:

- Experimental facts show that the expansion of the universe is accelerating yet no one understands why. Is this an example of something that we will never know?

Aims:

- **Aim 2:** unlike how it was just a few decades ago, the field of cosmology has now developed so much that cosmology has become a very exact science on the same level as the rest of physics
- **Aim 10:** it is quite extraordinary that to settle the issue of the fate of the universe, cosmology, the physics of the very large, required the help of particle physics, the physics of the very small

D.5 – Further cosmology

Guidance:

- Students are expected to be able to refer to rotation curves as evidence for dark matter and must be aware of types of candidates for dark matter
- Students must be familiar with the main results of COBE, WMAP and the Planck space observatory
- Students are expected to demonstrate that the temperature of the universe varies with the cosmic scale factor as $T \propto \frac{1}{R}$

Data booklet reference:

- $v = \sqrt{\frac{4\pi G\rho}{3}}r$
- $\rho_c = \frac{3H^2}{8\pi G}$

Assessment outline—SL

First assessment 2016

Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)
		1+2	3	
Paper 1	20	10	10	¾
Paper 2	40	20	20	1¼
Paper 3	20	10	10	1
Internal assessment	20	Covers objectives 1, 2, 3 and 4		10

Assessment outline—HL

First assessment 2016

Component	Overall weighting (%)	Approximate weighting of objectives (%)		Duration (hours)
		1+2	3	
Paper 1	20	10	10	1
Paper 2	36	18	18	2¼
Paper 3	24	12	12	1¼
Internal assessment	20	Covers objectives 1, 2, 3 and 4		10

External assessment

The method used to assess students is the use of detailed markschemes specific to each examination paper.

External assessment details—SL

Paper 1

Duration: 3/4 hour
Weighting: 20%
Marks: 30

- 30 multiple-choice questions on core, about 15 of which are common with HL.
- The questions on paper 1 test assessment objectives 1, 2 and 3.
- The use of calculators is not permitted.
- No marks are deducted for incorrect answers.
- A physics data booklet is provided.

Paper 2

Duration: 1¼ hours
Weighting: 40%
Marks: 50

- Short-answer and extended-response questions on core material.
- The questions on paper 2 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)
- A physics data booklet is provided.

Paper 3

Duration: 1 hour
Weighting: 20%
Marks: 35

- This paper will have questions on core and SL option material.
- Section A: one data-based question and several short-answer questions on experimental work.
- Section B: short-answer and extended-response questions from one option.
- The questions on paper 3 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)
- A physics data booklet is provided.

External assessment details—HL

Paper 1

Duration: 1 hour
Weighting: 20%
Marks: 40

- 40 multiple-choice questions on core and AHL, about 15 of which are common with SL.
- The questions on paper 1 test assessment objectives 1, 2 and 3.
- The use of calculators is not permitted.
- No marks are deducted for incorrect answers.
- A physics data booklet is provided.

Paper 2

Duration: 2¼ hours
Weighting: 36%
Marks: 95

- Short-answer and extended-response questions on the core and AHL material.
- The questions on paper 2 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)
- A physics data booklet is provided.

Paper 3

Duration: 1¼ hours
Weighting: 24%
Marks: 45

- This paper will have questions on core, AHL and option material.
- Section A: one data-based question and several short-answer questions on experimental work.
- Section B: short-answer and extended-response questions from one option.
- The questions on paper 3 test assessment objectives 1, 2 and 3.
- The use of calculators is permitted. (See calculator section on the OCC.)
- A physics data booklet is provided.