TAUNTON SCHOOL

Year 12 Syllabus in a nutshell

IB Physics SL & HL

Year 12 Syllabus in a nutshell – IB Physics SL & HL

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.

<table>
<tr><th colspan="2">1.1 – Measurements in physics p1-6</th></tr>
<tr><td colspan="2">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)</td></tr>
<tr><td>Understandings:
• Fundamental and derived SI units
• Scientific notation and metric multipliers
• Significant figures
• Orders of magnitude
• Estimation
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, $MeVc^{-2}$, 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</td>
<td>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?
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</td></tr>
</table>

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 p7-20

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

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 $\Delta y = \Delta a \pm \Delta b$

If $y = abc$
then $\frac{\Delta y}{y} = \frac{\Delta a}{a} \pm \frac{\Delta b}{b} + \frac{\Delta c}{c}$

If $y = a^n$
then $\frac{\Delta y}{y} = |n \frac{\Delta a}{a}|$

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

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 p21-31

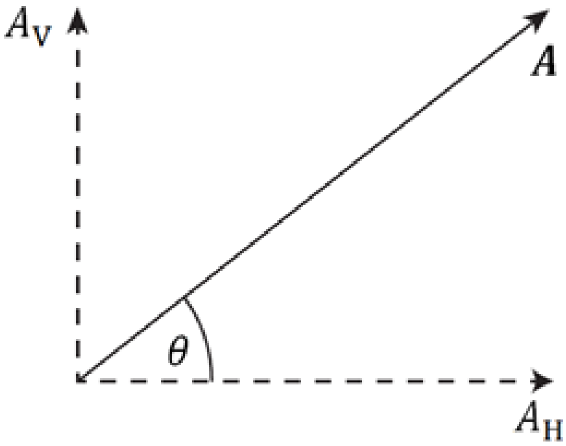
Nature of science:
Models: First mentioned explicitly in a scientific paper in 1846, scalars and vectors reflected the work of scientists and mathematicians across the globe for over 300 years on representing measurements in three-dimensional space. (1.10)

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

Data booklet reference:



$A_H = A\cos\vartheta$

$A_V = A\sin\vartheta$

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)

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 p35-56

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

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:

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

$$s = \frac{(v + u)t}{2}$$

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

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

REQUIRED PRACTICAL

Determining the acceleration of free-fall

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 p57-77

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

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:

$F = ma$

$F_f \leq \mu_s R$

$F_f = \mu_d R$

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)

***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 p78-97

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

Data booklet reference:

$W = Fs\cos\vartheta$

$E_K = \frac{1}{2}mv^2$

$E_P = \frac{1}{2}k\Delta x^2$

$\Delta E_P = mg\Delta h$

$Power = Fv$

$$\text{Efficiency} = \frac{\text{useful work out}}{\text{total work in}} = \frac{\text{useful power out}}{\text{total power in}}$$

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)

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 p98-109

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*:**

- 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

Guidance:

- Students should be aware that F = ma is equivalent of F=Δp/Δt 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:

$p = mv$

$F = \Delta p/\Delta t$

$E_K = p^2/2m$

$Impulse = F\Delta t = \Delta p$

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)

***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 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 p249-258

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 programmes

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 and11.3)
- 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 p259-264

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:

$F = GMm/r^2$

$g = Fm$

$g = GM/r^2$

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 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 p146-152

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

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:

$T = 1/f$

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?

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: 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 p346-360

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:
- 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

Data booklet reference:

$\omega = 2\pi T$

$a = -\omega^2 x$

$x = x_0 \sin \omega t;\ x = x_0 \cos \omega t$

$v = \omega x_0 \cos \omega t;\ v = -\omega x_0 \sin \omega t$

$v = \pm\omega\sqrt{(x_o{}^2 - x^2)}$

$E_K = \frac{1}{2} m\omega^2 (x_o{}^2 - x^2)$

$E_T = \frac{1}{2} m\omega^2 x_o{}^2$

Pendulum: $T = 2\pi\sqrt{\frac{l}{g}}$

Mass–spring: $T = 2\pi\sqrt{\frac{m}{k}}$

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-topic3.4)

Aims:
- 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: 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.

<table>
<tr><td colspan="2">4.2 – Travelling waves p153-161</td></tr>
<tr><td colspan="2">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)</td></tr>
<tr><td>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=fλ
• 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:
$c = f\lambda$</td>
<td>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 2and 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

REQUIRED PRACTICAL
Investigating the speed of sound</td></tr>
</table>

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 p172-181

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:

$I \propto A^2$

$I \propto x^{-2}$

$I = I_0 cos2\vartheta$

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 p172-181

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

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:

$$\frac{n_1}{n_2} = \frac{sin\theta_1}{sin\theta_2} = \frac{v_2}{v_1}$$

$$s = \frac{\lambda D}{d}$$

Constructive interference:
path difference = $n\lambda$

Destructive interference:
path difference = $(n + ½)\lambda$

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.

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

REQUIRED PRACTICAL
Determining refractive index

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

9.3 – Interference p365-375

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

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:

$n\lambda = d\sin\vartheta$

Constructive interference: $2dn = (m + \frac{1}{2})\lambda$

Destructive interference: $2dn = m\lambda$

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

REQUIRED PRACTICAL
Investigating Young's Double Slit (HL Only)

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 p361-364	
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) • 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:** $\vartheta = \lambda / b$	**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

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

4.5 – Standing waves p182-189

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
- 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

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

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

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 p376-380

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:

$\vartheta = 1.22\,\lambda/b$

$R = \lambda/\Delta\lambda = mN$

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 p381-389

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: $f' = f\left(\frac{v \pm u_o}{v}\right)$

$$\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}$$

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 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 p116-125

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

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:

$Q=mc\Delta T$

$Q=mL$

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 Physicstopic 9 and option sub-topic B.4)
- Particulate nature of matter (see Chemistry sub-topic 1.3) and measuring energy changes (see Chemistrysub-topic 5.1)
- Water (see Biology sub-topic 2.2)

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

REQUIRED PRACTICAL

Applying the calorimetric techniques of specific heat capacity or specific latent heat

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

3.2 – Modeling a gas p126-141

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

Data booklet reference:

$p = F/A$

$n = N/N_A$

$pV = nRT$

$$\overline{E_K} = \frac{3}{2}k_B T = \frac{3}{2}\frac{R}{N_A}T$$

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-topic1.3)
- 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

REQUIRED PRACTICAL

Investigating at least one gas law

Topic 5: Electricity and magnetism (15 hours)

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

5.1 – Electric fields p196-206

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 electron volts
- 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

Guidance:

- Students will be expected to apply Coulomb's law for a range of permittivity values

Data booklet reference:

$I = \Delta q/\Delta t$

$$F = k\frac{q_1 q_2}{r^2}$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

$V = W/q$

$E = F/q$

$I = nAvq$

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)

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 p207-226

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=VI
- 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

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:

$\sum V = 0$ *(loop)*

$\sum I = 0$ *(junction)*

$R = VI$

$P = VI = I^2R = V^2R$

$R_{total} = R_1 + R_2 + \cdots$

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

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

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$$ *ρ = RA/L* • Refer to electrical symbols on page 4 of the physics data booklet	***REQUIRED PRACTICAL*** *Investigating factors that affect resistance*

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

5.3 – Electric cells p227-231

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 have been through collaboration with chemists

REQUIRED PRACTICAL

Determining internal resistance

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 p232-242

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 charge

Guidance:

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

Data booklet reference:

$F = qvB\sin\vartheta$

$F = BIL\sin\vartheta$

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 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 p396-414

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

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:
- $W = q\Delta V_e$

  $W = m\Delta V_g$

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

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

10.2 – Fields at work p415-427

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

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:

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

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

$$V_{orbit} = \sqrt{\frac{GM}{r}}$$

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

Topic 7: Atomic, nuclear and particle physics (14 hours)

Essential idea: In the microscopic world energy is discrete.

7.1 – Discrete energy and radioactivity p270-284

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

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:

$E = hf$

$\lambda = hc/E$

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?

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

REQUIRED PRACTICAL

Investigating half-life

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 p285-294

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

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:

$\Delta E = \Delta mc^2$

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)

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 are 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 p295-308

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
- 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:

Charge	Quarks			Baryon number
2/3 e	u	c	t	1/3
−1/3 e	d	s	b	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	υ_e	υ_μ	υ_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

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
- Aim 8: scientific and government organizations are asked if the funding for particle physics research could be spent on other research or social needs