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:

- 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