Strand 1: Forces and Motion: Kinematics and Dynamics

In this strand, students learn about Newtonian mechanics as a successful physical theory that explains the motion of objects. They explore how objects move (kinematics) and the reason why objects move in the way they do (dynamics). They use the verbal, mathematical and graphical language of kinematics to discuss and explain motion in one dimension as well as motion in a circle.

They are introduced to Newton’s three laws of motion as valid mathematical models with underlying assumptions that accurately model systems as diverse as the planets of the solar system and helium atoms in a container. They learn how experiments and observations have confirmed the validity of Newtonian mechanics in many circumstances, but that the validity breaks down for objects moving close to the speed of light, or objects at the subatomic scale. In strand 4 they will learn how quantum mechanics is a more appropriate model when considering objects at the subatomic scale.

Given the central role that forces play in Newton’s laws of motion, students explore forces common in everyday life such as weight, tension, friction, buoyancy and air resistance. They learn how to model a situation in which more than one force is acting on an object and how to find the resultant of those forces. In strands 2 and 3 they will see how many of these everyday forces can also be modelled as gravitational and electromagnetic interactions, two of the four fundamental forces in nature.

The concept of energy as one of the most fundamental concepts in science, is considered in the context of Newtonian mechanics. Students understand that conservation of energy is an essential principle in physics and explore how the concept of work, as a means of transferring energy through the application of a force, links energy and force. They learn how in certain situations, the concepts of work and energy can be applied to solve the dynamics of a mechanical system without directly resorting to Newton’s laws. Students learn how this work-energy approach often provides a much simpler analysis than that obtained from the direct application of Newton’s Laws since it deals with scalar rather than vector quantities. Beyond this strand, they learn how this problem-solving approach focusing on energy can be applied to a range of phenomena in electromagnetism, and thermal and nuclear physics.

Strand 1 Learning Outcomes

Students learn about	Students should be able to
1.1. Particle motion in a straight line • basic concepts for describing the motion of a particle; displacement, velocity, acceleration and time. • relationships between the concepts; $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$	1. model motion of a particle in a straight line 2. investigate constant and varying linear motion using primary and secondary data
• graphical representation and interpretation: displacement-time graphs, velocity-time graphs • the kinematics equations under constant acceleration $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ • identifying and representing scalar and vector quantities • **resolving vectors into perpendicular components** • **calculating the resultant of two vectors**	3. **derive the kinematic equations** 4. **verify the law of addition of vectors using primary and secondary data in one and two dimensions**
1.2. Forces acting on a particle • Newton's 3 laws of motion • the concepts of mass, centre of mass and a force as a vector quantity • types of forces: Normal, Frictional, Resistant, Tension, Buoyancy, Gravitational • resultant force as the sum of all forces • $P = \frac{F}{A}$; in fluids $P = h\rho g$ • the concept of density $\rho = \frac{m}{v}$ • the concept of momentum $p = mv$ • collisions as governed by Newton's laws of motion and by conservation of momentum	1. model real-world situations using Newton's laws of motion 2. verify Newton's 2nd law of motion $F_{net} = ma$ using primary and secondary data 3. model problems involving the motion of a particle under a constant resultant force 4. solve problems relating to solids resting on a surface and pressure within fluids 5. investigate density 6. investigate the principle of conservation of momentum using primary and secondary data 7. verify using secondary data that collisions are governed by Newton's laws of motion 8. model direct collisions in one dimension **and in two dimensions using perpendicular and parallel components**

1.3. Stretching and compressing objects

- stretching and compressing objects
  - Hooke's law; $F = -ks$

1. investigate the force needed to compress or stretch an object using primary and secondary data
2. verify Hooke's law for elastic objects using primary and secondary data
3. solve problems involving compressed and stretched materials

1.4. A work-energy model for analysing particle motion

- $E_P = mgh$
- $E_k = \frac{1}{2}mv^2$
- $W = Fs$
- $P = \frac{W}{t}$
- **Work done in stretching or compressing** $\boldsymbol{E_P = \frac{1}{2}ks^2}$
- the principle of conservation of energy

1. define work done by a constant force
2. model real life situations describing gravitational potential energy, **elastic potential energy**, kinetic energy, work done and the rate of doing work
3. **solve problems involving compressed and stretched materials**
4. investigate the principle of conservation of energy using primary and secondary data
5. apply the principle of conservation of energy to real life situations

1.5. Forces acting in a gravitational field

- mathematical models for g the acceleration due to gravity

$$\boldsymbol{g = 4\pi^2 \frac{1}{T^2}} \qquad g = \frac{2s}{t^2} \qquad g = \frac{Gm}{r^2} \qquad g = \frac{P}{h\rho}$$

- Newton's law of Universal Gravitation as an inverse square law

$$F = \frac{Gm_1 m_2}{r^2}$$

$$\boldsymbol{v_e = \sqrt{\frac{2GM}{r}}}$$

1. verify at least one model to determine g using primary data and all four using secondary data
2. model the gravitational field strength at any point in a gravitational field, including at the surface of a planet
3. **calculate escape velocity from celestial bodies**

1.6. Uniform circular motion

- **the centripetal force required to maintain uniform motion in a circle**

$$\boldsymbol{F = \frac{mv^2}{r}}$$

- **evidence that the force of gravity meets the centripetal force requirements for planetary motion**

$$\boldsymbol{T^2 = \frac{4\pi^2 R^3}{GM}}$$

- relate the orbits of satellites to their uses

1. **explain centripetal force**
2. **model the dynamics of an object moving in a circle with constant angular velocity**
3. **verify Kepler's 3rd law using secondary data**
4. model situations involving the orbits of planets and satellites in near Earth and geostationary orbits