Motion

Subtopic 1.1: Projectile motion

Explanation of the difference between scalar and vector quantities and methods of measurement of these quantities is covered in Stage 1, Topic 1: Linear motion and forces.

This subtopic uses the concept of acceleration developed in Stage 1, Subtopic 1.1: Motion under constant acceleration.

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| Uniformly accelerated motion is described in terms of relationships between measurable scalar and vector quantities, including displacement, speed, velocity, and acceleration.Motion under constant acceleration can be described quantitatively using the following formulae:*
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Projectile motion can be analysed quantitatively by treating the horizontal and vertical components of the motion independently.* Construct, identify, and label displacement, velocity, and acceleration vectors.
* Resolve velocity into vertical and horizontal components, using  and  for the horizontal and vertical components respectively.
* Solve problems using the constant acceleration formulae.
* Use vector addition and trigonometric calculations to determine the magnitude and direction of the velocity of a projectile at any moment of time.
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| An object experiences a constant gravitational force near the surface of the Earth, which causes it to undergo uniform acceleration.* Explain that, in the absence of air resistance, the horizontal component of the velocity is constant.
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| The motion formulae are used to calculate measurable quantities for objects undergoing projectile motion. * Calculate the time of flight when a projectile is launched horizontally.
* Calculate the time of flight and the maximum height for a projectile when the launch height is the same as the landing height.
* Calculate the horizontal range of a projectile when it is launched horizontally or when the launch height is the same as the landing height (or the flight time is given).
* Determine the velocity of a projectile at any time using trigonometric calculations or vector addition.
* Explain qualitatively that the maximum range occurs at a launch angle of 45° for projectiles that land at the same height from which they were launched.
* Describe the relationship between launch angles that result in the same range.
* Describe and explain the effect of launch height, speed, and angle on the time of flight and the maximum range of a projectile.
* Analyse multi-image representations of projectile paths.
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| When a body moves through a medium such as air, the body experiences a drag force that opposes the motion of the body.* Explain the effects of speed, cross-sectional area, and density of the medium on the drag force on a moving body.
* Explain that terminal velocity occurs when the magnitude of the drag force results in zero net force on the moving body.
* Describe situations such as skydiving and the maximum speed of racing cars where terminal velocity is achieved.
* Describe and explain the effects of air resistance on the vertical and horizontal components of the velocity, maximum height, and range of a projectile.
* Describe and explain the effects of air resistance on the time for a projectile to reach the maximum height or to fall from the maximum height.
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Subtopic 1.2: Forces and momentum

Many of these ideas have been introduced in Stage 1 through one-dimensional situations. The focus here should be on two-dimensional situations.

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| Momentum is a property of moving objects and is defined as the product of the mass and the velocity of the object. It is conserved in an isolated system and may be transferred from one object to other objects when a force acts over a time interval.Kinetic energy is a property of moving objects, and is given by the formula $E\_{k}=\frac{1}{2}mv^{2}$Newton’s Second Law of Motion can be expressed as two formulae,  and , where  is the momentum of the object.* Derive  by substituting the defining formula for acceleration  into Newton’s Second Law of Motion,  for particles of fixed mass. (The net force,  and hence the acceleration,  are assumed to be constant. Otherwise, average or instantaneous quantities apply.)
* Draw vector diagrams in which the initial momentum is subtracted from the final momentum, giving the change in momentum, .
* Solve problems (in both one dimension and two dimensions) using the formulae   and .
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| Newton’s Third Law of Motion,  in conjunction with the Second Law expressed in terms of momentum, implies that the total momentum of a system of two interacting particles, subject only to the force of each one on the other, is conserved.* Derive a formula expressing the conservation of momentum for two interacting particles by substituting
* Use the law of the conservation of momentum to solve problems in one and two dimensions.
* Analyse multi-image representations to solve conservation of momentum problems, using only situations in which the mass of one object is an integral multiple of the mass of the other object(s). The scale of the representations and the flash rate can be ignored.

The conservation of momentum can be used to explain the propulsion of spacecraft, ion thrusters, and solar sails.* Use the conservation of momentum to describe and explain the change in momentum and acceleration of spacecraft due to the emission of gas particles or ionised particles.
* Use the conservation of momentum to describe and explain how the reflection of particles of light (photons) can be used to accelerate a solar sail.
* Use vector diagrams to compare the acceleration of a spacecraft, using a solar sail where photons are reflected with the acceleration of a spacecraft, using a solar sail where photons are absorbed.
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Subtopic 1.3: Circular motion and gravitation

This uses the concepts of acceleration and force developed in Stage 1, Subtopics 1.1: Motion under constant acceleration and 1.2: Forces.

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| Centripetal acceleration occurs when the acceleration of an object is perpendicular to the velocity of the of the object. An object that experiences centripetal acceleration undergoes uniform circular motion. The centripetal acceleration is directed towards the centre of the circular path.The magnitude of the centripetal acceleration is constant for a given speed and radius and given by .The formula  relates the speed, v, to the period, T, for an object undergoing circular motion with radius, *r*.* Solve problems involving the use of the formulae   and .
* Use vector subtraction to show that the change in the velocity, and hence the acceleration, of an object over a very small time interval is directed towards the centre of the circular path.

On a flat curve, the friction force between the tyres and the road causes the centripetal acceleration. To improve safety, some roads are banked at an angle above the horizontal.* Draw a diagram showing the force vectors (and their components) for a vehicle travelling around a flat curve and around a banked curve.
* Explain how a banked curve reduces the reliance on friction to provide centripetal acceleration.
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| Objects with mass produce a gravitational field in the space that surrounds them. An object with mass experiences a gravitational force when it is within the gravitational field of another mass. Gravitational field strength, g, is defined as the net force per unit mass at a particular point in the field.This definition is expressed quantitatively as  hence it is equal to the acceleration due to gravity. The magnitude of the acceleration due to gravity at the surface of the Earth is 9.80 m s–2.* Explain that the acceleration of a projectile is always downwards and independent of its mass.

All objects with mass attract one another with a gravitational force; the magnitude of this force can be calculated using Newton’s law of universal gravitation.Every particle in the universe attracts every other particle with a force that is directly proportional to the product of the two masses and inversely proportional to the square of the distance between them.The force between two masses,  separated by distance, r, is given by:* Solve problems using Newton’s Universal Law of Gravitation.
* Use proportionality to discuss changes in the magnitude of the gravitational force on each of the masses as a result of a change in one or both of the masses and/or a change in the distance between them.
* Explain that the gravitational forces are consistent with Newton’s Third Law.
* Use Newton’s Law of Universal Gravitation and Second Law of Motion to calculate the value of the acceleration due to gravity, g, on a planet or moon.
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| Many satellites orbit the Earth in circular orbits.* Explain why the centres of the circular orbits of Earth satellites must coincide with the centre of the Earth.
* Explain that the speed, and hence the period, of a satellite moving in a circular orbit depends only on the radius of the orbit and the mass of the central body (m2) about which the satellite is orbiting and not on the mass of the satellite.
* Derive the formula for the speed, v, of a satellite moving in a circular orbit of radius, r, about a spherically symmetric mass, M, given that its gravitational effects are the same as if all its mass were located at its centre.

Kepler’s Laws of Planetary Motion describe the motion of planets, their moons, and other satellites.Kepler’s First Law of planetary motion: All planets move in elliptical orbits with the Sun at one focus.Kepler’s Second Law of Planetary Motion: The radius vector drawn from the Sun to a planet sweeps equal areas in equal time intervals.* Use Kepler’s first two Laws to solve problems involving the motion of comets, planets, moons, and other satellites.
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| Kepler’s Third Law of Planetary Motion shows that the period of any satellite depends upon the radius of its orbit.For circular orbits, Kepler’s Third Law can be expressed as: .* Derive:

.* Solve problems using the mathematical form of Kepler’s Third Law for circular orbits.
* Solve problems involving the use of the formulae  and .
* Explain why a satellite in a geostationary orbit must have an orbit in the Earth’s equatorial plane, with a relatively large radius and in the same direction as the Earth’s rotation.
* Explain the differences between polar, geostationary, and equatorial orbits. Justify the use of each orbit for different applications.
* Perform calculations involving orbital periods, radii, altitudes above the surface, and speeds of satellites, including examples that involve the orbits of geostationary satellites.
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