UNIT 4 Motion and Force (M1)

Recommended Prior Knowledge. Students will need to have covered Unit 2 (Coordinate Geometry and Calculus) and it would be helpful, though not essential, if at least part of Unit 3 (Vectors) had also been completed. It is expected that all students have a basic knowledge of speed and that some will have worked with distance-time graphs and maybe velocity-time graphs.

Context. Ideally this Unit needs to follow Units 2 and 3. The topic of resolution and composition of forces is a difficult concept to grasp but is the basis of all future work on mechanics. Students will need to work through a large number of different examples, since understanding in mechanics cannot be replaced by stereotyping of examples. The idea of a particle is introduced and students must become familiar with realistic situations in which, for example a car might be treated as a particle. Particularly with good groups of students, the modelling context of each situation in this Unit should be emphasised. Students should be aware that there is considerable simplification in this Unit, and that the study of mechanics is a continuing one leading eventually to consideration of all the approximations being used at this simple level. This unit is worth roughly 30% of the AS assessment, compared with only 10% for Unit 5 (Energy, Work and Power).

Outline. This Unit looks at the fundamental ideas behind motion in a straight line. Following a study of velocity and acceleration, both constant and variable, the Unit looks at Newton's three laws of motion and the relationship between force and acceleration. It deals with the composition of force and looks at simple cases of motion in a straight line under gravity and simple cases of motion and equilibrium on an inclined plane. It concludes with a more detailed study of Newton's third law of motion in dealing with two connected particles.

Topic	Learning Outcomes	Suggested Teaching Activities	Resources	On-Line Resources
2	**Kinematics of motion in a straight line** • Understand the concepts of distance and speed as scalar quantities, and of displacement, velocity and acceleration as vector quantities (in one-dimension only).	An introduction to mechanics should emphasise the difference between statics and dynamics. Students will have only sketchy understanding of the terms distance, displacement, speed, velocity and acceleration. It is useful to emphasise the difference between vector and scalar quantities. Discuss the fact that displacement, velocity and acceleration can take values which may be positive or negative, whereas distance and speed can never be negative. [Deceleration is also a scalar quantity – the magnitude of the acceleration when the acceleration and velocity are of opposite signs]. Students should be familiar with the ideas that the distance between A and B is $\|\mathbf{d}_A - \mathbf{d}_B\|$, and that speed is the magnitude of the velocity.		

	• Sketch and interpret displacement-time graphs and in particular appreciate that the gradient of the graph represents velocity. • Sketch and interpret velocity-time graphs and in particular appreciate that the area under the graph represents distance and that the gradient of the graph represents acceleration. • Use differentiation and integration with respect to time to solve simple problems concerning displacement, velocity and acceleration (restricted to calculus within the scope of Unit P1).	Students should understand the basic definitions of velocity and acceleration as rate of change of distance and velocity with respect to time. They should be encouraged to draw displacement-time graphs and to calculate the velocity at a particular time by calculation of the gradient. Such exercises should include cases in which the displacement is at times negative and cases in which the gradient is at times negative. This work should then proceed to look at velocity-time graphs. A useful starting example is to look at the journey of an “underground” train; starting from rest, accelerating at a uniform rate, moving at constant speed and finally decelerating to rest with a constant deceleration. Students should be encouraged to sketch the graphs for themselves and discussion should follow on how acceleration and the distance travelled can be calculated. The general results that the area under the graph represents distance travelled and the gradient represents acceleration should be summarised. Students will need a lot of practice on similar examples, including cases where the velocity and the gradient may be positive or negative. Discuss with the group the motion of a particle (appropriate place to introduce the concept of a particle) that is not constant and on how can we deal with a varying acceleration. A good starting point is to look at the motion resulting from a given formula for distance (*s*), or velocity (*v*) or acceleration (*a*) in terms of time (*t*); e.g. $s = t^3 - 6t^2 + 12$. General discussion with students should lead them to formulae for *v* and *a* in terms of *t*. They should be encouraged to calculate where and when the particle is at rest (or changing its direction of motion), where and when it is not accelerating (or is travelling at its maximum or minimum speed) and what is happening at different values of *t* including when *t* is large.		

		There will be the need to emphasise that "at rest" implies "$v = 0$", not "$a = 0$". Similar work can follow from a starting formula for v or for a. Students should appreciate the need to integrate and to include, and subsequently evaluate, the constant (or constants) of integration. There will be the need for a lot of practice in this particular topic. Students should realise that "s" represents displacement, and not distance travelled. They should be able to solve problems requiring them to find the distance travelled in a particular time when the time period includes the instant when the particle is at rest (or changes its direction of motion).		
	• Use appropriate formulae for motion with constant acceleration in a straight line.	General discussion can now follow on a more formal look at motion with constant acceleration. Students should be shown the derivation of the various formulae, either from an algebraic base (using the properties of the v-t graph) or from calculus. (They do not need to learn these proofs). The students will need to look and work through a lot of examples, including harder ones such as being given the distance travelled in two different time intervals and being asked to calculate the initial speed and the acceleration. Although four of the formulae are included in the list of formulae provided for the examination, students should be encouraged, through practice, to memorise the equations (including $s = vt - \frac{1}{2}at^2$). A very common mistake in applying s = ½ (u + v)t is to apply it for a time span for which there are two stages of motion, both of constant acceleration, but for which the acceleration is different in each stage. Discuss with students motion under gravity. Look at the modelling situation where air resistance can be ignored. Students should be able to calculate a maximum height, a time of flight and solve more complex problems.		

1	**Forces and Equilibrium.** • Identify the forces acting in a particular situation.	General discussion on Newton's first two laws of motion should be followed by a look at different types of force. This should include weight, normal reaction, tension, frictional force. Although the connection between mass and weight is specifically a part of Topic 3, the idea of "*W=mg"* is needed for much of what follows in this section. It is worth discussing with students why equilibrium is possible for a particle under different conditions – hanging on a string, lying on a smooth slope, being pushed gently on a rough horizontal table etc.	Have available OHP slides showing different examples of forces keeping a body in equilibrium.	www.physicsclassroom.com/Class/newtlaws/newtltoc.html This is an American site which looks in detail at all the ideas covered in this Unit. It approaches the topic from a more descriptive nature as would be expected in a Physics site, but the material provided makes good reading and makes for good learning. There are some interesting ideas explored and self-test exercises throughout the 4 lessons.
	• Understand the vector nature of force, and find and use components and resultants.	Discuss the vector nature of force emphasising that it has both magnitude and direction. Discuss the addition of two forces with reference to two people pushing an object on a surface in different (but not directly opposite) directions. Students should appreciate that the magnitude of the resultant of two forces of magnitudes 3 N and 5 N can take any value from 2N to 8N . (It is helpful if students have completed the work on vectors in Unit 3). Students should be able to split a force into its two components (at right angles) or to work backwards and find the direction and magnitude of the resultant of two components.	Have available OHPs to illustrate the sum of two forces that may, or may not, be in the same direction. In particular show that the sum of two forces of magnitude 3N and 5N varies between 2N and 8N.	
	• Use the principle that, when a particle is in equilibrium, the vector sum of the forces is zero, or equivalently, that the sum of the components in any direction is zero.	Students should be encouraged to look at the examples in the opening section above and realise that if a particle is in equilibrium, then forces will balance in any given direction, and that it will be necessary to resolve forces where angles are involved.		→ Newton's Laws of motion.

	• Understand that the contact force between two forces can be represented by two components, the normal component and the frictional component.	Look in detail at the idea of a contact force and realise that it can be represented by two components, a normal component (*R, or N*) and a frictional component (*F*).		
	• Use the model of a "smooth" contact and understand the limitations of this model.	Talk in general terms of the implication of the word "smooth" and enable students to understand the limitations of this model.		
	• Understand the concepts of limiting friction and limiting equilibrium; recall the definition of coefficient of friction, and use the relationship $F=\mu R$ or $F\leq\mu R$, as appropriate.	Look in detail at "friction". A good starting point is to imagine a solid on a rough horizontal surface being pushed gently by a force that gradually increases in size. This leads students to an appreciation that there is only a limited amount of friction available in a particular situation, and that friction opposes motion. Putting imaginary values for mass and the pushing force can lead to the formula $F\leq\mu R$. It is important to stress that the formula $F=\mu R$ is only appropriate if the body is moving or is in "limiting" equilibrium.		
	• Use Newton's third law.	General discussion on the effects of a force on the person, or object applying the force. Stress that if a surface is applying a force to a body, then the body exerts an equal and opposite force on the surface. (Simple demonstrations such as leaning backwards on a wall should be sufficient to convince students of "equal and opposite forces!)		
3	**Newton's laws of motion.**			
	• Apply Newton's laws of motion to the linear motion of a particle of constant mass moving under the action of constant forces, which may include friction.	Derive the equation "$F=ma$" from Newton's second law of motion. This is the most appropriate place to introduce the idea of 1 newton as being the force necessary to give a particle of mass 1kg an acceleration of 1ms^{-2}. Look at different situations with the students, including the case of a		

		particle moving on a horizontal surface , with a given coefficient of friction, under a pushing force, which is either horizontal or at an angle.		
	• Use the relationship between mass and weight.	This will ideally have been covered at an earlier stage.		
	• Solve simple problems that can be modelled by the motion of a particle moving vertically or on an inclined plane with constant acceleration.	Discuss the motion of a particle moving under gravity and under a constant resisting force. There is an interesting article on sky-diving in the "Physics Classroom web-site – Lesson 4. Discuss the differences in the "upward" and "downward" motion. Look at the motion of a particle moving under gravity on an inclined plane, where the plane may be smooth or rough. Students should appreciate that the weight component on a slope inclined at an angle θ to the horizontal is $mg\sin\theta$. They should be able to find accelerations, either up or down the slope, and use the equations of uniform acceleration to solve various problems involving speeds, distances travelled and time taken. Emphasise the importance of the direction of the frictional force (which will change during the solution of a problem involving motion both upwards and downwards).		
	• Solve simple problems that can be modelled by the motion of two particles connected by a light inextensible string which may pass over a fixed smooth peg or light pulley.	Discuss with students the use of Newton's third law of motion as applied to two particles that are connected by a light inextensible string, passing over a fixed light pulley. (discuss the implication of "light" , "inextensible" and "smooth"). Students need to be aware of the situation of a car pulling a trailer, an electro-magnet lifting a car, a rescuer suspended from a helicopter lifting a rescued person or a person going up or down in a lift.		