UNIT 8: Forces and Newton's laws

Return to overview

SPECIFICATION REFERENCES

8.1 Understand the concept of a force; understand and use Newton's first law.

8.2 Understand and use Newton's second law for motion in a straight line (restricted to forces in two perpendicular directions or simple cases of forces given as 2D (**i**, **j**) vectors).

8.4 Understand and use Newton's third law; equilibrium of forces on a particle and motion in a straight line; application to problems involving smooth pulleys and connected particles.

PRIOR KNOWLEDGE

- Modelling and definitions/assumptions from the introduction in Unit 6

GCSE (9-1) in Mathematics at Higher Tier

A19 Solve two simultaneous equations in two variables (linear/linear or linear/quadratic) algebraically; find approximate solutions using a graph

KEYWORDS

Force, newtons, mass, weight, gravity, tension, thrust, compression, air resistance, reaction, driving force, braking force, resultant, force diagram, equilibrium, inextensible, light, negligible, particle, smooth, uniform, pulley, string, retardation, free particle.

NOTES

This section does *not* contain any resolving of forces into perpendicular components, nor does it consider the use of the coefficient of friction for frictional forces.

8a. Newton's first law, force diagrams, equilibrium, introduction to i, j system of vectors (8.1)

Teaching time
3 hours

OBJECTIVES

By the end of the sub-unit, students should:

- understand the concept of a force; understand and use Newton's first law.

TEACHING POINTS

Relate this topic back to the different types of forces defined in Unit 6b.

Newton said '*An object continues in state of rest or uniform motion unless acted on by an external force*.' Hence one can define a force as something which causes a body to accelerate. Explain to students that 'no force acting' means a body will either be stationary or be moving with constant velocity (i.e. acceleration = zero). This is why in outer space an object keeps moving at constant speed once pushed (there are no forces to speed it up, slow it down or stop it moving.)

So, an object at rest or constant velocity $\Rightarrow$ no resultant force; an object changing speed or direction $\Rightarrow$ resultant force. This will lead to Newton's second law in the next section.

Newton also stated '*When an object A exerts a force on another object B there is an equal and opposite reaction force of B on A.*' Explain that if a book is on a smooth, horizontal table, the forces acting on the book are the Weight, W (vertically down) and the normal reaction, R (always at 90° to the *surface* of contact). Assuming the table surface material is strong enough to hold the full weight of the book, the two forces balance each other and there is no resultant force. The book does not move, hence it is in equilibrium.

Ask questions such as: If the book has a mass of 5 kg, what is its weight? Therefore, what would the magnitude of the normal reaction be to guarantee equilibrium?

Draw different examples of force diagrams to illustrate: weight, reaction, tension (in strings), thrust (in rods), compression (in light rods, springs) etc.

To illustrate thrust, balance a book on a ruler.In which direction is the thrust force acting?

Introduce the **i** - **j** notation. The forces can be given in **i** - **j** form or as column vectors. Questions on equilibrium will be limited to perpendicular forces so the sum of the forces must be 0**i** + 0**j** for equilibrium.

OPPORTUNITIES FOR PROBLEM SOLVING/MODELLING

You could extend to rough inclined planes and show all the forces balancing to provide equilibrium. Resolving forces is not in the AS course (covered in A Level Mathematics – Mechanics content, see SoW Unit 5a).

COMMON MISCONCEPTIONS/EXAMINER REPORT QUOTES

Students are often good at drawing force diagrams, but common errors are omitting arrowheads, incorrectly labelling (e.g. 4 kg rather than $4g$) and missing off the normal reaction.

Students can easily be confused by the vocabulary, e.g. mixing up 'resultant' and 'reaction'.

NOTES

Resolving forces is not in the AS course and equilibrium problems will not require forces to be resolved. Scenarios will be restricted to forces in two perpendicular directions, or simple cases of forces, given as 2D vectors.

Resolving forces and the concept of a friction force (which opposes relative motion) is covered in A level Mathematics – Mechanics section, see SoW Unit 5.

8b. Newton's second law, '$F = ma$', connected particles (no resolving forces or use of $F = \mu R$); Newton's third law: equilibrium, problems involving smooth pulleys (8.2) (8.4)

Teaching time
4 hours

OBJECTIVES

By the end of the sub-unit, students should:

- understand and be able to use Newton's second law for motion in a straight line (restricted to forces in two perpendicular directions or simple cases of forces given as 2D (**i**, **j**) vectors.);
- understand and use Newton's third law; equilibrium of forces on a particle and motion in a straight line; application to problems involving smooth pulleys and connected particles.

TEACHING POINTS

Newton stated, '*Where there is a force, there is an acceleration (or deviation from uniform motion) and the force is proportional to the acceleration*'. Therefore $F \propto a$, and choosing the constant to suit the motion units gives $F = ma$. (Newton's second law). This is known as the 'equation of motion'.

Explain to students that if they sum all the effects of the forces acting, in a particular direction, this will be equal to the mass x the acceleration in that direction. This process is called resolving the forces in that direction e.g. resolving horizontally, or R(→) for short. It's usually best to resolve IN the direction of the acceleration and/or perpendicular to the direction of the acceleration.

When resolving always take the positive direction as the direction of the acceleration and put all the forces on one side of the equation and (mass x acceleration) on the other side.

When working on connected particles problems (such as trains or pulley systems) explain to students that they should consider the whole system as well as the separate parts. Applications to be covered are lift problems, car and caravan type questions and connected particles passing over a smooth pulley. Consider both pulley scenarios: a pulley with both stings hanging vertically; and a pulley at the end of a horizontal table.

OPPORTUNITIES FOR PROBLEM SOLVING/MODELLING

For the connected particle problems, discuss, the assumptions from Unit 6a, i.e. smooth pulley, inextensible string, same tension in the string. Extend the questions so that (for a pulley question) the particle moving down eventually hits the table and the string goes slack. This means the particle moving up continues as a 'free' particle so we now apply the equations of motion with $a = -9.8 \text{ m s}^{-2}$.

COMMON MISCONCEPTIONS/EXAMINER REPORT QUOTES

Pulleys: In past exam questions, most students used an equation of motion for each particle with very few 'single equation' solutions. Students may also mistakenly take the acceleration to be equal to g rather than the value obtained in the question.

2 Vehicles: In exam questions of a car-and-trailer type, students may consider the car and trailer as a single system. Common errors when resolving are: to add a tension force (when there is no rope): to consider the weight; or to confuse the positive and negative directions.

NOTES

Starting with the ‘winner’ is most useful when the dynamics move into more complicated questions later in the course (e.g. inclined planes and resolving forces).