

A2: Dynamics: Force , Momentum & Laws of motion

Duration: 2 Weeks, 10 hour
Unit dates: 3rd Nov 2026 - 17th Nov 2026
Subjects: Physics
Levels: SL, HL
Grades: DP 1
Owner: Utkarsh Kumar

Inquiry & action

Unit basics

Unit description and texts

In this unit students develop a quantitative and visual understanding of why bodies move as they do. The unit begins with a simple question: how can the forces acting on a system be represented, and how can they be used to predict the behaviour of interacting bodies?
Students first treat forces as interactions between bodies and represent them in free-body diagrams. They then meet the contact forces (normal, friction, tension, elastic restoring and viscous drag, buoyancy) and the field forces (gravitational, electric, magnetic), and learn to find a resultant force and to recognise equilibrium. From there the unit moves from force to momentum: Newton's second law is written first as $F = \Delta p/\Delta t$, impulse is introduced as the area under a force–time graph, and conservation of momentum is applied to collisions and explosions with energy considerations. The final strand is circular motion: a body moving at constant speed on a circle is accelerating, because the direction of its velocity keeps changing, and a centripetal force perpendicular to the velocity is needed.
Rather than learning formulae as isolated results, students decide which model fits a situation: a balance of forces, a change of momentum, or a net force towards a centre. Work moves from teacher-led demonstrations and the CritABCD A.2 online lessons (interactive Newton, collision, tension, terminal-velocity and circular-motion simulations) to independent problem solving, an in-class circular-motion practical, and exam-style questions. AI-supported Socratic questioning is used as a thinking tool, not an answer machine.
The unit builds on A.1 (vectors, graphs, uniformly accelerated motion) and prepares for B (thermal and energy ideas), C (waves), D (gravitational, electric and magnetic fields) and for the Individual Scientific Investigation.
Texts and resources: IB Physics guide (first assessment 2025), A.2 pages 35 to 36; IB Physics data booklet; CritABCD DP Physics A.2 Force and motion lessons (A.2 · 1 to 20, including the new lessons on free-body diagrams, field forces, impulse, explosions and circular motion); teacher-made practice papers and marking schemes; class trolleys, dynamics carts, spring balances, whirling-bung kits and stopwatches.

Final assessments for unit

A.2 Forces and Momentum Unit Test (summative), 45 minutes in Practice session 4. Paper 1 style multiple choice (about 10 questions) and Paper 2 style structured questions (about 20 marks). The paper mixes free-body diagrams and resultant force, impulse and force–time graphs, collisions and explosions, and circular motion, with at least one data-analysis question based on the circular-motion practical.

Circular-motion mini-investigation (formative, in Practice session 3). Students test the relationship $F = 4\pi^2 mr/T^2$ with a whirling bung. They:

- state a focused question and identify variables,
- collect T for several radii or several hanging masses, with measurement uncertainty,
- process the data (T, T^2, graph of T^2 against r or F against $1/T^2$),
- compare the result with the model and interpret deviations,
- evaluate limitations (friction at the tube, loss of control of r, reaction time),
- reach a supported conclusion.

Assessment evidence

Students should be able to demonstrate:

- correct free-body diagrams with labelled forces and a correct resultant,
- correct use of Newton's three laws, including force pairs on different bodies,
- selection of $F = ma$ or $F = \Delta p/\Delta t$ and of impulse as the area under a force–time graph,
- conservation of momentum applied to collisions and explosions, and correct energy reasoning (elastic, inelastic, explosion),
- correct use of period, angular velocity, linear speed and centripetal acceleration and force,
- appropriate units, significant figures and uncertainty treatment,
- clear scientific communication and evidence-based conclusions.

Learning goals

Aims

Subject group aims - Sciences

- Develop conceptual understanding that allows connections to be made between different areas of the subject, and to other DP sciences subjects
- Acquire and apply a body of knowledge, methods, tools and techniques that characterize science
- Develop the ability to analyse, evaluate and synthesize scientific information and claims
- Develop the ability to approach unfamiliar situations with creativity and resilience
- Design and model solutions to local and global problems in a scientific context
- Develop technology skills in a scientific context

Objectives

- Demonstrate knowledge of terminology, facts and concepts
- Understand and apply knowledge of terminology and concepts
- Demonstrate knowledge of skills, techniques and methodologies
- Understand and apply knowledge of skills, techniques and methodologies

Syllabus

- A Space, time and motion
  - A.2 Forces and momentum
    - Guiding questions
      - How can forces acting on a system be represented both visually and algebraically?
      - How can Newton's laws be modelled mathematically?
      - How can knowledge of forces and momentum be used to predict the behaviour of interacting bodies?
    - Understandings - SL and HL
      - Students should understand the nature and use of the following contact forces
        - normal force FN is the component of the contact force acting perpendicular to the surface that counteracts the body
        - surface frictional force Ff acting in a direction parallel to the plane of contact between a body and a surface, on a stationary body as given by $Ff \leq \mu_s FN$ or a body in motion as given by $Ff = \mu_d FN$ where μ_s and μ_d are the coefficients of static and dynamic friction respectively
        - tension
        - elastic restoring force FH following Hooke's law as given by $FH = -kx$ where k is the spring constant
        - viscous drag force Fd acting on a small sphere opposing its motion through a fluid as given by $Fd = 6\pi\eta rv$ where η is the fluid viscosity, r is the radius of the sphere and v is the velocity of the sphere through the fluid

        - buoyancy Fb acting on a body due to the displacement of the fluid as given by Fb = ρVg where V is the volume of fluid displaced
    - Students should understand the nature and use of the following field forces
        - gravitational force Fg is the weight of the body and calculated is given by Fg = mg
        - electric force Fe
        - magnetic force Fm
    - Students should understand
        - Newton's three laws of motion
        - forces as interactions between bodies
        - that forces acting on a body can be represented in a free-body diagram
        - that free-body diagrams can be analysed to find the resultant force on a system
        - that linear momentum as given by p = mv remains constant unless the system is acted upon by a resultant external force
        - that a resultant external force applied to a system constitutes an impulse J as given by J = FΔt where F is the average resultant force and Δt is the time of contact
        - that the applied external impulse equals the change in momentum of the system
        - that Newton's second law in the form F = ma assumes mass is constant whereas F = Δp /Δt allows for situations where mass is changing
        - the elastic and inelastic collisions of two bodies
        - explosions
        - energy considerations in elastic collisions, inelastic collisions, and explosions
        - that bodies moving along a circular trajectory at a constant speed experience an acceleration that is directed radially towards the centre of the circle—known as a centripetal acceleration as given by a = v 2 /r = ω 2 r = 4π2r/ T 2
        - that circular motion is caused by a centripetal force acting perpendicular to the velocity
        - that a centripetal force causes the body to change direction even if its magnitude of velocity may remain constant
        - that the motion along a circular trajectory can be described in terms of the angular velocity ω which is related to the linear speed v by the equation as given by v = 2πr /T = ωr
- Linking questions
    - How do collisions between charge carriers and the atomic cores of a conductor result in thermal energy transfer?
    - How can knowledge of electrical and magnetic forces allow the prediction of changes to the motion of charged particles?
    - How does the application of a restoring force acting on a particle result in simple harmonic motion?
    - How are concepts of equilibrium and conservation applied to understand matter and motion from the smallest atom to the whole universe?
    - Why is no work done on a body moving along a circular trajectory?
    - In which way is conservation of momentum relevant to the workings of a nuclear power station?
    - If experimental measurements contain uncertainties, how can laws be developed based on experimental evidence? (NOS)
    - What assumptions about the forces between molecules of gas allow for ideal gas behaviour? (NOS)

Learner Profile

- Inquirers
- Thinkers
- Knowledgeable
- Communicators
- Risk-takers
- Reflective
- Principled

Remarks:

Thinking skills develop as students choose between models and justify the choice. Communication skills are practised in notebook entries, mini-whiteboard explanations and exam-style answers. Self-management develops through the error log and the practical plan. Research skills are used in the data analysis of the circular-motion practical.

Inquiry: Establishing the purpose of the unit

Transfer goals

- Students will apply force, momentum and circular-motion models to unfamiliar systems: sports, vehicles, spacecraft, amusement rides, particle detectors.
- Students will critically judge which model (balance of forces, impulse and momentum, or centripetal force) is the most efficient for a given problem and state its assumptions.
- Students will plan, carry out and evaluate a simple quantitative practical, treating measurement uncertainty and comparing data with a model.

Students will know the following content:

Forces are interactions between two bodies, always in pairs, acting on different bodies (Newton III).
How to draw a free-body diagram, find a resultant force in one and two dimensions and recognise translational equilibrium.
The nature, direction and formula of normal force, friction (static and dynamic), tension, Hooke's restoring force, viscous drag, buoyancy, weight, electric and magnetic force.
Momentum is a vector, $p = mv$; $F = \Delta p/\Delta t$ and $F = ma$ (constant mass); impulse $J = F\Delta t = \Delta p$; the area under a force–time graph is the impulse.
Conservation of momentum for an isolated system; elastic collisions conserve kinetic energy, inelastic collisions do not; explosions release stored energy and conserve momentum.
Period, frequency, angular velocity, linear speed and centripetal acceleration; centripetal force is a net force, not a new kind of force.

Students will develop the following skills:

Representing forces visually (free-body diagrams) and algebraically (resolving into components, writing $F_{net} = ma$).
Choosing between $F = ma$, $F = \Delta p/\Delta t$, impulse and conservation of momentum.
Reading force–time and momentum–time graphs: area as impulse, gradient as force.
Moving between angular and linear descriptions of circular motion.
Collecting, processing and evaluating data with uncertainty in a short practical.
Using interactive simulations and AI Socratic questioning to test predictions and explain results.

Students will grasp the following concepts:

A force is an interaction; the resultant force, not the individual forces, decides the change in motion.
Momentum is conserved in an isolated system even when kinetic energy is not.
A change of momentum needs an impulse; a longer contact time means a smaller force for the same change.
Acceleration can change direction without changing speed; the centripetal force does no work.
Models (point masses, no friction, no air resistance) are idealisations whose limits should be stated.

Content inquiry questions

What forces act on a body, and what does a free-body diagram show? What is momentum, and when is it conserved? What is impulse? What provides the centripetal force in a given situation?

Skill inquiry questions

How can one situation be described by a free-body diagram, an equation and a graph? Why does the same collision look different on a momentum–time and a force–time graph?

Conceptual inquiry questions

Is a "centrifugal force" real? How does a model with no friction help us predict the behaviour of a real system? When is an elastic collision a good model?

Action: Teaching and learning through inquiry

Formative assessment

Concept checks: predict-then-test questions before each simulation (for example "which cart moves faster after the explosion?").
Free-body diagram checks: students draw and label the forces on a given object and the teacher checks quickly on mini-whiteboards.
Graph interpretation: force–time areas, momentum–time gradients, v–t and a–t for circular motion components.
Retrieval and quiz: A.2 retrieval items inside each online lesson; the A.2 quiz on momentum and force; a new circular-motion quiz.
AI/Socratic dialogue: the AI physics tutor questions students about their reasoning, for example "why does the net force point to the centre?".

Digital laboratory notebook: predictions, observations, uncertainty notes and conclusions for the whirling-bung practical.
Exam-style questions: A.2 exam question lessons and the practice papers, marked with the scheme in class.

Summative assessment

The A.2 Unit Test (45 minutes) assesses free-body diagrams and resultants, Newton's laws, impulse, collisions and explosions with energy reasoning, and circular motion (kinematics and dynamics), including one question that uses data from the circular-motion practical. Marks follow IB command-term conventions, with feedback given on the next lesson.

Learning process

The unit uses an inquiry-driven cycle of short teaching episodes, simulations, discussion and practice. Six one-hour theory sessions are followed by four one-hour practice sessions. Each theory session pairs a 15-minute teacher-led idea, a simulation or demonstration with prediction, and quick problem solving; the CritABCD lessons give pre-reading or consolidation.
HourTypeFocus and learning intentionsCritABCD resources (A.2)Activities and formative checks
1TheoryForces as interactions; free-body diagrams. Newton's three laws; identify force pairs; draw a free-body diagram; resultant force and translational equilibrium in 1D and 2D.A.2 · 1 Newton's first law; A.2 · 2 second law; A.2 · 4 third law; A.2 · 12 Free-body diagrams, resultant force and equilibriumDemonstration: book on a table, block on a slope. Mini-whiteboard FBDs. Newton's laws diagram widgets. Exit ticket: name the pair of the weight.
2TheoryContact and field forces. Normal force; static and dynamic friction ($F_f \le \mu_s F_N$, $F_f = \mu_d F_N$); tension; Hooke's law $F_H = -kx$; viscous drag $6\pi\eta r v$; buoyancy; weight; electric and magnetic force.A.2 · 3 What can a force do?; A.2 · 10 Friction, buoyancy, tension and the rest; A.2 · 9 four fundamental forces; A.2 · 13 Springs, viscous drag and field forcesSpring-extension and tension labs; terminal-velocity and drag simulations; prediction questions; "force detective": classify each force in a photo.
3TheoryMomentum and impulse. $p = mv$; $F = \Delta p/\Delta t$ versus $F = ma$; impulse $J = F\Delta t$; area under a force–time graph; effect of contact time (airbags, crumple zones).A.2 · 2 Newton's second law; A.2 · 7 Momentum change: four cases; A.2 · 14 Impulse: a force acting for a timeBounce-and-stick demonstration; impulse simulation (change the contact time, watch the area); concept check: same Δp, different Δt.
4TheoryCollisions and explosions. Conservation of momentum for an isolated system; elastic, inelastic and perfectly inelastic collisions; explosions and recoil; energy considerations; HL: two dimensions with components.A.2 · 5 Momentum conservation; A.2 · 6 Momentum vs kinetic energy; A.2 · 15 Explosions and recoil; A.2 · 16 Collisions in two dimensions (HL)Collision lab (cart-cart); spring-loaded cart explosion; before/after tables; "was KE conserved?" check.
5TheoryDescribing circular motion. Period, frequency, angular velocity, $v = \omega r = 2\pi r/T$; why a constant speed on a circle still means acceleration; $a = v^2/r = \omega^2 r = 4\pi^2 r/T^2$.A.2 · 17 Describing circular motion; A.2 · 18 Centripetal acceleration and force (first half); A.1 vector change of velocityCircular-motion simulation: change r and T, read v, ω, a; vector triangle for Δv; predict the direction of a.
6TheoryCentripetal force and circular dynamics. Centripetal force as a net force perpendicular to the velocity; what provides it (tension, friction, gravity, normal force); horizontal and vertical circles (top and bottom); uniform and non-uniform motion; no work done.A.2 · 18 (second half); A.2 · 19 Circular motion in practice: horizontal and vertical circlesCar on a bend, conical pendulum, bucket in a vertical circle: draw FBDs and write $F_{net} = mv^2/r$ at the top and bottom. Myth check: "centrifugal force".
7PracticeForces workshop. Mixed problems: resultants, equilibrium on a slope, friction, tension in a string, spring, drag and buoyancy.A.2 · 10 checks and apply tasks; A.2 · 12 apply tasks; the forces exam-style set in A.2 · 20Station rotation with FBD cards; peer marking; AI tutor for stuck points.
8PracticeImpulse, collisions and explosions problem solving.A.2 · 11 Exam questions: collisions; A.2 Quiz: momentum and force; A.2 · 20 sets 1 and 2Timed questions with the marking scheme; correct, then re-attempt; error log in the notebook.
9PracticeCircular-motion practical and problems. Whirling bung: investigate F against T and r; uncertainty and graph; circular-motion problems.A.2 · 20 circular-motion set; circular-motion quizCollect data (T for 10 revolutions), process in a table, plot T^2 against r or F against $1/T^2$, compare with $F = 4\pi^2 mr/T^2$; evaluate sources of error.
10PracticeMixed exam practice and unit test.Practice paper (Paper 1 and Paper 2 style) and marking scheme45-minute test, 15 minutes of feedback and reflection on the learning goals.
The ten learning experiences, in order: (1) forces as interactions; (2) free-body diagrams and equilibrium; (3) contact forces; (4) field forces; (5) momentum and impulse; (6) collisions; (7) explosions; (8) circular motion described; (9) circular dynamics; (10) practice and assessment. This progression moves from representing forces, to what forces do over time (momentum), to forces that change direction (circular motion).

Connections

Approaches to learning

- Thinking
  - Critical thinking
    - Interpret data

        - Draw reasonable conclusions and generalizations
        - Use models and simulations to explore complex systems and issues
    - Creative thinking
        - Apply existing knowledge to generate new ideas, products, or Processes
    - Reflection
        - Reflect on competencies in the different ATL skills
    - Transfer
        - Apply skills and knowledge in unfamiliar situations
- Communication
    - Exchange ideas coherently
    - Make inferences and draw conclusions
- Self-management
    - Organisation
        - Plan short- and long-term tasks to meet deadlines and goals by breaking down a larger task into specific steps
    - Affective
        - Practise analysing and attributing causes for failure
- Research
    - Information literacy
        - Collect, record, and verify data
        - Process data and report results
        - Evaluate and select information sources and digital tools based on their appropriateness and credibility to specific tasks
    - Media literacy
        - Analyze different media and news channels' points of view to identify bias and use triangulation of sources to verify sources

Details:

Thinking skills develop as students choose between models and justify the choice. Communication skills are practised in notebook entries, mini-whiteboard explanations and exam-style answers. Self-management develops through the error log and the practical plan. Research skills are used in the data analysis of the circular-motion practical.

Differentiation Approach

- Content
- Product

Details:

Support: structured free-body-diagram templates; guided prompts and sentence starters for "explain" questions; partially completed data tables; worked examples with colour-coded steps; the Essentials / Full / Stretch levels in the online walkthroughs; AI-generated Socratic hints; multiple representations (diagram, equation, graph) of the same situation.
Extension: derive $a = v^2/r$ from a velocity triangle; derive impulse = Δp from $F = ma$; analyse a rocket (variable mass) with $F = \Delta p/\Delta t$; two-dimensional collisions for SL students; non-uniform circular motion and the minimum speed at the top of a vertical circle; limits of the Stokes law.
Student choice: choice of practical variables (radius or mass), of data-collection method, of representation of the results, and of the exam question set to attempt first.

Language and Learning Connection

- Demonstrating proficiency
- Scaffolding for new learning
- Acquisition of new learning through practice
- Activating background knowledge

Details:

Subject vocabulary: resultant, equilibrium, normal, tension, restoring, viscous, impulse, momentum, elastic, inelastic, explosion, period, angular velocity, centripetal, tangential.
Command terms: state, outline, explain, deduce, determine, calculate, with example answers at each level of the mark scheme.
Mathematical literacy: resolving vectors, handling signs for direction, working with π and radians, rearranging formulae and checking units (N s = kg m s−1).
Scientific communication: written explanations that give cause and effect ("because the net force is zero, the velocity is constant"), and

annotated diagrams.
Activating prior knowledge: A.1 vectors, graphs and equations of motion; MYP forces.

TOK Connection

Areas of knowledge

- The natural sciences
- Mathematics

Concepts

- Evidence
- Interpretation
- Justification
- Perspective
- Truth

Details:

Models and idealisation: point particles, frictionless surfaces and isolated systems are useful but false. What makes an idealisation a good model?
Perspective and frames: "centrifugal force" is real in a rotating frame but not in an inertial frame. How does the choice of perspective change what we call a force?
Conservation laws: why do we trust the conservation of momentum? Is it a law of nature, a definition, or a pattern we have always found?
Evidence and uncertainty: how many measurements justify a conclusion about $F = 4\pi^2 mr/T^2$?

CAS Strands

- Creativity

Details:

Designing and building a simple demonstration (an egg-drop cushion, a water-rocket or a model roller-coaster loop) that applies impulse, momentum or circular motion.
Communicating the physics of a sport or ride through a short video, poster or animation for younger students.
Using the CritABCD simulations creatively to design a problem for classmates.

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