Forces and Newton's laws

Science, grade 9 - by Claude Opus 5.5 - status: written (unreviewed)

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Grade 9 Science — Forces and Newton's laws: measuring what pushes and pulls do

> **Unreviewed AI draft.** Written by Claude Opus 5.5 (an AI agent) on 2026-11-04. No teacher has checked it yet. Read it fully, adapt it to your class and local rules, and test any practical work yourself before using it.

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Big idea

Forces change how things move. If the forces on an object are balanced, it keeps doing what it was doing (staying still, or moving at a steady speed in a straight line). If they are unbalanced, it speeds up, slows down or changes direction, and a bigger net force or a smaller mass gives a bigger acceleration (F = ma). Forces always come in pairs acting on two different objects. These ideas are checked here with measured data, not just stated.

Outcomes

By the end of the unit, students can:

1. Explain the difference between mass (kilograms) and weight (a force, in newtons), and calculate weight using W = mg with g about 9.8 N/kg on Earth and about 1.6 N/kg on the Moon.
2. Use a spring and a newtonmeter to collect stretch data, plot a graph and describe when extension is proportional to force (Hooke's law).
3. Draw labelled free-body diagrams, find the net force along a line, and use Newton's first law to predict whether an object's motion will change.
4. Carry out a trolley experiment, calculate acceleration from distance and time, plot acceleration against force, and explain why the line may not pass exactly through zero.
5. Explain terminal velocity using drag and weight, and test it by dropping paper cases.
6. Identify Newton's third-law force pairs and use force and time ideas to explain seat belts and crumple zones.

Prior knowledge

- Pushes and pulls start, stop and turn things; a bigger push makes things go faster or farther; rough surfaces slow things down (kindergarten).
- Magnets pull through some materials, and a pull can act without touching (grade 3).
- Fair tests, repeats and medians; plotting and reading line graphs (grades 3–8).
- Rearranging simple formulas and working with decimals (mathematics, grades 7–8).

Lessons (about 50 minutes each)

#	Lesson	Practical?
1	Mass, weight and stretching springs	Weigh masses with a newtonmeter; spring stretch graph
2		

#	Lesson	Practical?
	Balanced and unbalanced: free-body diagrams and Newton's first law	Coin-on-card demonstration; force-diagram stations
3	F = ma: the trolley experiment	Trolley pulled by hanging masses; time over 1.0 m; graph
4	Falling, drag and terminal velocity	Drop 1–4 nested paper cases from 2.0 m
5	Force pairs, car safety + unit check	Third-law demonstrations; written assessment

Materials (whole unit)

- Lesson 1: newtonmeters (0–10 N); slotted masses (100 g each, with hangers); steel springs; clamp stands with bosses and clamps, weighed down or clamped to the bench; metre rulers; eye protection; a tray or box under every hanging load.
- Lesson 2: a playing card or stiff card, a coin and a cup or beaker for each group (or one for a teacher demonstration); force-diagram station cards (given in lesson 2).
- Lesson 3: dynamics trolleys or low-friction toy cars; a smooth level runway at least 1.5 m long; a bench pulley; string; a 10 g hanger and 10 g or 20 g slotted masses; masking tape; stopwatches or phones; a box of padding or a cushion at the end of the runway; a tray under the hanging masses.
- Lesson 4: paper cupcake or muffin cases (identical, at least 4 per group); metre rulers or a tape measure; stopwatches or phones; masking tape to mark a 2.0 m drop height.
- Lesson 5: two wheeled chairs or skateboards are NOT used (see lesson 5 safety); instead balloons, string, straws and tape for a balloon rocket; two spring newtonmeters hooked together.
- Student record sheets (tables are given in each lesson).

Assessment

- Ongoing: closing check questions at the end of each lesson (answers included).
- Lesson 3: the results table, acceleration calculations, graph and conclusion are a practical skills task.
- Lesson 5: a 10-question unit check (20 marks) with an answer guide and marking notes.

Sources

These are general references that a teacher can use to check facts. Links were checked to load on 2026-11-04.

- Wikipedia, "Newton's laws of motion": https://en.wikipedia.org/wiki/Newton%27s_laws_of_motion
- Wikipedia, "Force": https://en.wikipedia.org/wiki/Force
- Wikipedia, "Net force": https://en.wikipedia.org/wiki/Net_force
- Wikipedia, "Free body diagram": https://en.wikipedia.org/wiki/Free_body_diagram
- Wikipedia, "Inertia": https://en.wikipedia.org/wiki/Inertia
- Wikipedia, "Mass versus weight": https://en.wikipedia.org/wiki/Mass_versus_weight
- Wikipedia, "Weight": https://en.wikipedia.org/wiki/Weight
- Wikipedia, "Standard gravity": https://en.wikipedia.org/wiki/Standard_gravity
- Wikipedia, "Gravity of Earth": https://en.wikipedia.org/wiki/Gravity_of_Earth
- Wikipedia, "Moon": https://en.wikipedia.org/wiki/Moon
- Wikipedia, "Newton (unit)": https://en.wikipedia.org/wiki/Newton_(unit)

- Wikipedia, "Hooke's law": https://en.wikipedia.org/wiki/Hooke%27s_law
- Wikipedia, "Spring scale": https://en.wikipedia.org/wiki/Spring_scale
- Wikipedia, "Acceleration": https://en.wikipedia.org/wiki/Acceleration
- Wikipedia, "Velocity": https://en.wikipedia.org/wiki/Velocity
- Wikipedia, "Friction": https://en.wikipedia.org/wiki/Friction
- Wikipedia, "Drag (physics)": https://en.wikipedia.org/wiki/Drag_(physics)
- Wikipedia, "Terminal velocity": https://en.wikipedia.org/wiki/Terminal_velocity
- Wikipedia, "Momentum": https://en.wikipedia.org/wiki/Momentum
- Wikipedia, "Crumple zone": https://en.wikipedia.org/wiki/Crumple_zone
- Wikipedia, "Seat belt": https://en.wikipedia.org/wiki/Seat_belt

Known gaps and cautions

- **Not reviewed** by a teacher or a science technician. Check every practical against your school's or region's safety guidance before use.
- **Example data are invented for teaching**, chosen to look like typical classroom results. They are not real measurements. Run each practical yourself first and use your own results as the answer key.
- **Hand timing is rough.** Human reaction time adds error to short times (about 1–2 s here). That is a point to discuss, not to hide; light gates, data loggers or slow-motion phone video give better times if available.
- **Simplifications:** $a = 2d/t^2$ assumes the trolley starts from rest and accelerates steadily. Momentum is mentioned only in lesson 5 to explain car safety; impulse calculations, vectors at angles and circular motion are left to later grades.
- **Facts to check before quoting as exact:** standard gravity 9.80665 m/s² ("Standard gravity"); sea-level gravity from about 9.780 m/s² at the Equator to about 9.832 m/s² at the poles ("Gravity of Earth"); Moon surface gravity 1.62 m/s², about a sixth of Earth's ("Moon"); a belly-down skydiver's terminal speed about 55 m/s ("Terminal velocity"); seat belts "reduce serious crash-related injuries and deaths by about half" (CDC summary quoted in "Seat belt").

Lesson 1 — Mass, weight and stretching springs

Back to unit

Goal

Students measure the weight of known masses, work out that each kilogram weighs about 9.8 N on Earth, and collect spring-stretch data to test whether extension is proportional to force.

Materials

- Per group: a 0–10 N newtonmeter; five 100 g slotted masses and a hanger; a steel spring; a clamp stand, boss and clamp (clamped or weighed down so it cannot tip); a metre ruler; a tray or box under the hanging load.
- Eye protection for everyone (springs can snap or fly off).

Steps

✎ Opening (5 min)

Ask: "If you travelled to the Moon, would you weigh less? Would you have less stuff in you?" Take a vote on each question. Leave the answers open; students will be able to answer by the end.

✎ Main activity part A: weighing masses (10 min)

1. Hang 100 g, then 200 g, up to 500 g, on the newtonmeter. Record the reading in newtons.
2. Fill in the table:

Mass (g)	Mass (kg)	Weight (N)	Weight ÷ mass (N/kg)
100	0.1		
200	0.2		
300	0.3		
400	0.4		
500	0.5		

1. Typical readings are close to 1 N per 100 g (a cheap newtonmeter may read 0.9–1.0 N). Weight ÷ mass should come out close to 10 N/kg. The accepted value is about 9.8 N/kg; standard gravity is defined as 9.80665 m/s².
2. Introduce **W = mg**: weight (N) = mass (kg) × gravitational field strength (N/kg). Mass is the amount of matter and is measured in kilograms; weight is a force and is measured in newtons.

✎ Main activity part B: stretching a spring (20 min)

1. Hang the spring from the clamp and measure the length of the coiled part with no load. Put the ruler upright next to it and read at eye level.
2. Add one 100 g mass (about 1 N) at a time, up to 5 N. Measure the length each time and work out the extension (new length − original length).
3. Remove the masses one at a time and check whether the spring goes back to its original length.
4. Plot extension (cm, up) against force (N, along). Example class data (invented for teaching):

Force (N)	0	1	2	3	4	5
Extension (cm)	0	2.1	3.9	6.0	8.1	10.0

1. The points lie close to a straight line through zero: each extra newton stretches the spring by about 2 cm. This is **Hooke's law**: extension is proportional to force, up to a limit. Robert Hooke stated it in 1678 as ut tensio, sic vis ("as the extension, so the force").
2. Stretch: the spring constant k = force ÷ extension = 1 N ÷ 0.02 m = 50 N/m.

✓ Discussion questions (5 min)

1. A student says "my mass is 50 newtons". What is wrong? — Mass is measured in kilograms; newtons are for forces such as weight. Their mass might be 50 kg, which would weigh about 490 N.
2. Why does a newtonmeter contain a spring? — Because the spring's extension is proportional to the force (Hooke's law), so equal steps on the scale mean equal steps of force.
3. What would happen if we kept adding masses? — Eventually the spring would stretch past its limit, stop following the straight line, and not return to its original length. (Do not test this with the class springs.)

✓ Closing check (5 min, answers)

1. A 2 kg bag of flour: what is its weight on Earth (g = 9.8 N/kg)? — **19.6 N.**
2. The Moon's surface gravity is about 1.6 N/kg (1.62 m/s², about a sixth of Earth's). What is the same bag's mass and weight on the Moon? — **Mass still 2 kg; weight about 3.2 N.**
3. Using the example spring (about 2 cm per newton), how far would it stretch with 3.5 N? — **About 7 cm.**

Vocabulary

mass, weight, newton (N), kilogram (kg), gravitational field strength, newtonmeter, extension, proportional, Hooke's law, spring constant

Differentiation

- Support: give a partly filled table and pre-drawn axes; use 1 N steps only.
- Stretch: find the spring constant from the gradient; predict the extension of two identical springs side by side (half) or end to end (double), then test.

⚠ Safety

- Eye protection on throughout part B.
- Clamp stands must be clamped or weighted so they cannot tip. Keep feet and hands out from under hanging masses; a tray or box goes underneath.
- Never stretch springs beyond 5 N in this lesson; overstretched springs can snap or fly off.

Teacher notes and common misconceptions

- "Weight and mass are the same thing." In everyday speech they are; in science, weight is the pull of gravity on a mass. Bathroom scales show kilograms but actually measure a force.
- "There is no gravity in space." Gravity gets weaker with distance but does not vanish; astronauts in orbit are falling around the Earth. Keep this short; it returns in later grades.
- Gravity varies a little over Earth's surface: from about 9.780 m/s² at the Equator to about 9.832 m/s² at the poles (Wikipedia, "Gravity of Earth"). 9.8 N/kg is fine for class work.

Lesson 2 — Balanced and unbalanced: free-body diagrams and Newton's first law

Back to unit

Goal

Students draw free-body diagrams, add forces along a line to find the net force, and use Newton's first law to predict whether an object's motion will change.

Materials

- Per group (or one teacher demonstration): a playing card or piece of stiff card, a coin, and a cup or beaker.
- Six station cards (below), printed and placed around the room.
- Mini whiteboards or paper for diagrams.

Steps

✎ Opening (5 min): the coin and card

Put the card on top of the cup and the coin on the card, over the opening. Flick the card sharply sideways. The card flies off; the coin drops into the cup. Ask: "Why didn't the coin fly off with the card?" Collect ideas. The short answer, built up in this lesson: the quick flick gives only a small, brief sideways force on the coin through friction, so the coin barely moves sideways; once the card is gone, the unbalanced force on the coin is its weight, so it falls.

✎ Main activity part A: drawing free-body diagrams (15 min)

1. Model the rules on the board:
2. Draw the object as a box or dot.
3. Draw each force as an arrow starting on the object, pointing the way the force acts, with length showing size.
4. Label each arrow with its name and size if known (for example "weight 20 N").
5. Only show forces acting **on** this object.
6. Model a book resting on a table: weight 10 N down; the table's push (normal or contact force) 10 N up. Net force = 10 N up − 10 N down = 0 N. **Balanced.**
7. Introduce **Newton's first law** (first published by Isaac Newton in the Principia, 1687): if the net force on an object is zero, it stays at rest or keeps moving at a steady speed in a straight line. Its resistance to changes in motion is called **inertia**.

✎ Main activity part B: force stations (20 min)

Groups visit the stations, draw a free-body diagram for each, find the net force, and say what happens to the motion.

Station	Situation	Forces (given on the card)	Answer: net force and motion
1	Hanging lamp at rest	weight 15 N down; cable pull 15 N up	0 N; stays at rest
2	Bike at steady speed on a flat road	forward push 40 N; air resistance + friction 40 N backward	0 N; keeps the same steady speed
3	Car pulling away	engine force 3,000 N forward; resistance 800 N backward	2,200 N forward; speeds up
4	Sledge sliding on rough snow with nobody pushing	friction 60 N backward; no forward force	60 N backward; slows down
5	Lift starting to go up	cable 9,000 N up; weight 8,000 N down	1,000 N up; speeds up upward
6	Tug-of-war (picture only, do not act it out)	team A 700 N left; team B 650 N right	50 N left; rope and teams start moving left

✓ Discussion questions (5 min)

1. Station 2: "If the bike is moving, there must be more force forward than backward." Is that right? — No. At a steady speed the forces are balanced. An unbalanced force is needed to **change** speed, not to keep moving.
2. Why does a passenger lurch forward when a bus brakes? — The brakes slow the bus, but nothing slows the passenger straight away; their body tends to keep moving at the old speed (inertia) until the seat or a seat belt pushes on them.
3. A spacecraft far from any planet switches its engines off. What happens? — It keeps moving at the same speed in a straight line; nothing is needed to keep it going.

✓ Closing check (5 min, answers)

1. A box has 30 N pushing right and 30 N pushing left. What is the net force, and what could the box be doing? — **0 N; it could be at rest or moving at a steady speed in a straight line.**
2. A skater glides with 5 N of friction backward and no forward force. What happens to her speed? — **It decreases (net force 5 N backward).**
3. Draw a free-body diagram of an apple hanging from a tree. — **Weight down, pull of the stalk up, equal lengths.**

Vocabulary

force, net force (resultant force), balanced, unbalanced, free-body diagram, normal (contact) force, friction, inertia, Newton's first law

Differentiation

- Support: give station cards with the arrows already drawn; students only add labels and the net force.

- Stretch: station 7 (extra): a parachutist just after opening the parachute (drag 1,200 N up, weight 800 N down) — net 400 N up, so she slows down while still moving downward. Ask why "force upward" does not mean "moving upward".

⚠ Safety

- The coin-and-card demonstration uses a plastic cup or a sturdy beaker on a tray; flick sideways, away from faces.
- Tug-of-war is shown as a picture only; rope pulls can cause rope burns, falls and finger injuries.

Teacher notes and common misconceptions

- "Moving things need a force to keep moving." This is the biggest misconception in the unit, and many adults hold it. Everyday objects stop because of friction and air resistance, which are forces; take those away and motion continues.
- "A book on a table has no forces on it." It has at least two, and they are balanced.
- Students often draw forces acting **by** the object (for example the book pushing on the table) on the free-body diagram. Keep asking "is that force acting on this object?"

Lesson 3 — F = ma: the trolley experiment

Back to unit

Goal

Students change the pulling force on a trolley while keeping the total mass the same, calculate acceleration from distance and time, plot acceleration against force, and explain what the graph shows (Newton's second law, F = ma).

Materials

- Per group: a dynamics trolley (or a low-friction toy car of known mass); a smooth, level runway at least 1.5 m long; a bench pulley clamped at one end; about 1.5 m of string; a 10 g hanger and enough 10 g slotted masses to make 80 g in total; masking tape; a stopwatch or phone; a box of padding or a cushion at the pulley end; a tray under the hanging masses.
- Kitchen or lab scales to find the trolley's mass.
- Graph paper or a spreadsheet.

Steps

✎ Opening (5 min)

Recall station 3 from lesson 2 (the car pulling away). Ask: "If we double the unbalanced force, what happens to the acceleration? What if we double the mass instead?" Record predictions.

Setting up (10 min)

1. Mark a start line and a finish line **1.00 m** apart on the runway with tape.
2. Tie the string to the trolley, run it over the pulley and attach the hanger. The falling hanger provides the pulling force.
3. **Keep the total mass the same.** Weigh the trolley and add slotted masses on top so that trolley + everything on it + hanger = 1.0 kg in total (the example uses a trolley of about 0.92 kg plus 80 g of slotted masses and hanger). To change the force, **move** masses from the trolley to the hanger, never add new ones. This way only the force changes.
4. A hanging mass of 20 g pulls with about 0.2 N (using g ≈ 10 N/kg; with 9.8 N/kg it is 0.196 N; the difference is small compared with timing error).

✎ Main activity (20 min)

1. Hold the trolley still at the start line, release (do not push), and time it to the finish line. Do three runs at each force; record the median.
2. Calculate acceleration with **$a = 2d \div t^2$** (d = 1.00 m, starting from rest).
3. Example results (invented for teaching, total mass 1.0 kg):

Pulling force (N)	Run 1 (s)	Run 2 (s)	Run 3 (s)	Median t (s)	a = 2 × 1.00 ÷ t² (m/s²)
0.2	3.6	3.8	3.5	3.6	0.154
0.4	2.4	2.3	2.9	2.4	0.347
0.6	1.9	1.9	2.0	1.9	0.554
0.8	1.6	1.5	1.6	1.6	0.781

1. Plot acceleration (up) against force (along) and draw a line of best fit.

✓ Discussion questions (10 min)

1. What pattern does the graph show? — A straight line: equal increases in force give equal increases in acceleration. Acceleration is proportional to the unbalanced force (for a fixed mass).
2. Why does the line not go exactly through zero? — Friction. Some of the pulling force is used up balancing friction, so the line crosses the force axis a little above zero (in the example, about 0.06 N). The net force is the pull minus friction.
3. The gradient of the example line is about 1.05 m/s² per newton. What does that tell you? — Gradient = a ÷ F = 1 ÷ m, so the mass is about 1 ÷ 1.05 ≈ 0.96 kg, close to the 1.0 kg used.
4. At 0.4 N, run 3 took 2.9 s. What should we do with it? — Use the median (2.4 s), which is not pulled off by one odd run; it was probably a late start or slow stop of the stopwatch.

Introduce **Newton's second law**: F = ma, where F is the net (unbalanced) force in newtons, m the mass in kilograms and a the acceleration in m/s². One newton is the force that gives a 1 kg mass an acceleration of 1 m/s² (1 N = 1 kg·m/s²).

✓ Closing check (5 min, answers)

1. What net force gives a 1,200 kg car an acceleration of 2 m/s²? — **2,400 N.**
2. A 0.5 kg trolley has a net force of 1.5 N. What is its acceleration? — **3 m/s².**
3. Why did we move masses from the trolley to the hanger instead of adding new ones? — **To keep the total mass constant so that only the force changed (a fair test).**

Vocabulary

acceleration, velocity, net force, Newton's second law, gradient, line of best fit, median, friction, reaction time

Differentiation

- Support: give the a = 2d ÷ t² calculations for one row worked out; students complete the rest with a calculator.
- Stretch: keep the force at 0.4 N and change the total mass (add masses to the trolley: 1.0, 1.5, 2.0 kg). Predict, then test, that doubling the mass halves the acceleration. Plot a against 1/m.

⚠ Safety

- Padding or a cushion at the pulley end so the trolley does not fly off the bench; a second student catches it.
- A tray under the hanger; keep feet out from under falling masses.
- Runways on benches, not on the floor where people walk.

Teacher notes and common misconceptions

- "A bigger force means a bigger speed." It means a bigger **acceleration**: the speed keeps increasing for as long as the net force acts.
- Hand timing over 1.5–4 s has an error of roughly 0.1–0.3 s; ask students to estimate how much that changes a. Light gates, a data logger, or counting frames in slow-motion phone video make good upgrades.
- Some trolleys have a friction-compensation trick: tilt the runway very slightly until the trolley, given a small push, rolls at a steady speed. This makes the line pass much closer to zero. It is a good stretch discussion of "balancing friction with a component of weight", which is beyond this unit.

Lesson 4 — Falling, drag and terminal velocity

Back to unit

Goal

Students explain why falling objects stop speeding up (terminal velocity) using drag and weight, and test how the terminal speed of paper cases depends on their weight.

Materials

- Per group: at least 4 identical paper cupcake or muffin cases; a metre ruler or tape measure; masking tape; a stopwatch or phone.
- A marked drop height of **2.0 m** (tape on a wall or door frame). Many students cannot reach 2.0 m standing on the floor. Use a step stool only if your school allows it, with an adult holding it; otherwise use a lower height that everyone can reach standing (for example 1.5 m), mark it, and use that height instead of 2.0 m in the speed calculation (speed = drop height ÷ time).

Steps

✎ Opening (5 min)

Hold a flat sheet of paper and a crumpled sheet of the same size. Ask which will land first, then drop them together. Then drop a book and a flat sheet with the sheet resting on top of the book (they fall together). Ask: "If the paper isn't lighter than it was a moment ago, why did it fall more slowly on its own?" The answer is **air resistance (drag)**, a force that acts against motion through air or water.

Explaining terminal velocity (10 min)

Draw four free-body diagrams for a skydiver:

1. **Just after jumping:** weight large, drag almost zero → net force down → speeds up.
2. **Falling faster:** drag grows as speed grows (at these speeds, roughly with the square of the speed) → net force down but smaller → still speeds up, but less each second.
3. **Terminal velocity:** drag = weight → net force zero → no acceleration; falls at a steady speed. For a belly-down skydiver this is about 55 m/s (Wikipedia, "Terminal velocity").
4. **Parachute opens:** drag suddenly much bigger than weight → net force **up** → slows down (while still moving down) until a new, lower terminal velocity is reached.

✎ Main activity (20 min)

1. Drop one paper case, open side up, from 2.0 m. Time the fall. Three drops; take the median.

2. Repeat with 2, 3 and 4 cases nested together (same shape and size, so the drag at a given speed is about the same, but the weight doubles, triples, quadruples).
3. Paper cases reach terminal velocity very quickly, so the average speed over 2.0 m is close to the terminal speed: **speed ≈ 2.0 m ÷ time**.
4. Example results (invented for teaching):

Cases	Median time (s)	Speed = 2.0 ÷ t (m/s)
1	1.9	1.05
2	1.4	1.43
3	1.15	1.74
4	1.0	2.00

1. Plot speed against number of cases.

✓ Discussion questions (10 min)

1. Does doubling the weight double the terminal speed? — No. In the example, 2 cases fall about 1.4 times as fast as 1, not 2 times. Heavier cases need a bigger drag force to balance them, and drag rises steeply with speed, so a modest rise in speed is enough.
2. Stretch: if drag grows with the square of speed, how much faster should 4 cases fall than 1? — Weight is 4 times bigger, so drag must be 4 times bigger at terminal velocity; speed² must be 4 times bigger, so speed doubles. Example: 1.05 × 2 = 2.1 m/s, close to the measured 2.0 m/s.
3. Why are these times hard to measure well? — They are short (1–2 s), so a reaction time of about 0.1–0.2 s at each end is a big fraction. Repeats and medians help; slow-motion video helps more.
4. Where else does drag matter? — Cyclists crouching, streamlined cars, fish and birds, parachutes, and drag in water when swimming.

✓ Closing check (5 min, answers)

1. A skydiver is falling at a steady speed. Compare the drag and her weight. — **They are equal (balanced); net force zero.**
2. Her parachute opens. Which way is the net force just afterwards, and what happens to her speed? — **Upward; she slows down (but keeps moving downward).**
3. Why does a feather fall more slowly than a hammer on Earth but not on the Moon? — **On Earth air resistance on the feather is large compared with its weight; the Moon has almost no air, so there is no drag and both fall together.**

Vocabulary

air resistance, drag, terminal velocity, streamlined, average speed, reaction time

Differentiation

- Support: give the speed column worked out for one row; focus on the four skydiver diagrams.

- Stretch: test the square relationship by plotting speed² against number of cases (it should be roughly a straight line through zero).

⚠ Safety

- Use a step stool only if your school allows it, with an adult holding it; never stand on chairs or desks. Otherwise reduce the drop height.
- Keep the drop zone clear of people walking past.

Teacher notes and common misconceptions

- "Heavier things always fall faster." Without air, all objects fall with the same acceleration. With air, a heavier object of the **same shape** reaches a higher terminal speed, which is what the paper cases show.
- "At terminal velocity there are no forces." There are two large forces, balanced.
- "When the parachute opens, the skydiver goes up." Video taken from a falling camera can look like this; in fact she slows down, and the camera keeps falling faster.
- Drag growing with the square of speed is a simplification that fits these speeds reasonably well (Wikipedia, "Drag (physics)").

Lesson 5 — Force pairs, car safety + unit check

Back to unit

Goal

Students identify Newton's third-law force pairs, use force and time ideas to explain seat belts and crumple zones, and complete the unit check.

Materials

- Two spring newtonmeters hooked together (one per pair of students).
- Balloon rocket: a long balloon, a drinking straw, about 5 m of smooth string tied tight across the room, tape.
- Unit check sheets.

Steps

✎ Opening (5 min): two newtonmeters

Pairs hook two newtonmeters together and pull gently in opposite directions. Whatever one reads, the other reads the same, even when one student "tries harder". Introduce **Newton's third law**: when object A pushes or pulls on object B, B pushes or pulls on A with a force of the same size in the opposite direction. The two forces act on **different** objects, so they never cancel each other out.

✎ Main activity part A: finding the pairs (10 min)

Teacher demonstration: the balloon rocket. Thread the straw on the string, tape the blown-up (not tied) balloon to the straw, and let go. The balloon pushes air backward; the air pushes the balloon forward.

Students write the partner force for each:

Force	Its third-law partner
Your foot pushes the ground backward as you walk	The ground pushes your foot forward
The Earth pulls an apple down (its weight)	The apple pulls the Earth up, with the same size of force
A swimmer's hands push water backward	The water pushes the swimmer forward
A rocket pushes hot gas downward	The gas pushes the rocket upward

Point out: a book on a table has weight (Earth pulls book) and the table's push (table pushes book). These are equal and opposite but are **not** a third-law pair: both act on the book, and

they are different kinds of force. Its third-law partners are "book pulls Earth" and "book pushes table".

✎ Main activity part B: why seat belts and crumple zones work (10 min)

1. In a crash the car and passengers must lose all their speed. From F = ma, the force on a passenger depends on how quickly they slow down: stopping in a longer time means a smaller acceleration and so a smaller force.
2. **Crumple zones** are parts of a car (usually the front) designed to crush in a controlled way, increasing the time over which the car's speed changes in a collision (Wikipedia, "Crumple zone").
3. **Seat belts** hold the passenger to the car so they slow down with it, instead of continuing forward (first law) and hitting the dashboard or windscreen over a much shorter time. A CDC summary quoted on Wikipedia's "Seat belt" page says seat belts "reduce serious crash-related injuries and deaths by about half".
4. Worked comparison (invented numbers): a 60 kg passenger slows from 15 m/s to 0. If this takes 0.1 s, a = 150 m/s² and F = 60 × 150 = 9,000 N. If a crumple zone and belt stretch it to 0.5 s, a = 30 m/s² and F = 1,800 N, five times smaller.

✓ Unit check (25 min)

10 questions, 20 marks. Use g = 10 N/kg unless told otherwise.

1. A rock has a mass of 3 kg. (a) What is its weight on Earth? (b) What is its mass on the Moon? (2 marks)
2. Explain the difference between mass and weight. (2 marks)
3. A spring stretches 4 cm with 2 N. How far will it stretch with 5 N, assuming it obeys Hooke's law? (2 marks)
4. A cyclist moves at a steady speed with a forward force of 50 N. What is the total backward force? Explain. (2 marks)
5. A 1,000 kg car has an engine force of 2,500 N and resistance of 500 N. (a) What is the net force? (b) What is its acceleration? (2 marks)
6. In a trolley experiment, the repeat times were 2.2 s, 2.3 s and 3.0 s. What value should be used, and why? (2 marks)
7. A trolley experiment gave a straight-line graph of acceleration against force that crossed the force axis at 0.1 N instead of 0. Suggest why. (2 marks)
8. Describe what happens to the forces and the speed of a skydiver from jumping until she reaches terminal velocity. (2 marks)
9. Ana says "When I push on a wall, the wall doesn't push back, because it doesn't move." Is she right? Explain using Newton's third law. (2 marks)
10. Explain how a crumple zone reduces the force on passengers in a crash. (2 marks)

Answer guide and marking notes

1. (a) 30 N (1); (b) 3 kg — mass does not change (1).
2. Mass is the amount of matter, in kg, and is the same everywhere (1); weight is the force of gravity on a mass, in N, and depends on where you are (1).
3. 2 cm per newton (1), so 10 cm (1).
4. 50 N (1); at steady speed the forces are balanced / net force is zero (1).

5. (a) 2,000 N (1); (b) 2 m/s² (1). Allow (b) follow-through from a wrong (a).
6. 2.3 s (1), the median, because 3.0 s is probably a timing mistake and the median is not pulled off by one odd value (1). Accept "the mean of 2.2 and 2.3 after leaving out 3.0" for 1 mark only if a reason is given.
7. Friction (1): some of the pulling force (about 0.1 N) was used to balance friction before the trolley would accelerate (1).
8. At first weight is bigger than drag, so she speeds up (1); drag grows with speed until it equals her weight, then the net force is zero and she falls at a steady (terminal) speed (1).
9. No (1); the wall pushes back on her hand with an equal and opposite force; the wall doesn't move because other forces on it (from the ground and building) balance her push (1).
10. It crushes so the car takes longer to stop (1); a longer stopping time means a smaller acceleration, so from F = ma a smaller force on the passengers (1). Do not award the second mark for "absorbs the force" without the time idea.

There is no pass mark. Use the results to see which ideas to revisit: questions 4, 8 and 9 test the main misconceptions in the unit.

Vocabulary

Newton's third law, force pair, interaction, crumple zone, seat belt, collision

Differentiation

- Support: allow a formula sheet (W = mg, F = ma, a = 2d ÷ t²) and a calculator; read questions aloud if needed.
- Stretch: momentum = mass × velocity. Ask students to show that the passenger's change of momentum in part B is 900 kg·m/s in both cases, and that force × time = 900 in both cases too.

⚠ Safety

- The balloon rocket string is tied at head height or above, across a part of the room where nobody walks during the demonstration. Students with latex allergies do not handle balloons; use latex-free balloons.
- Do not demonstrate the third law with students on wheeled chairs or skateboards pushing each other; falls are a real risk. The newtonmeters show the same idea safely.

Teacher notes and common misconceptions

- "The bigger object pushes harder." In a collision between a truck and a car, the forces on each are equal in size; the car's occupants are hurt more because the same force gives the smaller mass a bigger acceleration.
- "Third-law pairs cancel out." They act on different objects, so they cannot cancel. Only forces on the **same** object add up to a net force.
- Weight and the normal force on a resting book are the classic false pair (see part A).