**5. FORCES**

1. Forces and their interactions
2. Work done and energy transfer
3. Forces and elasticity
4. *Practical activity: investigate the relationship between force and extension for a spring.*
5. Moments, levers and gears (physics only)
6. Pressure and pressure differences in fluids (physics only)
7. Forces and motion
8. *Practical activity: investigate the effect of varying the force on the acceleration of an object of constant mass, and the effect of varying the mass of an object on the acceleration produced by a constant force.*
9. Momentum (HT only)
10. *Practical activity: make observations to identify the suitability of apparatus to measure the frequency, wavelength and speed of waves in a ripple tank and waves in a solid and take appropriate measurements.*

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| **4.5 Forces** |  |  |  |
| *4.5.1 Forces and their interactions* |  |  |  |
| **4.5.1.1 Scalar and vector quantities** |  |  |  |
| 1. Scalar quantities have magnitude (size) only.
2. Vector quantities have magnitude and an associated direction.
3. A vector quantity may be represented by an arrow. The length of the arrow represents the magnitude, and the direction of the arrow the direction of the vector quantity.
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| **4.5.1.2 Contact and non-contact forces** |  |  |  |
| 1. A force is a push or pull that acts on an object due to the interaction with another object. All forces between objects are either:
* contact forces – the objects are physically touching
* non-contact forces – the objects are physically separated.
1. Examples of contact forces include
	* friction
	* air resistance
	* tension
	* normal contact force
2. Examples of non-contact forces are
	* gravitational force
	* electrostatic force
	* magnetic force
3. Force is a vector quantity.
4. Students should be able to describe the interaction between pairs of objects which produce a force on each object. The forces to be represented as vectors.
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| **4.5.1.3 Gravity** |  |  |  |
| 1. Weight is the force acting on an object due to gravity.
2. The force of gravity close to the Earth is due to the gravitational field around the Earth.
3. The weight of an object depends on the gravitational field strength where the object is.
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| a) The weight of an object can be calculated using the equation:* $weight=mass x gravitational field strength$
* $W=m x g$

weight, *W*, in newtons, Nmass, *m*, in kilograms, kggravitational field strength, *g*, in newtons per kilogram, N/kg (In any calculation the value of the gravitational field strength (*g*) will be given.)b) The weight of an object may be considered to act at a single point referred to as the object’s ‘centre of mass’.c) The weight of an object and the mass of an object are directly proportional.d) Weight is measured using a calibrated newton meter (spring-balance). |  |  |  |
| **4.5.1.4 Resultant forces** |  |  |  |
| 1. A number of forces acting on an object may be replaced by a single force that has the same effect as all the original forces acting together.
2. This single force is called the resultant force.
3. Be able to calculate the resultant of two forces that act in a straight line.

(HT only, d to g)1. describe examples of the forces acting on an isolated object or system
2. use free body diagrams to describe qualitatively examples where several forces lead to a resultant force on an object, including balanced forces when the resultant force is zero.
3. know a single force can be resolved into two components acting at right angles to each other. The two component forces together have the same effect as the single force.
4. use vector diagrams to illustrate resolution of forces, equilibrium situations and determine the resultant of two forces, to include both magnitude and direction (scale drawings only).
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| *4.5.2 Work done and energy transfer* |  |  |  |
| a) When a force causes an object to move through a distance work is done on the object. So a force does work on an object when the force causes a displacement of the object.b) The work done by a force on an object can be calculated using the equation:* $work done=force x distance moved along the line of action of the force$
* $W=F x s$

work done, *W*, in joules, Jforce, *F*, in newtons, Ndistance, *s*, in metres, me) One joule of work is done when a force of one newton causes a displacement of one metre.1 joule = 1 newton-metref) Students should be able to describe the energy transfer involved when work is done.g) Students should be able to convert between newton-metres and joules.h) Work done against the frictional forces acting on an object causes a rise in the temperature of the object. |  |  |  |
| *4.5.3 Forces and elasticity* |  |  |  |
| a) Students should be able to:* give examples of the forces involved in stretching, bending or compressing an object
* explain why, to change the shape of an object (by stretching, bending or compressing), more than one force has to be applied – this is limited to stationary objects only
* describe the difference between elastic deformation and inelastic deformation caused by stretching forces.

b) The extension of an elastic object, such as a spring, is directly proportional to the force applied, provided that the limit of proportionality is not exceeded.* $force=spring constant x extension$
* $F=k x e$

force, *F*, in newtons, Nspring constant, *k*, in newton per metre, N/mextension, *e*, in metres, mc) This relationship also applies to the compression of an elastic object, where ‘*e*’ would be the compression of the object.d) A force that stretches (or compresses) a spring does work and elastic potential energy is stored in the spring. Provided the spring is not permanently deformed, the work done on the spring and the elastic potential energy stored are equal.Students should be able to:1. describe the difference between a linear and non-linear relationship between force and extension
2. calculate a spring constant in linear cases
3. interpret data from an investigation of the relationship between force and extension
4. calculate work done in stretching (or compressing) a spring (up to the limit of proportionality) using the equation:
* $elastic potential energy=\frac{1}{2} x spring constant x extension^{2}$
* $E\_{e}= \frac{1}{2} x k x e^{2}$

This equation is also given in Changes in energy.i) Students should be able to calculate relevant values of stored energy and energy transfers. |  |  |  |
| **Required practical activity 6**: investigate the relationship between force and extension for a spring. |  |  |  |
| *4.5.4 Moments, levers and gears (physics only)* |  |  |  |
| a) A force or a system of forces may cause an object to rotate.b) Students should be able to describe examples in which forces cause rotation.c) The turning effect of a force is called the moment of the force. The size of the moment is defined by the equation:* $moment=force x distance$
* $M=F x d$

moment of a force, *M*, in newton-metres, Nmforce, *F*, in newtons, Ndistance, *d*, is the perpendicular distance from the pivot to the line of action of the force, in metres, m.d) If an object is balanced, the total clockwise moment about a pivot equals the total anticlockwise moment about that pivot.e) Students should be able to calculate the size of a force, or its distance from a pivot, acting on an object that is balanced.f) A simple lever and a simple gear system can both be used to transmit the rotational effects of forces.g) Students should be able to explain how levers and gears transmit the rotational effects of forces. |  |  |  |
| *4.5.5 Pressure and pressure differences in fluids (physics only)* |  |  |  |
| **4.5.5.1 Pressure in a fluid**  |  |  |  |
| ***4.5.5.1.1 Pressure in a fluid 1*** |  |  |  |
| a) A fluid can be either a liquid or a gas.b) The pressure in fluids causes a force normal (at right angles) to any surface.c) The pressure at the surface of a fluid can be calculated using the equation:* $pressure= \frac{force (normal to the surface)}{area}$
* $P= \frac{F}{A}$

pressure, *p*, in pascals, Pa (or N/m**2**)force, *F*, in newtons, Narea, *A*, in metres squared, m**2** |  |  |  |
| ***4.5.5.1.2 Pressure in a fluid 2 (HT only)*** |  |  |  |
| a) The pressure due to a column of liquid can be calculated using the equation:* $pressure=height of the column x density of the liquid$
* $p=h x ρ x g$

pressure, *p*, in pascals, Paheight of the column, *h*, in metres, mdensity, *ρ*, in kilograms per metre cubed, kg/m3gravitational field strength, g, in newtons per kilogram, N/kg (In any calculation the value of the gravitational field strength (*g*) will be given.)b) Students should be able to explain why, in a liquid, pressure at a point increases with the height of the column of liquid above that point and with the density of the liquid.c) Students should be able to calculate the differences in pressure at different depths in a liquid.d) A partially (or totally) submerged object experiences a greater pressure on the bottom surface than on the top surface. This creates a resultant force upwards. This force is called the upthrust.e) Students should be able to describe the factors which influence floating and sinking. |  |  |  |
| **4.5.5.2 Atmospheric pressure** |  |  |  |
| 1. The atmosphere is a thin layer (relative to the size of the Earth) of air round the Earth. The atmosphere gets less dense with increasing altitude.
2. Air molecules colliding with a surface create atmospheric pressure.
3. The number of air molecules (and so the weight of air) above a surface decreases as the height of the surface above ground level increases. So as height increases there is always less air above a surface than there is at a lower height. So atmospheric pressure decreases with an increase in height.

Students should be able to:1. describe a simple model of the Earth’s atmosphere and of atmospheric pressure
2. explain why atmospheric pressure varies with height above a surface.
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| *4.5.6 Forces and motion* |  |  |  |
| **4.5.6.1 Describing motion along a line** |  |  |  |
| ***4.5.6.1.1 Distance and displacement*** |  |  |  |
| 1. Distance is how far an object moves. Distance does not involve direction. Distance is a scalar quantity.
2. Displacement includes both the distance an object moves, measured in a straight line from the start point to the finish point and the direction of that straight line. Displacement is a vector quantity.
3. Students should be able to express a displacement in terms of both the magnitude and direction.
 |  |  |  |
| ***4.5.6.1.2 Speed*** |  |  |  |
| 1. Speed does not involve direction. Speed is a scalar quantity.
2. The speed of a moving object is rarely constant. When people walk, run or travel in a car their speed is constantly changing.
3. The speed at which a person can walk, run or cycle depends on many factors including: age, terrain, fitness and distance travelled.
4. Students should be able to recall typical values of speed for a person walking, running and cycling as well as the typical values of speed for different types of transportation systems. Typical values may be taken as:
	* + - walking ≈ 1.5 m/s
			- running ≈ 3 m/s
			- cycling ≈ 6 m/s
5. It is not only moving objects that have varying speed. The speed of sound and the speed of the wind also vary.
6. A typical value for the speed of sound in air is 330 m/s.
7. Students should be able to make measurements of distance and time and then calculate speeds of objects.

h) For an object moving at constant speed the distance travelled in a specific time can be calculated using the equation:* $distance travelled=speed x time$
* $s=v x t$

distance, *s*, in metres, mspeed, *v*, in metres per second, m/stime, *t*, in seconds, si) Students should be able to calculate average speed for non-uniform motion. |  |  |  |
| ***4.5.6.1.3 Velocity*** |  |  |  |
| 1. The velocity of an object is its speed in a given direction. Velocity is a vector quantity.
2. Students should be able to explain the vector–scalar distinction as it applies to displacement, distance, velocity and speed.
3. (HT only) Students should be able to explain qualitatively, with examples, that motion in a circle involves constant speed but changing velocity.
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| ***4.5.6.1.4 The distance–time relationship*** |  |  |  |
| 1. If an object moves along a straight line, the distance travelled can be represented by a distance–time graph.
2. The speed of an object can be calculated from the gradient of its distance–time graph.
3. (HT only) If an object is accelerating, its speed at any particular time can be determined by drawing a tangent and measuring the gradient of the distance–time graph at that time.

Students should be able to:1. draw distance–time graphs from measurements
2. extract and interpret lines and slopes of distance–time graphs, translating information between graphical and numerical form
3. determine speed from a distance–time graph
 |  |  |  |
| ***4.5.6.1.5 Acceleration*** |  |  |  |
| a) The average acceleration of an object can be calculated using the equation:* $acceleration= \frac{change in velocity}{time taken}$
* $a= \frac{Δv}{t}$

acceleration, *a*, in metres per second squared, m/s**2**change in velocity, Δ*v*, in metres per second, m/stime, *t*, in seconds, s1. An object that slows down is decelerating.
2. Students should be able to estimate the magnitude of everyday accelerations.
3. The acceleration of an object can be calculated from the gradient of a velocity–time graph.
4. (HT only) The distance travelled by an object (or displacement of an object) can be calculated from the area under a velocity–time graph.

Students should be able to:1. draw velocity–time graphs from measurements and interpret lines and slopes to determine acceleration
2. (HT only) interpret enclosed areas in velocity–time graphs to determine distance travelled (or displacement)
3. (HT only) measure, when appropriate, the area under a velocity–time graph by counting squares.
 |  |  |  |
| a) The following equation applies to uniform acceleration (e.g. acceleration due to gravity):* $final velocity^{2}- initial velocity^{2}=2 x acceleration x distance$
* $v^{2}- u^{2}=2 x a x s$

final velocity, *v*, in metres per second, m/sinitial velocity, *u*, in metres per second, m/sacceleration, *a*, in metres per second squared, m/s**2**distance, *s*, in metres, mb) Near the Earth’s surface any object falling freely under gravity has an acceleration of about 9.8 m/s**2**.c) An object falling through a fluid initially accelerates due to the force of gravity. Eventually the resultant force will be zero and the object will move at its terminal velocity.(Physics only) Students should be able to:d) draw and interpret velocity–time graphs for objects that reach terminal velocitye) interpret the changing motion in terms of the forces acting. |  |  |  |
| **4.5.6.2 Forces, accelerations and Newton’s Laws of motion** |  |  |  |
| ***4.5.6.2.1 Newton’s First Law*** |  |  |  |
| 1. Newton’s First Law:

If the resultant force acting on an object is zero:* and the object is stationary, the object remains stationary
* and the object is moving, the object continues to move at the same speed and in the same direction and at the same velocity.
1. When a vehicle travels at a steady speed the resistive forces balance the driving force.
2. The velocity (speed and/or direction) of an object will only change if a resultant force is acting on the object.

Students should be able to apply Newton’s First Law to explain:1. the motion of objects moving with a uniform velocity
2. the motion of objects where the speed and/or direction changes.
3. (HT only) The tendency of objects to continue in their state of rest or of uniform motion is called inertia.
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| ***4.5.6.2.2 Newton’s Second Law*** |  |  |  |
| 1. Newton’s Second Law:

The acceleration of an object is proportional to the resultant force acting on the object, and inversely proportional to the mass of the object.1. As an equation:

$$resultant force=mass x acceleration$$$$F=m x a$$force, *F*, in newtons, Nmass, *m*, in kilograms, kgacceleration, *a*, in metres per second squared, m/s**2**1. Students should recognise and be able to use the symbol for proportionality, ∝
2. (HT only) Students should be able to explain that:
* inertial mass is a measure of how difficult it is to change the velocity of an object
* inertial mass is defined as the ratio of force over acceleration.
1. Students should be able to estimate the speed, accelerations and forces involved in large accelerations for everyday road transport.
2. Students should recognise and be able to use the symbol that indicates an approximate value or approximate answer, ≈, ~.
 |  |  |  |
| **Required practical activity 7:** investigate the effect of varying the force on the acceleration of an object of constant mass, and the effect of varying the mass of an object on the acceleration produced by a constant force. |  |  |  |
| ***4.5.6.2.3 Newton’s Third Law*** |  |  |  |
| Newton’s Third Law:* Whenever two objects interact, the forces they exert on each other are equal and opposite.
* Students should be able to apply Newton’s Third Law to examples of equilibrium situations.
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| **4.5.6.3 Forces and braking** |  |  |  |
| ***4.5.6.3.1 Stopping distance*** |  |  |  |
| 1. The stopping distance of a vehicle is the sum of the distance the vehicle travels during the driver’s reaction time (thinking distance) and the distance it travels under the braking force (braking distance).
2. For a given braking force the greater the speed of the vehicle, the greater the stopping distance.
3. (Physics only) Students should be able to estimate how the distance for a vehicle to make an emergency stop varies over a range of speeds typical for that vehicle.
4. (Physics only) Students will be required to interpret graphs relating speed to stopping distance for a range of vehicles.
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| ***4.5.6.3.2 Reaction time*** |  |  |  |
| 1. Reaction times vary from person to person. Typical values range from 0.2 s to 0.9 s.
2. A driver’s reaction time can be affected by tiredness, drugs and alcohol. Distractions may also affect a driver’s ability to react.

Students should be able to:1. explain methods used to measure human reaction times and recall typical results
2. interpret and evaluate measurements from simple methods to measure the different reaction times of students
3. evaluate the effect of various factors on thinking distance based on given data.
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| ***4.5.6.3.3 Factors affecting braking distance 1*** |  |  |  |
| 1. The braking distance of a vehicle can be affected by adverse road and weather conditions and poor condition of the vehicle.
2. Adverse road conditions include wet or icy conditions. Poor condition of the vehicle is limited to the vehicle’s brakes or tyres.

Students should be able to:1. explain the factors which affect the distance required for road transport vehicles to come to rest in emergencies, and the implications for safety
2. estimate how the distance required for road vehicles to stop in an emergency varies over a range of typical speeds.
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| ***4.5.6.3.4 Factors affecting braking distance 2*** |  |  |  |
| 1. When a force is applied to the brakes of a vehicle, work done by the friction force between the brakes and the wheel reduces the kinetic energy of the vehicle and the temperature of the brakes increases.
2. The greater the speed of a vehicle the greater the braking force needed to stop the vehicle in a certain distance.
3. The greater the braking force the greater the deceleration of the vehicle. Large decelerations may lead to brakes overheating and/or loss of control.

Students should be able to:1. explain the dangers caused by large decelerations
2. (HT only) estimate the forces involved in the deceleration of road vehicles in typical situations on a public road.
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| *4.5.7 Momentum (HT only)* |  |  |  |
| **4.5.7.1 Momentum is a property of moving objects** |  |  |  |
| Momentum is defined by the equation:* $momentum=mass x velocity$
* $p=m x v$

momentum, *p*, in kilograms metre per second, kg m/smass, *m*, in kilograms, kgvelocity, *v*, in metres per second, m/s |  |  |  |
| **4.5.7.2 Conservation of momentum** |  |  |  |
| 1. In a closed system, the total momentum before an event is equal to the total momentum after the event.
2. This is called conservation of momentum.

Students should be able to use the concept of momentum as a model to:1. describe and explain examples of momentum in an event, such as a collision
2. (physics only) complete calculations involving an event, such as the collision of two objects.
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| **4.5.7.3 Changes in momentum (physics only)** |  |  |  |
| 1. When a force acts on an object that is moving, or able to move, a change in momentum occurs.
2. The equations $F=m x a and a= \frac{v-u}{t}$ combine to give the equation $F=m x \frac{Δv}{Δt}$

where *m* Δ*v* = change in momentumie force equals the rate of change of momentum.1. Students should be able to explain safety features such as:
* air bags
* seat belts
* gymnasium crash mats
* cycle helmets
* cushioned surfaces for playgrounds

with reference to the concept of rate of change of momentum.1. Students should be able to apply equations relating force, mass, velocity and acceleration to explain how the changes involved are inter-related.
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**PHYSICS EQUATIONS TO LEARN BY HEART (SEPARATE PHYSICS)**

| **FORCES** |
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|  | **Quantity** | **Unit** | **Equation** |
| *FORCES* | *14* | **W****m****g** | weightmassgravitational field strength | newtonkilogramnewton per kilogram | NkgN/kg | $$W=m x g$$ |
| *15* | **W****F****s** | work doneforce distance travelled | joulenewtonmetre | JNm | $$W=F x s$$ |
| *16* | **F****k****e** | forcespring constantextension | newtonnewton per metremetres | NN/mm | $$F=k x e$$ |
| *17\** | **M****F****d** | momentforcedistance (perpendicular to pivot) | newton metrenewtonkilogram | NmNkg | $$M=F x d$$ |
| *18\** | **p****F****A** | pressureforcearea | pascalnewtonmetre**2** | PaNm**2** | $$p=\frac{F}{A}$$ |
| *19* | **s****v****t** | distancevelocitytime | metremetre per secondsecond | mm/ss | $$s=v x t$$ |
| *20* | **a****v****u****t** | accelerationfinal velocityinitial velocitytime | metre per second**2**metre per secondmetre per secondsecond | m/s**2**m/sm/ss | $a=\frac{Δv}{t}$OR$$a=\frac{(v-u)}{t}$$ |
| *21* | **F****m****a** | forcemassacceleration | newtonkilogrammetre per second**2** | Nkgm/s**2** | $$F=m x a$$ |
| *22HT* | **p****m****v** | momentummassvelocity | kilogram metre per secondkilogrammetre per second | kg m/skgm/s | $$p=m x v$$ |

 \* For separate sciences only.

 HT Higher tier only.