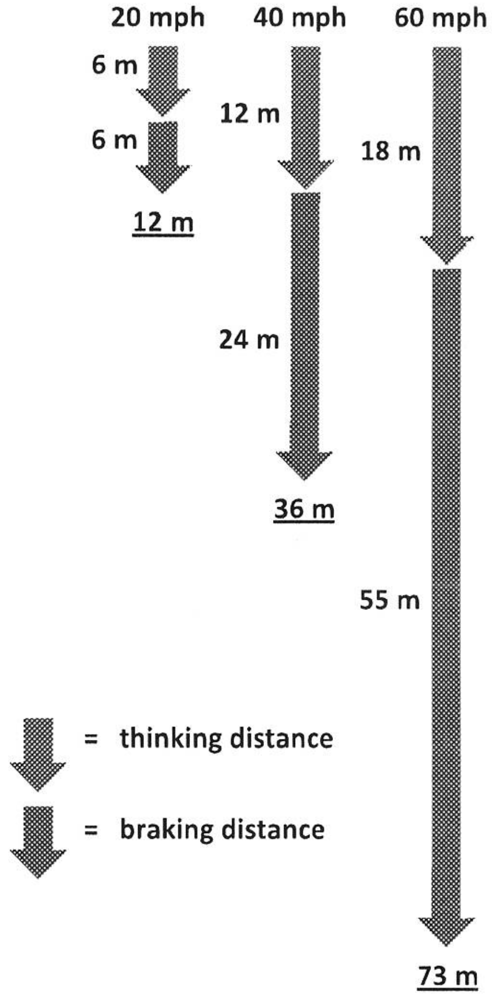
P2 Topic 4: Stopping Distances

The **greater the speed** of a vehicle the **greater the braking force** needed to stop it in a certain distance. For a given braking force the **greater the speed**, the **greater the stopping distance**.

Calculating stopping distances

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)**.The chart opposite shows **typical car stopping distances** at different speeds. Notice that braking distance increases greatly with speed. Braking distance is also affected by the **mass of the vehicle** e.g. if a wagon is carrying a heavy load it will take longer to come to a stop.

Car stopping distances



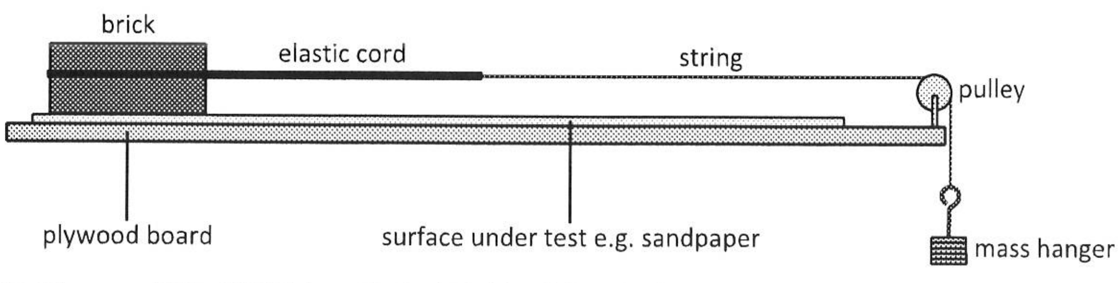
A driver's reaction time can be affected by **tiredness**, **drugs** and **alcohol**. **Distractions** such as changing radio stations or looking for equipment may also affect a driver's ability to react.

When the brakes of a vehicle are applied, **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**.

A vehicle's braking distance can be affected by **adverse road and weather conditions** including wet or icy conditions. Braking distance is also affected by **poor condition** of the car's **brakes** or **tyres**.

Investigating the frictional forces of surfaces

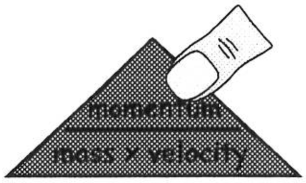
To investigate how the **frictional forces** of different surfaces vary you could set up the apparatus in the diagram below. You **change the surface under test** and keep all other factors the same. As more masses are added to the hanger, the force pulling on the brick increases until it begins to slide. The greater the frictional force between the two surfaces the greater the mass needed to make the brick slide. Various surfaces can be tested e.g. sandpaper, plastic and rubber.



P2 Topic 4: Momentum

Momentum is a property of **moving objects**. Momentum is calculated using the following equation:

momentum (kg m/s) = mass (kg) × velocity (m/s)

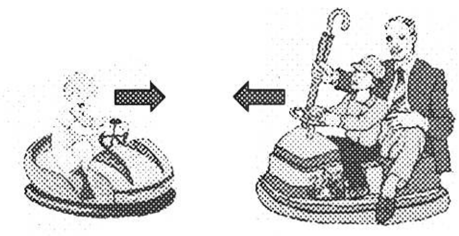


Therefore the greater the mass and velocity of an object the greater its momentum will be. Momentum is a **vector quantity** because it depends on the objects **velocity**. Heavy objects are much harder to slow down or change direction because they have a lot of momentum. The momentum of an object can change if it **speeds up or slows down**, or if it **changes direction**.

In a **closed system** (no external forces acting) the total momentum before an event such as a collision is **equal to** the total momentum after the event. This is called **conservation of momentum**. This is most easily observed when forces are acting along a straight line (**linear momentum**).

Example - bumper car collision

One bumper car has a total mass of 120 kg and is moving at 4 m/s to the right. Another car has a total mass of 200 kg and is moving at 3m/s to the left. The two bumper cars collide and move off together. What is the velocity of the cars after the collision?



120 kg, 4 m/s   200 kg, 3 m/s

Answer - total momentum before collision = 120 x 4 = 480 kg m/s to the right
200 x 3 = 600 kg m/s to the left

The cars are moving in **opposite directions** therefore the total momentum after they collide = momentum to the left - momentum to the right = 600 - 480 = 120 kg m/s to the left.

Velocity = total momentum ÷ total mass = 120 ÷ 320 = 0.37 m/s to the left

Force and momentum (H)

If a **force** acts on an object for a **period of time** the **change in momentum** can be calculated using the following equation:

force (N) = $\frac{\text{change in momentum (kg m/s)}}{\text{time (s)}}$ $F = \frac{(mv - mu)}{t}$ (= rate of change of momentum)

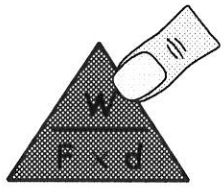
Car safety - When a person is involved in a **car crash** their **momentum changes very quickly** resulting in **very large forces** acting on their body. The **impact force** on a person can be **reduced** by increasing the amount of time taken for them to slow down. During a car crash **seat belts**, **crumple zones** and **air bags** all act to **reduce peoples' rate of change of momentum**.

P2 Topic 4: Work and Power

Work

When a force causes an object to move through a distance **work** is done. Work can be calculated using the following equation:

$$W\ (J) = F\ (N) \times d\ (m)$$



W is the work done in joules, J
F is the force applied in newtons, N
d is the distance moved in the direction of the force in metres, m

When work is done **energy is transferred from one form into another** e.g. when a car slows down **kinetic energy** is converted to **heat energy** due to friction between the wheels and brakes. Work is often being done against **frictional forces**.

Example

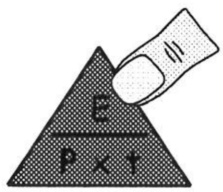
A man pushes a wheelbarrow with a force of 100 N for a distance of 20 m. How much work does he do?

Answer - $W = F \times d = 100\ N \times 20\ m = \underline{2000\ J}$

Power

Power is the work done or energy transferred in a given **time** (the **rate** at which work is done). Power can be calculated using the following equation:

$$P\ (W) = \frac{E\ (J)}{t\ (s)}$$



P is the power in watts, W (1 W is 1 J of energy transferred per second.)
E is the energy transferred in joules, J
t is the time taken in seconds, s

Example

A lawnmower transfers 6000 J of energy in 5 s. What is its power output?

Answer - $P = E \div t = 6000\ J \div 5\ s = \underline{1200\ W}$

P2 Topic 4: Gravitational Potential Energy

Gravitational potential energy is the energy that an object has due to its position in a gravitational field.

When an object is **raised vertically** (lifted up) work is done **against the force of gravity** and the object **gains** gravitational potential energy.

Calculating gravitational potential energy (GPE)

The change in gravitational potential energy when an object is raised vertically can be calculated using the following equation:

GPE (J) = m (kg) × g (N/kg) × h (m)

GPE is the change in gravitational potential energy in joules, J

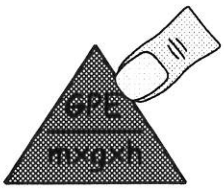
m is the mass in kilograms, kg

g is the gravitational field strength in newtons per kilogram, N/kg

h is the change in height in metres, m

On Earth the gravitational field strength is approximately **10 N/kg**

This equation can be put into a **formula triangle**. Cover over the quantity you want to find out with your finger tip and whatever is left shows you how to do the calculation.



Example

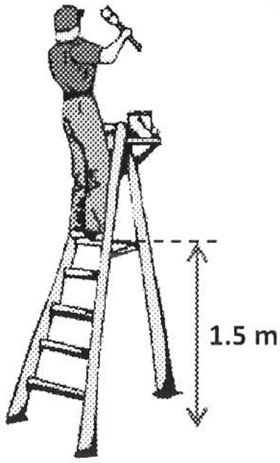
A painter with a mass of 80 kg climbs up a step ladder to a height of 1.5 m.

Question - How much gravitational potential energy does he gain?

Answer - GPE (J) = m (kg) × g (N/kg) × h (m)

= 80 kg × 10 N/kg × 1.5 m

= 1200 J



P2 Topic 4: Kinetic Energy

The **kinetic energy** of an object depends on its **mass** and its **speed**.

Calculating kinetic energy (KE)

The kinetic energy of a moving object can be calculated using the following equation:

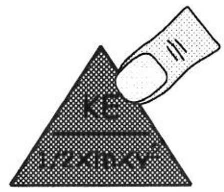
$$KE = 1/2 \times m \times v^2$$

KE is the kinetic energy in joules, J

m is the mass in kilograms, kg

v is the speed in metres per second, m/s

This equation can be put into a **formula triangle**. Cover over the quantity you want to find out with your finger tip and whatever is left shows you how to do the calculation.



An increase in speed makes the biggest difference

Increasing the speed of an object makes a **bigger difference** to the amount of kinetic energy it has than increasing its mass. This is because kinetic energy depends on the speed **squared** so if you **double** the speed, the kinetic energy increases by a factor of **four**.

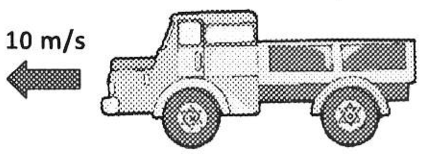
Example

A truck with a mass of 2000 kg and a car with a mass of 1000 kg are both travelling at 10 m/s.

Question 1 - How much kinetic energy does each vehicle have?

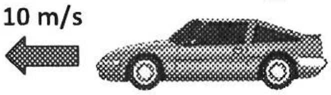
truck = 2000 kg

10 m/s



car = 1000 kg

10 m/s



$KE = 1/2 \times m \times v^2$

$= 1/2 \times 2000\ kg \times (10\ m/s)^2$

$= \underline{100\ 000\ J}$

$KE = 1/2 \times m \times v^2$

$= 1/2 \times 1000\ kg \times (10\ m/s)^2$

$= \underline{50\ 000\ J}$

Question 2 - If the car doubles its speed how much kinetic energy does it have?

$$KE = 1/2 \times m \times v^2 = 1/2 \times 1000\ kg \times (20\ m/s)^2 = \underline{200\ 000\ J}$$

P2 Topic 4: Conservation of Energy

The principle of **conservation of energy** states that energy cannot be created or destroyed; it can only be transformed into different forms. For example:

- When a skydiver falls his gravitational potential energy (GPE) is transformed into kinetic energy (KE) and a little heat and sound energy.
- A motor bike transforms chemical energy into kinetic, heat and sound energy.
- When a car brakes kinetic energy is transformed into heat energy in the brakes and a little sound energy.

Using the conservation of energy principle to calculate the speed of a falling object

When an object falls its gravitational potential energy (GPE) is transformed mainly into kinetic energy. If we ignore the small amount of energy converted into heat and sound due to air resistance we can calculate the speed the object reaches when it falls a certain height:

kinetic energy gained ($1/2mv^2$) = gravitational potential energy lost (mgh)

Example

A diver with a mass of 70 kg dives from a height of 5 m into a swimming pool.

Question – What is the diver's speed as he enters the water?

Answer – GPE (J) = 70 kg x 10 N/kg x 5 m

= 3500 J

KE (J) = $1/2mv^2$ = 3500 J (conservation of energy)

Therefore v^2 = KE ÷ 1/2m = 3500 ÷ 35 = 100

Therefore v = $\sqrt{100}$ = 10 m/s

Braking distance and the velocity of a vehicle (H)

When a vehicle brakes its kinetic energy is transferred into heat energy by the brakes. The work done by the brakes is equal to the kinetic energy of the vehicle:

Work done by brakes ($F \times d$) = kinetic energy ($1/2mv^2$)

F = maximum braking force

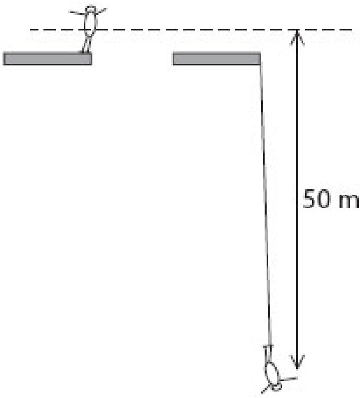
d = braking distance

When the velocity is **doubled** the kinetic energy increases by a factor of **four** because kinetic energy depends on v^2. The maximum braking force cannot be increased, therefore the braking distance must increase by a factor of four to transfer all of the kinetic energy.

Questions

Q1.

A 60 kg student weighs 600 N.
He does a bungee jump.



The bungee cord becomes straight and starts to stretch when he has fallen 50 m.

(a) Complete the sentence by putting a cross (☒) in the box next to your answer.

He first stops moving

(1)

☐ **A** before all the energy has disappeared

☐ **B** before the bungee cord starts to stretch

☐ **C** when the bungee cord is stretched the most

☐ **D** when the elastic potential energy is zero

(b) Complete the sentence by putting a cross (☒) in the box next to your answer.

When his speed is 10 m/s his momentum is

(1)

☐ **A** 600 kg m/s

☐ **B** 3 000 kg m/s

☐ **C** 6 000 N m/s

☐ **D** 30 000 N m/s

(c) (i) Calculate the change in gravitational potential energy as the student falls 50 m.

Give the unit.

(3)

change in gravitational potential energy = ... unit . . . .

(ii) State at what point in the bungee jump the student has maximum kinetic energy.

(1)

. . . .

. . . .

(iii) Explain why his maximum kinetic energy is likely to be less than your answer to (c)(i).

(2)

. . . .

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(Total for Question = 8 marks)

Q2.

A pilot begins to land an aircraft.

(a) The height of the aircraft decreases from 200 m above the ground to 100 m.

(i) What happens to the gravitational potential energy of the aircraft?

Put a cross (☒) in the box next to your answer.

(1)

☒ **A** it becomes zero

☒ **B** it decreases

☒ **C** it does not change

☒ **D** it increases

(ii) The velocity of the aircraft remains constant.

What happens to the kinetic energy of the aircraft?

Put a cross (☒) in the box next to your answer.

(1)

☒ **A** it becomes zero

☒ **B** it decreases

☒ **C** it does not change

☒ **D** it increases

(b) The aircraft lands with its wheels on the runway as shown.

The aircraft is moving forwards.

(i) Draw an arrow on the diagram to show the direction of the momentum of the aircraft.

(1)

(ii) The velocity of the aircraft when it lands is 75 m/s.

The mass of the aircraft is 130 000 kg.

Calculate the momentum of the aircraft.

(2)

momentum = ... kg m/s

(iii) The aircraft comes to a stop.

State the momentum change of the aircraft from when it lands to when it stops.

(1)

change in momentum = ... kg m/s

(c) When the aircraft lands, the momentum of each passenger also changes.

(i) Explain why it is more comfortable for a passenger if the aircraft takes a longer time to slow down.

(2)

. . . .

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(ii) Suggest why some aircraft need a very long runway to land safely.

(2)

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(Total for Question is 10 marks)

Q3.

Andrew skis down a hill.

(a) Andrew starts from the top of the hill and his speed increases as he goes downhill.

He controls his speed and direction by using his skis.

He brings himself to a stop at the bottom of the hill.

Describe the energy changes that happen between starting and stopping.

(3)

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(b) Andrew returns to the top of the hill and starts again.

(i) His mass is 67 kg.

Show that his momentum is about 2000 kg m/s when his velocity is 31 m/s.

(2)

(ii) He falls over when his momentum is 2000 kg m/s.

After he falls over, he slows down by sliding across the snow.

It takes 2.3 s for his momentum to reduce to zero.

Calculate the average force on Andrew as he slows down.

(2)

force = ... N

(iii) Andrew is not injured by the fall even though he was moving quickly.

Use ideas about force and momentum to explain why he is not injured.

(2)

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(Total for Question is 9 marks)

Q4. * The items in the box are packed in bubble wrap to protect them from damage.

Explain, by considering changes either in momentum or in kinetic energy, how bubble wrap protects the items in a box from damage caused by a fall.

(6)

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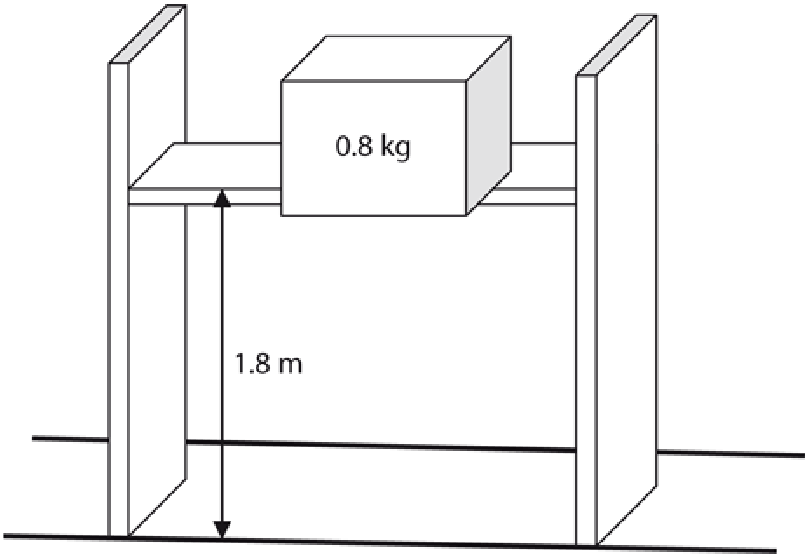
Q5. **Momentum, energy and forces**

A box with a mass of 0.8 kg is lifted from the floor and placed on a shelf.

The shelf is 1.8 m above the floor.



(a) (i) The box has gained gravitational potential energy.

Calculate the gain in gravitational potential energy.

Gravitational field strength = 10 N/kg

(2)

gain in gravitational potential energy = ... J

(ii) The box falls off the shelf.

State the kinetic energy of the box just before it hits the floor.

(1)

.... J

(iii) Just before the box hits the floor it has a momentum of 4.8 kg m/s.

Calculate the velocity of the box just before it hits the floor.

(3)

velocity = ... m/s

*(b) The items in the box are packed in bubble wrap to protect them from damage.

Explain, by considering changes either in momentum or in kinetic energy, how bubble wrap protects the items in a box from damage caused by a fall.

(6)

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Q6.

Some students investigate a model of the craters produced by meteorite impacts.

They drop balls into a tray filled with sand.

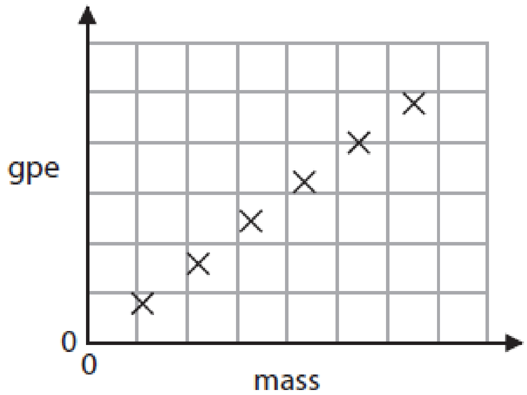
They use six balls with different masses.

They drop each ball from the same height.

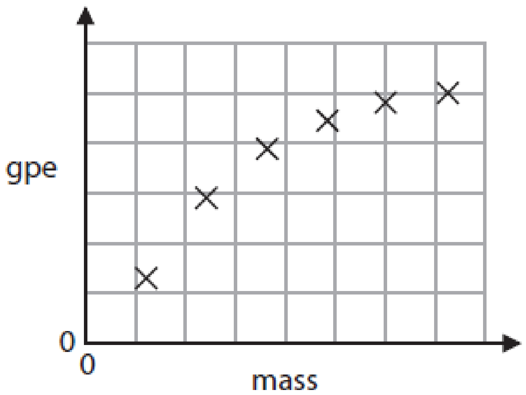
(a) (i) Which one of these graphs shows the relationship between the gravitational potential energy (gpe) of the balls and their mass when they are all at the same height?

Put a cross (☒) in the box next to your answer.

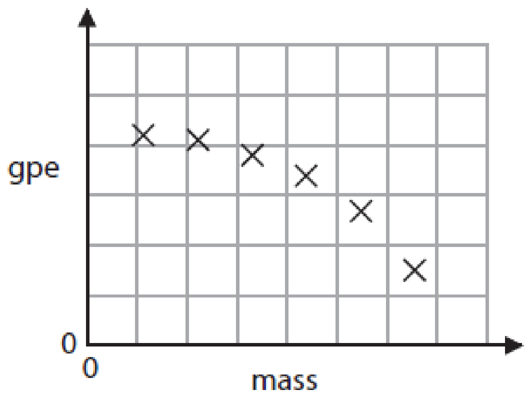
(1)



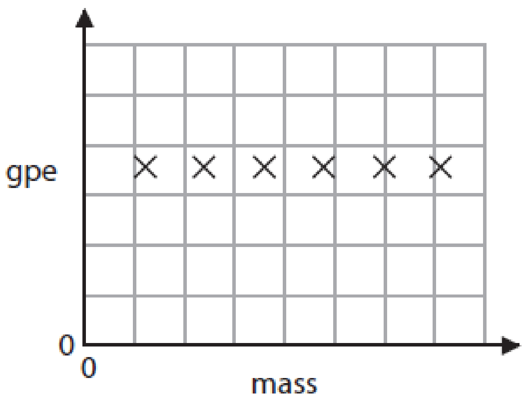
☐ **A**



☐ **B**



☐ **C**



☐ **D**

(ii) Describe how the energy of a ball changes as it drops towards the sand.

(2)

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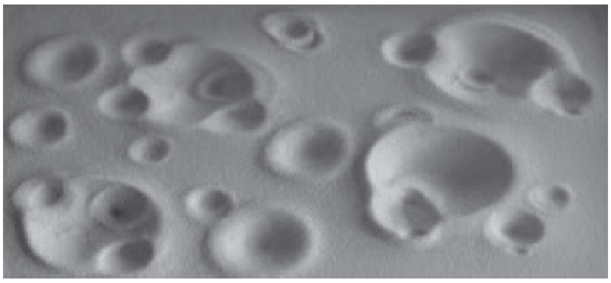
(b) This photograph shows the sand after several balls have hit it.



The students read this information in a textbook:

'When work is done, energy is transferred.'

Explain how work is done when the balls impact on the sand.

(2)

....

....

....

....

(c) When one ball hits the sand, it has a velocity of 6.2 m/s.

It has a momentum of 0.46 kg m/s.

(i) Calculate the mass of the ball.

(3)

mass of ball = ... kg

(ii) The ball takes 0.17 s to come to rest after it hits the sand.

Calculate the average impact force.

(2)

average impact force = ... N

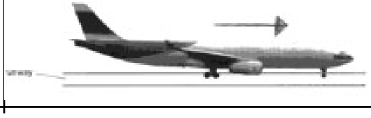
Mark Scheme

Q1.

	Answer	Acceptable answers	Mark
(a)	**C** when the bungee		**(1)**

	cord is stretched the most		
(b)	**A** 600 kg m/s		**(1)**
(c)(i)	Substitution: (1) 60 × 10 × 50 or 600 × 50 Evaluation: (1) 30 000 Unit: (1) J / Nm	give two marks for correct answer no working j / joule 30 kJ for full marks	**(3)**
(c)(ii)	After falling 50 m / when the cord becomes straight/when cord starts to stretch	tension starting to increase at terminal velocity ignore maximum velocity/speed	**(1)**
(c)(iii)	An explanation linking any two of not all GPE is transferred to KE (1) some {of the GPE transfers to thermal energy /work is done} (1) due to drag (1)	not all GPE goes to KE maximum energy is same (value) as GPE before falling /speed does not reach the speed at which he should fall some lost as heat/sound (of rope or movement through air) (air) resistance / friction ignore wind	**(2)**

Q2.

	Answer	Acceptable answers	Mark
(a)(i)	B it decreases		**(1)**
(a)(ii)	C it does not change		**(1)**
(b)(i)	horizontal arrow (judge by eye), pointing to the right **anywhere**on the diagram 		**(1)**

(b)(ii)	substitution: (1) 130 000 × 75 evaluation: (1) 9 750 000 (kgm/s) (Ns)	give full marks for correct answer, no working Ignore minus sign 9.75×10^6 (kgm/s) (Ns)	**(2)**
(b)(iii)	9 750 000 kgm/s	same value as answer to (b)(ii) Ignore minus sign	**(1)**
(c)(i)	An explanation linking two of the following: • force is smaller/less (1) • momentum changes more slowly (1) • lower deceleration (1) • use of the formula (1)	pressure is smaller/less slower deceleration force is proportional to rate of change of momentum/F= (mv – mu)/t	**(2)**
(c)(ii)	Any two from: (for loaded aircraft) • has more mass (1) • has more momentum (1) • has more k.e. (1) • higher velocity • brakes need to do more work (1)	accept reverse argument for empty aircraft heavier/more passengers/more cargo higher speed/moving faster	**(2)** **expert**

Total marks for question = 10 marks

Q3.

	Answer	**Acceptable answers**	**Mark**
(a)	Description including 3 of the following: • (Gravitational) potential energy (transferred) to KE(1) • Idea of energy transfer to heat/sound whilst descending (1) • Chemical energy is transferred to heat energy in Andrew (1) • Idea of energy dissipated on stopping (1)	(G)PE (transferred) to KE Allow gravitational energy for GPE Energy transferred to heat because of air resistance/ friction The energy goes to heat as he stops. Energy is transferred to the surroundings	**(3)**
(b)(i)	substitution (1)		

	67 × 31 evaluation (1) 2077 (kg m/s)	2080, 2100 working backwards using 2000 (v=) 29.85, 30 (m=) 64.52, 65 67 X 31=2000 scores only one mark	**(2)**
(b)(ii)	substitution (1) 2000 ÷ 2.3 evaluation (1) 870 (N)	answer to (b)(i)) ÷ 2.3 900, 869.6, 869.5 903	**(2)**
(b)(iii)	an explanation linking two of the following • Force on Andrew is quite small (1) • Because impact time is long (1) • The acceleration/deceleration is quite small (1) • Because impact distance is far (1)	force is reduced/ less /not as strong slows down/changes momentum gradually acceleration = 1.35 'g' or 13.5 m/s^2 slows down (rate of) change of momentum scores 2 marks	**(2)**

Total question = 8 marks

Q4.

Question Number		Indicative Content	Mark
QWC	*	An explanation linking some of the following points **Either** momentum • item must lose momentum in order to come to rest • force of impact depends on rate of change of momentum • if item is dropped from greater height	**(6)**

		then velocity at impact is greater • so momentum to be lost is greater • bubble wrap works by increasing the time taken for the item to come to rest • reduces the rate of change of momentum • this reduces the force of impact to a safe value **Or** kinetic energy • item must lose kinetic energy in order to come to rest • force of impact depends on work done • if item is dropped from greater height then velocity at impact is greater • so kinetic energy to be lost is greater • loss of kinetic energy equals work done bringing item to rest • bubble wrap works by increasing the distance travelled for the item to come to rest • this reduces the force of impact to a safe value		
Level	**0**	No rewardable content		
1	**1 - 2**	• a limited explanation of the cushioning effect e.g. bubble wrap reduces the force of impact • the answer communicates ideas using simple language and uses limited scientific terminology		

		• spelling, punctuation and grammar are used with limited accuracy
2	**3 - 4**	• some explanation linking cushioning effect with either increased time of impact or increased distance of impact e.g. bubble wrap reduces the force of impact by increasing the time of impact • the answer communicates ideas showing some evidence of clarity and organisation and uses scientific terminology appropriately • spelling, punctuation and grammar are used with some accuracy
3	**5 - 6**	• a detailed explanation linking either force with rate of change in momentum or energy with work done and distance e.g. the bubble wrap increases the time of impact which reduces the rate of change of momentum which reduces the force of impact • the answer communicates ideas clearly and coherently uses a range of scientific terminology accurately • spelling, punctuation and grammar are used with few errors

Q5.

Question Number	Answer	Acceptable answers	Mark
(a)(i)	substitution (1) 0.8 × 10 × 1.8 evaluation (1) 14.4 (J)	give full marks for correct answer, no working	**(2)**

Question Number	Answer	Acceptable answers	Mark
(a)(ii)	14.4 (J)	e.c.f from part (i)	**(1)**

Question Number	Answer	Acceptable answers	Mark
(a)(iii)	substitution (1)	**allow** substitution and transposition in either	**(3)**

	4.8 = 0.8 × v transposition (1) v = 4.8/0.8 evaluation (1) 6 (m/s)	order give full marks for correct answer, no working		

Question Number		Indicative Content	Mark
QWC	***(b)**	An explanation linking some of the following points **Either** momentum • item must lose momentum in order to come to rest • force of impact depends on rate of change of momentum • if item is dropped from greater height then velocity at impact is greater • so momentum to be lost is greater • bubble wrap works by increasing the time taken for the item to come to rest • reduces the rate of change of momentum • this reduces the force of impact to a safe value **Or** kinetic energy • item must lose kinetic energy in order to come to rest • force of impact depends on work done • if item is dropped	**(6)**

		from greater height then velocity at impact is greater • so kinetic energy to be lost is greater • loss of kinetic energy equals work done bringing item to rest • bubble wrap works by increasing the distance travelled for the item to come to rest • this reduces the force of impact to a safe value	
Level	**0**	No rewardable content	
1	**1 - 2**	• a limited explanation of the cushioning effect e.g. bubble wrap reduces the force of impact • the answer communicates ideas using simple language and uses limited scientific terminology • spelling, punctuation and grammar are used with limited accuracy	
2	**3 - 4**	• some explanation linking cushioning effect with either increased time of impact or increased distance of impact e.g. bubble wrap reduces the force of impact by increasing the time of impact • the answer communicates ideas showing some evidence of clarity and organisation and uses scientific terminology appropriately • spelling, punctuation and grammar are used with some accuracy	
3	**5 - 6**	• a detailed explanation linking either force with rate of change in momentum or energy with work done and distance e.g. the bubble wrap increases the time of impact which reduces the rate of change of momentum which reduces the force of impact • the answer communicates ideas clearly and coherently uses a range of scientific terminology accurately	

		• spelling, punctuation and grammar are used with few errors

Q6.

Question Number	Answer	Acceptable answers	Mark
(a)(i)	**A**		**(1)**

Question Number	Answer	Acceptable answers	Mark
(a)(ii)	A description to include any two of • Gravitational / potential energy reduces (1) • kinetic energy increases (1) • total energy remains constant (1)	Ignore energy changes resulting from impact with sand GPE reduces KE increases Allow GPE is transferred to KE for 2 mark	**(2)**

Question Number	Answer	Acceptable answers	Mark
(b)	A explanation linking • (work is done) displacing the sand (1) with EITHER • (as) <u>kinetic</u> energy of the ball(s) has been transferred (1) OR • by the force between the ball and the sand (1)	sand moving/ pushing/ blowing upwards OWTTE or ball sinking into sand	**(2)**

Question Number	Answer	Acceptable answers	Mark
(c) (i)	transposition mass = momentum / velocity (1) substitution mass = 0.46 / 6.2 (1) evaluation 0.074 (kg) / 74g (1)	Subst. and transform. either order 1 mark only can be scored for correct substitution after incorrect transposition. Give full marks for correct answer with no working. Answers that round to 0.074 (kg) 0.07 (kg)	**(3)**

Question Number	Answer	Acceptable answers	Mark
(c)(ii)	substitution (impact) force = 0.46 / 0.17 (1) evaluation 2.7 (N) (1)	Give full marks for correct answer with no working. Ignore power of ten error until evaluation Answers which round to 2.7 Allow ECF if candidate has used mass from part (i) in F=m(v-u) / T $F = \frac{6.2 - 0}{0.17} \times 0.074$ (1) = 2.7 (N) (1)	**(2)**