Mark scheme – Newton's Law of Motion and Momentum

Question			Answer/Indicative content		Marks	Guidance
1			**C**		1	
			Total		**1**	
2			**C**		**1**	
			Total		**1**	
3			(Resultant) force is (directly) <u>proportional</u> to the rate of change of momentum.		**B1**	**Allow** equation with symbols defined. **Allow** equal for proportional **Ignore** reference to direction **Ignore** F = ma **<u>Examiner's Comments</u>** Less than half of the candidates could state Newton's second law correctly. A significant number of candidates wrote force = mass × acceleration. Another common error was stating the principle of conservation of momentum. Some candidates were confused by the term impulse and incorrectly gave the answer as change of momentum as opposed to stating that the resultant force is directly proportional to the rate of change of momentum. Examiners allowed "equal" for proportional. For these type of questions, if a candidate gives an equation, then all the symbols must be defined.
			Total		**1**	
4			(Resultant) force is (directly) proportional / equal to the rate of change of momentum		B1	**Not** force = mass × acceleration **Not** ' force ∝ change in momentum over time' **Examiner's Comments** A few candidates answered this question well demonstrating their knowledge of this fundamental law of physics. The most frequent incorrect answer was '*Force is equal to mass multiplied by acceleration*' rather than '*Force is proportional to the rate of change of momentum*'.
			Total		**1**	
5			C		1	
			Total		**1**	
6			B		1	

			Total		**1**	
7			C		1	**Examiner's Comments** All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions. The correct key was **C**: *The total force acting on the two-trolley system during the collision is zero.* The most frequent distractor was **A**: *The momentum of each trolley* is *conserved*. The term '*each*' did not register with most candidates. It is the total momentum of the two trolleys that is conserved.
			Total		**1**	
8			A		1	**Examiner's Comments** All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions.
			Total		**1**	
9			**B**		**1**	
			Total		**1**	
10			A		1	
			Total		**1**	
11			**B**		**1**	
			Total		**1**	
12			A		1	
			Total		**1**	
13			**A**		1	**Examiner's Comments** This question was more challenging still. In this question, candidates often forgot that the impulse provided by the hockey stick is in the opposite direction to the momentum of the puck, again giving option A as the correct answer.
			Total		**1**	
14			B		1	

			Total		**1**	
15			**C**		1	**Examiner's Comments** There was a significant amount of working shown by candidates across the ability spectrum. Most of the time, the answers put down were the distractors. This question is about Newton's second law of motion. The force on the javelin is equal to the rate of change of its momentum. Therefore, the answer is simply **C**. The kg m s^{-2} is equivalent to the newton N.
			Total		**1**	
16			**A**		1	
			Total		**1**	
17			**C**		1	
			Total		**1**	
18			B		1	
			Total		**1**	
19			**A**		1	**Examiner's Comments** This question was based on a force-time graph for a ball. All the information that can be extracted from the graph. The majority of the candidates inserted A in the answer box, and secured 1 mark. All the other statements are correct. The statement B is correct, because the maximum acceleration of the ball is proportional to the maximum force. The area under a force-time graph is impulse, so statement C is correct. The area under the graph is also equal to change in momentum, therefore the area under the graph does have the unit's kg m s^{-1}. So, statement D is also correct. Statement A is incorrect. Work done is the area under a force-distance graph, but here the horizontal axis has **time**, and not **distance**.
			Total		**1**	
20			Area under graph = 0.5 × 0.06 × 1.8 = 0.054 (Ns)		C1	
			0.05 × v = 0.054, therefore v = 1.1 (ms^{-1})		A1	
			Total		**2**	
21			momentum		B1	
			kinetic energy / total energy		B1	**Allow** energy / mass

			Total		**2**	
22			$E_k = {}^1/_2\ mv^2$ <u>and</u> $p = mv$ (Correct manipulation leading to) $E_k = {}^1/_2\ p^2/m$		**M1** **A1**	**Allow:** any subject **Allow:** $E_k = p^2/(2m)$
			Total		**2**	
23			Earth mentioned (as an integral part of the system) The Earth has (equal and) opposite momentum to the (falling) ball (so momentum is conserved) or The Earth moves upwards / towards the ball (with a tiny speed, so momentum is conserved)		**M1** **A1**	**Not** 'ground' **Allow:** The Earth experiences an upward force (and moves upwards) **Examiner's Comments** This question on the principle of conservation of momentum was not answered well. Only a small number of exceptional candidates recognised that momentum of the Earth-ball system was conserved which meant that the Earth must have momentum equal to that of the falling ball but in the *opposite* direction. Most of the candidates thought either air resistance had a role to play, or that momentum was conserved only when the ball collided with the ground. A small number of candidates thought that the conservation of momentum was intrinsically linked with the principle of conservation of energy. This prompted incorrect physics such as *'momentum transferred to KE and then GPE after impact with the ground'.*
			Total		**2**	
24			Both forces act on the same object (AW) The types of forces are different / one force is gravitational and the other force is electrostatic		**B1** **B1**	**Allow:** one force is gravitational (and the other is not) **<u>Examiner's Comments</u>** Many candidates incorrectly quoted Newtons' Third Law (N3L) or did not realise that a pair of N3L forces must be of the same type. The two forces in the question are acting on the same object, whereas N3L forces must act on different objects. Some candidates thought that the clothes were in motion, while the question states that the clothes are at rest. *Normal Contact Force* Normal contact force is essentially an electrostatic force between the two objects in contact.
			Total		**2**	

25	a		$mv - mu = F\Delta t$ (u = 0) / area under graph = Δp		C1	**Allow** 'impulse' for Δp
			$mv = \frac{0.010 + 0.040}{2} \times 150$		C1	**Allow** alternative methods for finding area.
			mv = 3.75 or $v = \frac{3.75}{0.16}$			
			v = 23 (m s $^{-1}$)		A1	**Note** answer to 3 s.f. is 23.4 m s^{-1}
	b		Curve upwards with decreasing gradient.		M1	
			Curve starts at a non-zero velocity at t = 30 ms.		A1	
	c		$F\Delta t = mv - mu$			**Allow** other correct methods
			$T = \frac{0.16 \times 23}{0.80}$		C1	Possible ECF from **(a)**
			T = 4.6 (s)		A1	**Note** the answer is 4.7 (s) when 23.4 (m s^{-1}) is used
			Total		**7**	
26	a		$F = \frac{\Delta mv}{\Delta t}$ or $F\Delta t = \Delta mv$ or (resultant force) = rate of change of momentum area under graph = Δmv or Δp or change in momentum or impulse		B1 B1	**Allow** p instead of mv **Allow**: proportional for equals (rate of change of momentum) **Examiner's Comments** It was good to see that most candidates understood that Newton's second law of motion is more than the statement that $F=ma$. Many had successful attempts with some candidates missing that it is the rate of change of momentum, rather than the change of momentum that is required. About two-thirds of candidates also correctly indicated that the area under the graph represents the impulse or the change in momentum. In Question 20(b), some candidates assumed, incorrectly, that the maximum force multiplied by the time taken would give the change in momentum and so scored zero marks. Rather more simply divided the maximum force by the mass, which gave the right answer yet with incorrect physics. This approach also scored zero. In fact, more successful responses made it clear that the area of the triangle on the graph was the impulse and that that area gave a change in momentum of 900 Ns.
	b		area under graph = 0.5 x 2.0 x 900 = 900 (N s) (mU = 900) U = 13 (m s^{-1})		C1 A1	**Not**: (initial force/mass) **Examiner's Comments** It was good to see that most candidates understood that Newton's second law of motion is more than the statement that $F=ma$. Many had successful attempts with some candidates missing that it is the rate of change of momentum, rather than the change of momentum that is

						required. About two-thirds of candidates also correctly indicated that the area under the graph represents the impulse or the change in momentum. In Question 20(b), some candidates assumed, incorrectly, that the maximum force multiplied by the time taken would give the change in momentum and so scored zero marks. Rather more simply divided the maximum force by the mass, which gave the right answer yet with incorrect physics. This approach also scored zero. In fact, more successful responses made it clear that the area of the triangle on the graph was the impulse and that that area gave a change in momentum of 900 Ns.
	c		The graph showing a (smooth) **curve** of continuously/always decreasing magnitude of gradient (with respect to time). **Curve** starts at (0,*U*) and stops at (2.0,0)		M1 A1	**Note:** curve must not be asymptotic at either end of the curve. **Examiner's Comments** Successful candidates spotted that the resultant force, the acceleration and hence the gradient of this speed- time graph decreased in magnitude with time. A constant gradient, ie a straight line between (0,U) and (2.0,0), can only be achieved by a constant decelerating resultant force. This gives a curve that starts off (0,U) with a steep negative gradient and finishes with a small negative gradient at (2.0,0).
			Total		**6**	
27	a		(s =) 1.23 (m) **or** (**t** =) 0.50 (s) $v^2 = 2 \times 9.81 \times 1.23$ **or** $1.23 = 0.50 \times \frac{v}{2}$ **or** $1.23 = v \times 0.50 - ½ \times 9.81 \times 0.50^2$ **or** $v = 9.81 \times 0.50$ **or** $1.23 = ½ \times 9.81 \times t^2$; $t = 0.50$ (s) **and** $v = 9.81 \times 0.50$ v = 4.9 (m s^{-1})		C1 C1 A0	**Note** there are no marks for gradient calculations here **Allow** s between 1.22 (m) and 1.26 (m) **Allow** t between 0.495 (s) and 0.505 (s) Substitution into $v^2 = u^2 + 2as$ with $u = 0$ Substitution into $s = \frac{(v+u)}{2} \times t$ with $u = 0$ Substitution into $s = vt - ½at^2$ Substitution into $v = u + at$ with $u = 0$ Substitution into $s = vt - ½at^2$ and $v = u + at$ with $u = 0$ **Allow** $g = 9.8$ **Not** $g = 10$, unless already penalised in **21(c)(ii)** **Examiner's Comments** This question was generally well-answered with candidates using a range of equations of motion to show the speed to be 4.9 m s^{-1}. The most popular route was: $v = 0 + (9.81 \times 0.50) = 4.905$ m s^{-1}.

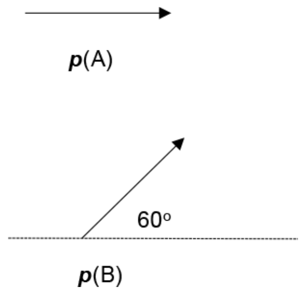
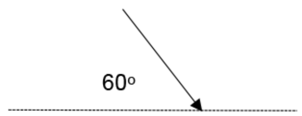
	b		Correct tangent at t = 0.50 s with positive gradient Attempt at calculating the gradient of a tangent Gradient calculated in the range 3.20 to 3.80 (m s^{-1})		B1 M1 A1	**Note** must evidence for Δs and Δt values either here or on Fig. 22 **Allow** this M1 mark for tangent not drawn at t = 0.50 s **Note** this mark can only be scored if the tangent is drawn at t = 0.50 s and the calculated value falls in this range **Examiner's Comments** In this question, candidates had clear instructions on what to do. Most candidates drew adequate tangents at t = 0.50 s and did the correct analysis to determine the rebound speed of the ball. Most responses were in the range required (3.20 to 4.00 m s^{-1}) and most candidates scored 3 marks. About a quarter of the candidates drew tangents at times other than t = 0.50 s. This meant that they could only score a maximum of 1 mark for correctly calculating the gradient of their tangent.
	c		(Δv =) 4.9 + 3.5 **or** (Δv =) 8.4 (ms^{-1}) force = $\frac{8.4 \times 0.056}{1.8 \times 10^{-3}}$ force = 260 (N)		C1 A1	Possible ECF from **(c)** **Allow** (Δp =) (4.9 + 3.5) × 0.056 **or** (Δp =) 0.47 (kg ms^{-1}) **Allow** 1 mark for 44 (N); Δv = 4.9 - 3.5 used **Ignore** sign **Examiner's Comments** The correct answer of 260 N eluded even many of the top-end candidates. The vector nature of velocity, or momentum, was overlooked, with many candidates calculating the magnitude of the force as follows: force = $\frac{\Delta p}{\Delta t} = \frac{0.056\,(4.9-3.5)}{1.8 \times 10^{-3}}$ = 44 N The magnitude of the change in the velocity of the ball 0.056(4.5 + 3.5), which would have given the correct answer of 260 N. **Misconception** Some examples of **incorrect** physics were: • force = weight of the ball = 0.056 × 9.81 • Using Δt = 0.50 s instead of 1.8 ms.

						• Using either 4.9 m s^{-1} or 3.5 m s^{-1} to calculate the force.
			Total		**7**	
28		i	Earth		B1	**Allow** planet / ground **Examiner's Comments** This question was poorly answered, with only the very top candidates realising that it was the Earth experiencing the force *W* in the opposite direction. 'Ground' instead of the Earth was allowed by examiners – but such answers were extremely rare. Newton's third law remains enigmatic to many candidates. The most popular incorrect answers were 'ball' and 'table'.
		ii	The forces are not of the same type / The forces act on the same object		B1	**Allow** The forces do not act on different objects **Examiner's Comments** Examiners were looking for the idea that in Newton's third law, the pair of forces were of the same type and had to act on two separate objects. The force *W* is a **gravitational** force and *N* is the normal contact force is an **electrostatic** force between the base of the ball and the top of the table. The variety of incorrect answers demonstrated the lack of comprehension of this law. The two exemplars below show answers from a top-end candidate and a candidate securing a middle-grade. **Exemplar 4** According to a student, *W* = *N* is a consequence of Newton's third law of motion. State why this is incorrect. W and N are not the same type of forces and this is not a consequence of Newton's third law of motion. [1] In this exemplar from a top-end candidate, the response is half of the total response, but it was given 1 mark by the examiners. Some candidates went a step further by mentioning that *W* is a gravitational force and *N* is an electrostatic force. **Exemplar 5** According to a student, *W* = *N* is a consequence of Newton's third law of motion. State why this is incorrect. There was no force applied on the ball to cause a equal and opposite force. [1] This illustrates a strange response from a low-grade candidate. It shows poor understanding of this important law. There is nothing worthy here for credit.
			Total		**2**	

29			'No motion' explained either in terms of the first law or second law There is no / negligible resultant force		B1 B1	**Allow** $F = ma$, since $F = 0$, a is zero (hence at rest) **Allow** an object continues in a state of rest or uniform motion unless acted upon by a (resultant) force. **ALLOW** no frictional / extra/new force
			Total		**2**	
30			(k.e. =) $E = 5.0 \times 10^6 \times 1.6 \times 10^{-19}$ $v = \sqrt{(2E/m)}$ **or** $= \sqrt{(2 \times 8.0 \times 10^{-13} / 6.6 \times 10^{-27})} = 1.6 \times 10^7$ (ms^{-1}) p (= mv) = $6.6 \times 10^{-27} \times 1.6 \times 10^7$ giving $p = 1.1 \times 10^{-19}$ (kg m s^{-1})		C1 C1 A1	$E = 8(.0) \times 10^{-13}$ J **or** ($E = p^2/2m$ so) $p = \sqrt{(2mE)}$ **Note:** A value of $v = 1.6 \times 10^7$ (ms^{-1}) automatically scores both C1 marks even if the calculation for E is not shown **or** p (= $\sqrt{(2mE)}$ = $\sqrt{(2 \times 6.6 \times 10^{-27} \times 8.0 \times 10^{-13})}$) giving $p = 1.0 \times 10^{-19}$ (kg m s^{-1}) Full substitution of values must be shown and answer (if calculated) must be correct **<u>Examiner's Comments</u>** This question provided an excellent opportunity for candidates to produce immaculate responses: identify the physics involved, select and write down the correct formula, do the necessary conversion (MeV to J), rearrange the formula, substitute correctly and then write the final response in standard form to a correct number of significant figures. Some of the common errors were: • forgetting to convert 5.0 MeV into J • not showing a full substitution of values (which is necessary for a 'show that' question) • not calculating the response to more than 1 s.f. (which is necessary for a 'show that' question).
			Total		**3**	
31	a		(t =) 2 × 1.3 **or** 2.6 (s) (x =) 68 cos11° × 2.6 or 174 (m) horizontal distance = 174 – 90 horizontal distance = 84 (m)		C1 C1 A1	**Note** answer is 86 (m) if 1.32 s is used **Note** answer is 87 (m) if 1.3226… s is used **Allow** 1.3 × 68 cos11° for 1 mark **Allow** 3 or −3 m for 2 marks
	b	i	A collision in which kinetic energy is lost		B1	**Allow** KE is not conserved
		ii	Conservation of momentum Idea that velocity is to the right **and** velocity is very small / much smaller than 68 (m s^{-1})		B1 B1	**Not** 'goes backwards'
			Total		**6**	

32	a		Ft = mv + mu		C1	
			Ft = 0.6 (6 + 11) = 10(.2)		C1	
			F = 10/0.18 = 57 (N)		A1	award 1 mark out of 3 for mv − mu; = 0.6 (11 − 6) = 3 giving 17 (N).
	b	i	48 (N); 0.25 (s)		A1	both values correct; no tolerance
		ii	estimate area under graph by counting squares **or**		B1 B1	second mark awarded for some detail about how to estimate area.
		ii	method of estimating mean F multiplied by time of contact (0.25 s)			e.g. areas above and below mean under curve are equal.
	c	i	(F = ma) a = 48/0.6		C1	**ecf a(i)**
		i	a = 80 (m s^{-2})		A1	
		ii	(Ft = mv) v = 6.5/0.6		C1	**ecf a(i)**
		ii	v = 11 (m s^{-1})		A1	allow 10.8
			Total		**10**	
33			(Motion / speed / force / acceleration of person or skateboard is to the) left / opposite direction to ball / 'backwards'		B1	
			momentum is conserved / momentum of person = momentum of ball (but in opposite direction)		B1	**Allow** 'principle of conservation of momentum' **Allow** 'equal and opposite forces (acting on ball and person for the same time interval)'
			(total) momentum is zero (at start or at the end or during the throwing of the ball) / speed of person < speed of ball		B1	**Allow** 'different speed' **Allow** velocity
			Total		**3**	
34			*Method 1: Momentum is conserved*			
			$1.7 \times 10^{-27} \times 500$ or $1.7 \times 10^{-27} \times (-) 420$ or $2.0 \times 10^{-26} \times v$		C1	
			$1.7 \times 10^{-27} \times 500 = 1.7 \times 10^{-27} \times -420 + 2.0 \times 10^{-26} \times v$		C1	
			v = 78 (m s^{-1}) *Method 2: Kinetic energy is conserved*		A1	**Allow** 1 mark for 6.8 (m s^{-1}); + 420 used instead of − 420
			$½ \times 1.7 \times 10^{-27} \times 500^2$ or $½ \times 1.7 \times 10^{-27} \times 420^2$ or $½ \times 2.0 \times 10^{-26} \times v^2$		C1	**Allow** full credit for correct use of 'velocity of approach = −velocity of recession', e.g:
			$½ \times 1.7 \times 10^{-27} \times 500^2 = ½ \times 1.7 \times 10^{-27} \times 420^2 + ½ \times 2.0 \times 10^{-26} \times v^2$		C1	'speed' of approach = (−) 'speed' of recession **C1**

			v = 79 (m s^{-1})		A1	500 = v + 420 **C1** v = 80 (m s^{-1}) **A1** **Examiner's Comments** This was a good discriminator with many of the top-end candidates scoring full marks. Most candidates opted to answer the question using the principle of conservation of momentum. A few candidates used ideas of conservation of kinetic energy for this perfectly elastic collision. It is good to report that most candidates coped well with powers of ten. The most common mistake was to use +420 m s^{-1} for the final velocity of the hydrogen atom, rather than −420 m s^{-1}; this gave the incorrect answer of 6.8 m s^{-1}. A small number of candidates used relative velocities before and after to arrive at an alternative correct answer of 80 m s^{-1}.
			Total		**3**	
35			Area under graph = 0.5 × 0.4 × 18 or 3.6 $\frac{3.6}{0.045}$ 80 (m s^{-1})		C1 C1 A1	**Allow** alternative methods
			Total		**3**	
36		i	Any two from: momentum, (total) energy and mass		B1	**Not**: kinetic energy Most candidates gained one mark for correctly stating two quantities from momentum, energy and mass. The most frequent incorrect answers were kinetic *energy* and *velocity*.
		ii	The force will have the same magnitude (at any time t)		B1	**Not** 'This is because action = reaction'
		ii	The force is in the opposite direction / has negative value		B1	**Not** Newton's third law **Allow** 1 mark for a correct graph if there is no description or explanation **Examiner's Comments** This question required knowledge and understanding of Newton's third law. Although many candidates were familiar with the law, they could not adequate describe or explain the force on the asteroid. There were vague answers such as *'The force goes up proportionally and then decreases exponentially'*. Some answers also focused unnecessarily on the transfer of momentum or kinetic energy but it was often the succinct answers such as *'The force on the asteroid is equal in magnitude but in opposite direction to the force F; NIII law' that scored full marks.*

			Total		**3**	
37		i	Example (not to scale): 		B1 B1	horizontal arrow (judge by eye), in the direction shown arrow drawn at an angle of 60° to the horizontal (angle must be shown), in the direction shown
		ii	Example (not to scale):  (Can apply principle of) conservation of momentum (since no external forces are acting)		B1 B1	arrow drawn at an angle of 60° to the horizontal (angle must be shown), in the direction shown **<u>Examiner's Comments</u>** This was not an easy question but, even so, a good number of candidates did well. The marks were given for the direction (rather than for the magnitude) of the momentum vectors. Some of the common errors were: • forgetting to label relevant angles • not using arrows to show direction • drawing a vector triangle without any indication of which arrow was meant to be the final momentum.
			Total		**4**	
38		i	<u>KE</u> is conserved (as well as momentum)		**B1**	**Allow:** No <u>KE</u> lost
		ii	Attempt at conservation of momentum in x– or y– direction Correct expression of conservation of momentum in x– or y–direction / correct determination for velocity of Y of 55(3) m s^{-1} $p = 3.7 \times 10^{-24}$ (kg m s^{-1})		**C1** **C1** **A1**	**Allow** confusion of sin and cos at this stage **Allow** attempt at conservation of KE **Allow** any subject e.g. p cos(25°) + m × 258cos(65°) = m × 610 or p sin(25°) = m × 258sin(65°) or $(p)^2 + (m \times 258)^2 = (m \times 610)^2$ or $^1/_2\ mv^2 + {}^1/_2\ m\ (258)^2 = {}^1/_2\ m(610)^2$ Answer is 3.67×10^{-24} (kg m s^{-1}) to 3 sf **<u>Examiner's Comments</u>** Most candidates correctly remembered that an elastic collision is one in which KE is conserved. In this series, it was acceptable to refer to 'no loss of KE'.

						Using the idea that the KE was conserved would have made calculating the velocity of particle Y straightforward. Most candidates preferred a conservation of momentum approach, which of course still works. Many candidates remembered that momentum is conserved in both the x– and y–directions independently and consideration of either was enough. Some candidates forgot that trigonometry was necessary to complete this step, or made errors with which of sine or cosine was required.
			Total		**4**	
39	a		$^{238}_{92}U \rightarrow\ ^{234}_{90}Th$ + ... $^{4}_{2}He$ or $^{4}_{2}\alpha$		**B1** **B1**	**allow** proton and / or nucleon number to the right of symbol **allow** γ-photon; zero for any other extra particle **Examiner's Comments** Most candidates made a good start to the paper writing a correct equation for the nuclear decay.
	b		mv = (4.00 − 0.0665) × 10^{-25} × 2.40 × 10^{5} = 9.44 × 10^{-20} v = 9.44 × 10^{-20}/ 6.65 × 10^{-27} = 1.42 × 10^{7} k.e. = ½ × 6.65 × 10^{-27} × (1.42 × 10^{7})^{2} = 6.70 × 10^{-13} (J) 6.70 × 10^{-13} / 1.60 × 10^{-13} = 4.19 (MeV)		**C1** **C1** **A1** **B1**	**allow** 0.07 × 10^{-25} for α-particle mass **max** 3 if use 4.00 instead of 3.93 in momentum eq'n **allow** ratio of masses 234 and 4 **or** calculations using 234u and 4u **allow** $p^2/2m$ calculation for k.e. **accept** 4.0 to 4.2; **ecf** (calculated value of k.e. in J)/e **N.B.** the correct answer automatically gains all 4 marks **Examiner's Comments** One mark in this question was reserved for converting units from joule into mega electronvolt. This was the only mark awarded to half of the candidates. Few recognised this to be an isolated system, applying the conservation of momentum to solve the problem. Few appeared to realise that the mass of an alpha particle is given in the Data, Formulae, and Relationships Booklet, calculating it instead by summing the masses of neutrons and protons. The most common incorrect approach was to use the formula $E = mc^2$ or to equate the kinetic energies of the thorium nucleus and alpha particle.
	c		ΔA = 32 = $4n_\alpha$ so n_α = 8 ΔZ = 10 = $2n_\alpha - n_\beta$ so n_β = 6 argument / reasoning given for both n_α and n_β		**B1** **B1** **B1**	**allow** 8 (decays), i.e no mention of α particles **allow** 10 − 16 = −6; **NOT** 14 − 8 = 6; **must state** β(−) particles e.g. change in mass number caused by α decay,change in proton number combination of α and β **Examiner's Comments** A significant number had no idea where to start and left the page blank. Of the rest most managed to decide on 8 alpha particles. A minority worked initially with the proton number rather than the nucleon number incorrectly choosing 5. The explanations about the choice of 6 beta particles were often just restricted to equating the numbers correctly rather than giving any description of the transformation of neutrons into protons.

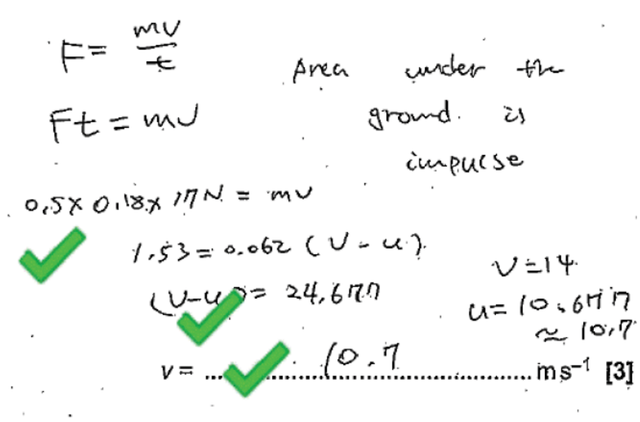
			Total		**9**	
40		i	$(F = \frac{\Delta p}{\Delta t})$; $F = (-)\frac{10-6}{0.2}$ or $F = (-)\frac{4}{0.2}$ force = (−) 20 (N)		**C1** **A1**	**Ignore** sign **Note** '$F = (-)\frac{10+6}{0.2}$ = 80 N' scores zero **Examiner's Comments** Some of the answers were quite brief but most of the candidates knew that force was equal to the rate of change of momentum. The correct answer of 20 N appeared on numerous scripts. A few candidates used Δ*t* = 2.0 s rather than Δ*t* = 0.20 s.
		ii	momentum = 8 (kg m s^{-1}) between *t* = 0 and 0.40 s momentum = 12 (kg m s^{-1}) after *t* = 0.60 s momentum increases linearly between 0.40 s and 0.60 s		**B1** **B1** **B1**	**Ignore** omission of label **Y** **Examiner's Comments** This was a good discriminator with many of the top-end candidates scoring full marks. A good number of candidates had the momentum of **Y** constant at 8.0 kg m s^{-1} up to 0.40 s, but then instead of the momentum increasing uniformly with time between *t* = 0.40 s and *t* = 0.60 s, the momentum decreased. This showed poor understanding of the principle of conservation of momentum. The total momentum of the two balls had to remain constant at 18 kg m s^{-1}. A very small number of candidates drew wobbly freehand lines. This was not penalised, but in future, candidates are reminded to draw straight lines using rulers.
			Total		**5**	
41		i	250 × 60 = 15000 J		C1	
		i	energy = $\frac{15000}{0.65}$ = 2.3 x 10^4 (J)		A1	
		ii	drag force = 0.4 × 6.0^2 = 14.4 N		C1	
		ii	forward force = power / velocity = 250/6.0 = 41.7 N		C1	
		ii	acceleration = $\frac{41.7 - 14.4}{85}$ = 0.32 m s^{-2}		A1	
			Total		**5**	
42		i	Tangent drawn at *t* = 4.0 s Attempt at calculating the gradient *v* calculated from gradient and between 9.50 - 10.50 (m s^{-1}) **OR**		C1 C1 A1 C1 C1	**Allow** other correct methods **Note** working required for this mark

			s = 20 (m) and $s = ½ at^2$ 20 = ½ a × 4.0^2 **or** a = 2.5 (m s^{-2}) v = 2.5 × 4.0 **or** v^2 = 2 × 2.5 × 20 v = 10 (m s^{-1})		C1 A0	
		ii	change in momentum = 1200 x 10 or 12000 (kg m s^{-1}) rate of change of momentum = 3000 unit: kg m s^{-2} or N **OR** F = 1200 X 2.5 rate of change of momentum = 3000 unit: kg m s^{-2} or N		C1 A1 B1 C1 A1 B1	**Allow** ECF from **(i)** **Allow** 2850 - 3150 **Allow** newton **Allow** ECF from **(i)** **Allow** newton
			Total		**6**	
43		i	($p1$ = 4.4 × 0.050) = 0.22 (kg m s^{-1})		B1	
		ii	(impulse =) ½ × 30 × 0.02 **or** 0.30 (kg m s^{-1}) -0.30 = $p2$ – 0.22 $p2$ = (–) 0.08 (kg m s^{-1})		C1 C1 A1	Allow any correct re-arrangement Possible ECF from **(i)** **Ignore** sign **Allow** 0.52 for 2 marks
		iii	(momentum of trapdoor =) 0.30 (kg m s^{-1}) v = 3.0 (m s^{-1})		C1 A1	Allow ($KE_{trapdoor}$ =) ½ × 0.05 × (4.4^2 – 1.6^2) **or** 0.42 (J) Possible ECF from **(ii)** **Allow** 1 SF answer here **Allow** alternate methods involving CoE (giving 2.9) and e(giving 2.8) **Examiner's Comments** In this part the momentum of the trapdoor is not equal to the final momentum of the ball but is equal to the impulse provided to the ball by the trapdoor (albeit in the opposite direction to that of the rebounding ball).
			Total		**6**	
44			**Level 3 (5–6 marks)** Description and explanation of pattern changes **and** quantitatively explains link between de Broglie wavelength and potential difference. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear description of how pattern changes and explanation of pattern changes and qualitatively explains link		B1 ×6	***Indicative scientific points may include:*** ***Description of pattern changes*** • Rings become closer (not just smaller) • Rings become brighter ***Qualititative explanation of pattern changes in terms of de Broglie wavelength and potential difference*** • Electrons gain greater energy • Electrons have a greater speed • Electrons have a greater momentum

			between de Broglie wavelength and potential difference **or** limited description of how pattern changes and quantitatively explains link between de Broglie wavelength and potential difference. *There is a line of reasoning presented with some structure.* *The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description of how pattern changes and limited attempts to explain qualitatively the link between de Broglie wavelength and potential difference **or** qualitatively explains link between de Broglie wavelength and potential difference. *The information is basic and communicated in an unstructured way.* *The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.			• Implies smaller wavelength • Smaller wavelength means less diffraction • Shorter wavelength gives shorter path differences between areas of constructive and destructive interference ***Quantitative explanation of pattern changes in terms of de Broglie wavelength and potential difference*** • $eV = \frac{1}{2}mv^2$ • $p = mv$ • $v^2 \propto V$ or $p^2 \propto V$ • $\lambda = \frac{h}{p}$ or $\lambda \propto \frac{1}{v}$ • $\lambda = \frac{h}{\sqrt{2meV}}$ or $\lambda \propto \frac{1}{\sqrt{V}}$ **<u>Examiner's Comments</u>** This question tested an understanding of electron diffraction. Many candidates gave a good qualitative explanation of how the pattern would change. High achieving candidates clearly demonstrated how the de Broglie wavelength λ was related to the potential difference V by equating the energy eV to kinetic energy, then using the definition of momentum and the de Broglie wavelength. Some candidates confused speed v with potential difference V. Many candidates gave a good qualitative explanation. Many candidates did not state that the rings would become brighter. **AfL** Candidates should be able to describe how to use light gates. In particular, candidates should be able to indicate the measurements that are needed to determine speed and acceleration. Candidates should state that the light gates should be connected to a timer or data-logger. **AfL** When analysing experimental data, candidates should be able to determine appropriate graphs to plot which will give a straight line (if the given relationship is true). Candidates should also be able to describe how unknown quantities may be determined using the gradient and / or *y*-intercept. **Misconception** There is some confusion between the equations to use for photoelectric effect and the equations to use when

						considering the de Broglie wavelength. For the de Broglie wavelength, a common misconception is to relate the energy to wavelength by the equation for the energy of a photon, $E = \frac{hc}{\lambda}$
			Total		**6**	
45			**Level 3 (5–6 marks)** Clear description of experiment **and** measurements **and** clear analysis. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description of experiment **and** some measurements **and** some analysis. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description of experiment **or** Limited measurements **or** Limited analysis *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		B1×6	**Indicative scientific points may include:** **Description** • Release method • Ensure bob is not pushed • Repeat experiment for same *H* • Repeat for different H • Centre of mass of single bob and joined bob considered • Keep bob string taught **Measurements** • Measure heights *h* and *H* with ruler • Use centre of mass of bob or another suitable method • Use video camera to record motion • Use of datalogger and appropriate sensor to measure *H* and *h* • Measure mass with (top pan) **balance** **Analysis** • Construct a table of *h* and *H* • Plot graph of *h* against *H* • LoBF should pass through origin. • Determine gradient or calculate *h*/*H* ***repeatedly*** • gradient $= \left(\frac{M}{M+m}\right)^2$ (gradient must be consistent with the plot) • Masses substituted into above expression and checked against experimental gradient
			Total		**6**	
46			**Level 3 (5–6 marks)** Clear explanation of terms **and** explanation of results correctly comparing momentum and kinetic energy. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.*		B1 × 6	***Indicative scientific points may include:*** ***Explanation of terms*** • *p* = *mv* • $E_k = \frac{1}{2}mv^2$ • Total momentum conserved in all collisions • Total energy conserved in all collisions • E_k conserved in elastic collision • E_k NOT conserved in inelastic collision

			Level 2 (3–4 marks) Clear explanation of terms **and** limited explanation of results comparing momentum **or limited explanation of terms and** some explanation of results **or** correct comparison of momentum and kinetic energy. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Has limited explanation of terms **or** limited comparison of momentum / kinetic energy. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.			• Speed of approach = speed of separation in elastic collision ***Explanation of results*** • Initial p_A= 15 kg cm s^{-1} or 0.15 kg m s^{-1} • Initial E_{kA} = 0.015 J • Expt 1: ○ Speed of separation = 0.150 + 0.050 = 0.200 m s^{-1} ○ p_A after collision = (-) 0.375 kg m s^{-1} ○ p_B after collision = 0.1875 kg m s^{-1} ○ Total p after collision = 0.15 kg m s^{-1} ○ E_{kA} after collision = 0.0009375 J ○ E_{kB} after collision = 0.0140625 J ○ Total E_k after collision = 0.015 J ○ Collision is elastic since E_k conserved • Expt 2: ○ p after collision = 0.15 kg m s^{-1} ○ E_k after collision = 0.005625 J ○ Collison is inelastic since E_k not conserved • Momentum conserved in both collisions
			Total		**6**	
47		i	$\rho = m/V = m/Av$; so $m = A\rho v$		C1	
		i	$7.5 \times 10^{-5} \times 1000 \times v = 0.070$		A1	
		i	giving v = 0.93 (m s^{-1})		A0	
		ii	3.7 (m s^{-1})		A1	Accept 3.72
		iii	$F = \Delta(mv)/\Delta t = 0.070 \times (3.72 - 0.93)$		C1	**ecf (ii)**
		iii	F = 0.195 (N)		A1	accept 0.19 or 0.2(0)
		iv	arrow into the shower head perpendicular to its face.		B1	award mark for a reasonable attempt.
			Total		**6**	
48		i	Both forces shown in correct direction and arrows of same length.		B1	
		ii	Zero.		B1	
		iii	(Conservation of momentum) $u_x = v_x + v_z$		C1	

		iii	(Conservation of kinetic energy) $u^2_x = v^2_x + v^2_z$		C1	
		iii	Shows $v_x = 0$ by substitution		C1	
		iii	$v_z = u_x$ by substitution of $v_x = 0$		A1	
			Total		**6**	
49		i	0.868 or 0.87		**B1**	**Allow** – 0.868 or – 0.87 **<u>Examiner's Comments</u>** This question was well answered. Many candidates helpfully showed their working.
		ii	change in momentum = 0.5 × 17 × 0.18 or 1.53 (N s) Momentum of tennis ball = 1.53 − 0.868 = 0.662 *v* = 0.662/0.062 = 10.6 or 10.7 (m s^{-1}) = 11 (m s^{-1})		**C1** **C1** **A1**	**ECF** from (b)(i) Or 0.062(v- -14) = 1.53 Or *v* = 24.7 -14 = 10.7 **Allow** 1 mark for 24.7 (m s^{-1}) or 38.7 (m s^{-1}) **<u>Examiner's Comments</u>** Candidates found this question difficult. Candidates needed to realise the importance of Fig. 5.2 and understand that the area under the graph was equal to the change of momentum of the ball. It is important that candidates show their working so that if the graph is misread they may still obtain credit later. Having determined the change in momentum correctly, candidates then needed to determine the momentum of the ball leaves the ground. **Exemplar 4**  This exemplar demonstrates that the candidate understands that the area under the graph is the impulse. The method to calculate the area is shown and although the candidate has

						not used the answer to (b)(i), the method in terms of the change of velocity is correct and clearly indicated.
		iii	For an elastic collision, kinetic energy/<u>KE</u> is conserved speeds are different (so for the same mass KE is different)		**B1** **B1**	**Allow** speed of approach = speed of separation **Allow** correct calculations of KE for both speeds **Ignore** reference to the ball heating up **<u>Examiner's Comments</u>** Many candidates did not state that the kinetic energy is conserved − often there were general statements about energy being conserved. Some candidates did not relate their answer to part (ii) as required by the question. Some candidates determined the kinetic energy before and after the ball left the ground − candidates could gain full marks with this approach.
			Total		**6**	
50		i	$a = 4π^2f^2$ ×		C1	condition for SHM
		i	so $k = (m4π^2f^2) = 1.7 × 10^{−27} × 4 × 9.87 × 43.7 × 10^{26}$		B1	substitution
		i	k = 292 (N $m^{−1}$)		A1	**ecf** if incorrect mass used
		ii	(N2 gives) $F_H = m_Ha_H$ and $F_I = m_Ia_I$		B1	**allow** total momentum = 0 at all times
		ii	(N3 gives) $F_H = F_I$ *can be implicit*		B1	SHM gives $v = 2πfx_{max}$
		ii	SHM gives a α (−)x		B1	so $m_HX_H = m_Ix_I$
		ii	hence $x_H/x_I = a_H/a_I = m_I/m_H = 127$		B1	**accept** $127 = x_H/x_I ≈ 10/0.08 = 125$
			Total		**7**	
51		i	*T* = 293 K		M1	
		i	3/2 kT = ½ mv^2		C1	
		i	$3/2 × 1.38 × 10^{−23} × 293 = ½ × 4.7 × 10^{−26} × v^2$		M1	
		i	v = 510 (m $s^{−1}$)		A0	Note answer is 509.8 m $s^{−1}$ to 4 s.f.
		ii	**1.** Total vertical momentum after = 0 Total vertical momentum before = 0 (momentum is conserved)		B1 B1	
		ii	**2.** $4.7 × 10^{−26} × v × \sin 88° = 1.4 × 10^{−24} × 23 × \sin 45°$		C1	
		ii	*v* = 480 (m $s^{−1}$)		A1	**Allow** other correct methods.
			Total		**7**	
52		i	(*p* =) $6.6 × 10^{−26} × 990$ **or** $6.5(3) × 10^{−23}$ (kg m $s^{−1}$)		C1	

			(Δp =) 2 × 6.6 × 10^{-26} × 990 Δp = 1.3 × 10^{-22} (kg m s^{-1})		A1	**Ignore** sign of answer
		ii	990/[2 × 0.46] (= 1080) (F = Δp/Δt) (*F* =) 1.3 × 10^{-22} × 1000 *F* = 1.3 × 10^{-19} N		B1 C1 A1	Possible ECF from **(b)(i)** **Note** 1080 would give 1.4 × 10^{-19} (N)
		iii	Use of *p* = *F*/*A* **or** pressure = (total) force / area Idea of multiplying by total number of atoms		B1 B1	 **Allow** particles or molecules for atoms
			Total		**7**	
53		i	From *t* = 0 to *t* = 2.0 s: a non–zero horizontal line From *t* = 2.0 to *t* = 3.5 s: line showing *v* = 0 From *t* = 3.5 to *t* = 4.0 s: non–zero horizontal line showing *v* is <u>opposite</u> in direction <u>and</u> magnitude larger than that of line drawn at *t* = 0 to *t* = 2.0.		**B1** **B1** **B1**	Judgement by eye
		ii	KE is constant. GPE increases linearly / proportional to *t*		**B1** **B1**	**Allow:** 'at constant rate' for 'linear' Not: unqualified 'constantly' **<u>Examiner's Comments</u>** Nearly four fifths of candidates completed 20a well, especially if they clearly stated the equations for momentum and kinetic energy. Those that did not generally forgot that the question required an expression with 'p' and 'm' in it. $^1/_2$ pv was a common wrong answer. 20bi was answered well, with some candidates either slightly misreading the graph when the velocity became negative or not spotting that the line was steeper for the last section of the movement than it was in the first. Most candidates spotted that the KE was constant because the velocity was constant. Rather fewer candidates explained that the GPE increased *at a constant rate*.

		iii	$V^2 = 0.80^2 + 2 \times 9.81 \times 0.40$ $V = 2.9$ (m s^{-1})		C1 A1	**Allow** 1 mark for $(2 \times 9.81 \times 0.40)^{1/2} = 2.8$ (m s^{-1}) **Examiner's Comments** Many candidates selected the correct equation, although did not realise that the load was not at rest when it was released. The initial velocity was found from the graph on page 22 of the paper and was 0.80 ms^{-1}.
		iv	$F = 0.12 \times 2.9/0.025$ $F = 14$ (N)		C1 A1	Possible ECF from **(iii)1** **Note:** use of 2.8 m s^{-1} gives F = 13(.44 N) **Note:** 1.4×10^n (N) scores 1 mark **Examiner's Comments** Nearly three quarters of the candidates used the correct method for finding the average force acting on the load by considering the rate of change of momentum.
			Total		**9**	