Further Mechanics MS

1. C

[1]

2. (a) Conversion from per minute to per second 1

Conversion from revolutions to radians 1

Example of calculation

20 revolutions = 20 × 2π
/60 (= 2.1 rads s^{-1})

(b) Use of $r\omega^2$ 1

Answer in range 6 – 13 1

ms^{-2} 1

[5]

3. QWC i and iii – Spelling of technical terms must be correct and the answer must be organised in a logical sequence

Momentum conservation **(1)**
Total/initial momentum = 0 **(1)**
Momentum of slime equal momentum of bacteria **(1)**
(Bacteria) moves in opposite direction [backwards or forwards OK] **(1)**

OR

Force on slime **(1)**
Equal and opposite force (on bacteria) **(1)**
Cause rate of change of momentum / Δmv/t /ma to bacteria **(1)**
(Bacteria) moves in opposite direction [backwards or forwards OK] **(1)** Max 4

[4]

4. (a) (i) Calculation of time period **(1)**

Use of $v = \frac{\Delta s}{\Delta t}$ *or* $\omega = \frac{2\pi}{T}$ **(1)**

Use of $a = \frac{v^2}{r}$ *or* $a = r\omega^2$ **(1)**

Correct answer **(1)** 4

Example of calculation:

$T = \dfrac{25 \times 60 \times 60s}{15} = 5760s$

$v = \dfrac{2\pi r}{T} = \dfrac{2\pi \times 6.94 \times 10^6 m}{5760s} = 7.57 \times 10^3\ ms^{-1}$

$a = \dfrac{v^2}{r} = \dfrac{(7.6 \times 10^3 ms^{-1})^2}{6.94 \times 10^6 m} = 8.26ms^{-2}$

OR

$\omega = \dfrac{2\pi}{T} = \dfrac{2\pi}{5760s} = 1.09 \times 10^{-3}\ ms^{-1}$

$a = r\omega^2 = 6.94 \times 10^6 \times (1.09 \times 10^{-3})^2 = 8.26\ ms^{-2}$

(ii) mg equated to gravitational force expression **(1)**

g (= a) = 8.3 ms^{-2} substituted **(1)**

Correct answer **(1)** 3

Example of calculation:

$mg = \dfrac{GMm}{r^2}$

$\therefore 8.3ms^{-2} = \dfrac{6.67 \times 10^{-11}\ Nm^2\ kg^{-2}\ M}{\left(6.94 \times 10^6\ m\right)^2}$

$\therefore M = \dfrac{8.3ms^{-1} \times \left(6.94 \times 10^6\ m\right)^2}{6.67 \times 10^{-11}\ Nm^2\ kg^{-2}} = 6.0\ 10^{24}$ kg

(b) The observed wavelength is longer than the actual wavelength / the wavelength is stretched out **(1)**

One from:

The universe is expanding **(1)**
(All distant) galaxies are moving apart **(1)**
The (recessional) velocity of galaxies is proportional to distance **(1)**
The furthest out galaxies move fastest **(1)** Max 2

(c) (i) A light year is the distance travelled (in a vacuum) in 1 year by light / em-radiation **(1)**

The idea that light has only been able to travel to us for a time equal to the age of the universe. **(1)** 2

(ii) (Use of v = Ho d to show) $H_o = \frac{1}{t}$ **(1)**

Correct answer **(1)** 2

Example of calculation:

$$H_o = \frac{1}{t} = \frac{1}{12 \times 3.15 \times 10^{16} s} = 2.65 \times 10^{-18} s^{-1}$$

(iii) The answer must be clear and be organised in a logical sequence

There is considerable uncertainty in the value of the Hubble constant **(1)**

QWC

Any sensible reason for uncertainty **(1)**

Idea that a guess implies a value obtained with little supporting evidence
OR the errors are so large that our value is little better than a guess **(1)** 3

[16]

5. B

[1]

6. A

[1]

7. D

[1]

8. A

[1]

9. (a) Use of $F=mv/t$ or $F = ma$ **(1)**
Answer = 2.0×10^5 N **(1)**

Eg $F = 12000 \times 57 / 3.5$ 2

(b) Arrow down labelled mg / W **(1)**
Arrow up labelled eg R /reaction / force from seat **(1)**
Equal length vertical arrows from a clear single point
/ centre of mass and "bottom" **(1)** 3

(c) $4mg - mg$ OR $3mg$ **(1)**
$(m)v^2 / r$ seen **(1)**
Answer = 110 (m) **(1)**

Eg $3mg = mv^2 /r$
$r = (57)^2 /3g$ 3

(d) Use of KE / PE conservation **(1)**
Answer = 23 (m s^{-1}) **(1)**

Eg $\frac{1}{2} m(57)^2 = \frac{1}{2} mv^2 + mg139$
$v^2 = \frac{1}{2} (57)^2 - 9.81 \times 139$ 2

(e) Using $(m)g$ only **(1)**
Answer r = 54 m [allow ecf] **(1)**

Eg $mg = mv^2 /r$
$r = (23)^2 / 9.81$ 2

[12]

10. (a) $u\bar{d}$ identified **(1)** 1

(b) Conversion of G **(1)**
Conversion of either eV or divided by c2 **(1)**
2.5×10^{-28} (kg) **(1)**

eg
$m = 0.14 \times 10^9 \times 1.6 \times 10^{-19} / 9 \times 10^{16}$ 3

(c) **QWC**

QWC i and iii – Spelling of technical terms must be correct and the answer must be organised in a logical sequence

Electric fields:
Electric field provides force on the charge/proton **(1)**
gives energy to /work done / E = qV/ accelerate protons **(1)**

Magnetic fields:
Force on moving charge/proton **(1)**
Produces circular path/centripetal force **(1)** — 4

labelled diagram showing Dees
with E field indicated across gap OR B field through Dees **(1)**
E field is reversed/alternates **(1)** — Max 1

(d) **QWC**

QWC i and iii – Spelling of technical terms must be correct and the answer must be organised in a logical sequence

momentum **(1)**
Zero / negligible momentum before **(1)**
To conserve momentum (fragments go in all directions) **(1)** — 3

[12]

11. (a) (i) measured thickness of lead 4-5 mm **(1)**
measured radius 32 - 38 mm **(1)**
Value between 38 – 57 mm **(1)**

Eg actual radius = 35 mm × 6 mm/4.5 mm — 3

(ii) Use of $p = Bqr$ [any two values sub] **(1)**
Answer range 9.1×10^{-21} - 1.4×10^{-20} N s or kg m s^{-1}
[allow ecf]**(1)** — 2

(b) Track gets more curved above lead / r smaller above lead **(1)**
Must be slowing down / less momentum / loses energy **(1)**
Up [dependent on either answer above] **(1)** — 3

(c) Into page **(1)**
[ecf out of page if down in b] — 1

(d) (i) Division by 9.11×10^{-31} kg **(1)**
Answer range $1.0 – 1.6 \times 10^{10}$ m s^{-1} **(1)** 2

(ii) greater than speed of light **(1)**
(impossible) so mass must have increased **(1)** 2

[13]

12. B

[1]

13. (a) They act on the same body **or** do not act on different bodies **(1)**
They are different types of, **or** they are not the same type of, force**(1)** 2

(b) As the passenger **or** capsule **or** wheel has constant speed **(1)**
there is No resultant tangential force (acting on the passenger) **(1)** 2

(c) Friction between seat & person or push of capsule wall on person **(1)** 1

[5]

14. (a) <u>Total</u> (linear) momentum of a system is constant, **(1)**

provided no (resultant) <u>external</u> force acts on the system **(1)** 2

(b) The answer must be clear, use an appropriate style and be organised in a logical sequence

Use of a light gate **(1)**
Use of second light gate **(1)**

Connected to timer **or** interface + computer (accept 'log-it') **(1)**

Cards on gliders **(1)**

Measure length of cards **(1)**
Velocity = length ÷ time **(1)** 6

(c) Multiplies mass × velocity to find at least one momentum **(1)**

1560 g cm s^{-1} (0.0156 kg m s^{-1}) before <u>and</u> after **(1)** 2

[10]

15.	(a)	(i)	Use of $A = \pi r^2$ leading to 0.87 (m) **(1)**	1
		(ii)	Correct use of $\omega = 2\pi/t$ leading to 62.8 (rad s^{-1}) **(1)**	1
		(iii)	Correct use of $v = r\omega = 55$ m s^{-1} [allow use of show that value] **(1)**	1
	(b)	(i)	Substitution into $p = ½\ \rho A v^3$ **(1)** 3047 (W) **(1)**	2
		(ii)	Air is hitting at an angle/all air not stopped by blades **(1)** Energy changes to heat and sound **(1)**	2
	(c)	(i)	Attempts to find volume per second ($A \times v$) **(1)** 44 kg s^{-1} **(1)**	2
		(ii)	Use of $F = \Delta mv/\Delta t$ **(1)** F = 610 N **(1)**	2

(d) Recognises that 100 W is produced over 24 hours **(1)**
Estimates if this would fulfil lighting needs for a day**(1)**
Estimates energy used by low energy bulbs in day**(1)**
Conclusion **(2)**
The answer must be clear and be organised in a logical sequence

<u>Example:</u>

The 100 W is an average over the whole day. Most households would use light bulbs for 6 hours a day in no more than 4 rooms, so this would mean no other energy was needed for lighting.
4 low energy bulbs would be 44 W for 6 each hours so would require energy from the National grid.

[Accept an argument based on more light bulbs/longer hours that leads to the opposite conclusion] 5

[16]

16. (a) (i) Why speed is unchanged

Force/Weight [not acceleration] is perpendicular to velocity/motion/direction of travel/instantaneous displacement [not speed]
OR no component of force/weight in direction of velocity etc **(1)**

No work is done
OR No acceleration in the **direction of motion (1)** 2

(ii) Why it accelerates

Direction (of motion) is changing **(1)**

Acceleration linked to a change in velocity **(1)** 2

(b) Speed of satellite

Use of $a = v^2/r$ **(1)**

Correct answer [3.8 to 4.0 × 10^3 m s^{-1}] **(1)**

Example calculation:
$v = \sqrt{(2.7 \times 107 \text{ m} \times 0.56 \text{ m s}^{-2})}$

[Allow 1 mark for $\omega = 1.4 \times 10^{-4}$ rad s^{-1}] 2

[6]

17. Any 8 marks from:
Recall of $p = mv$ **(1)**
Use of momentum before collision = momentum after collision **(1)**
Correct value for speed **(1)**

Example:
1250 × 28.0 + 3500 x25.5 = (1250 + 3500) v
v = 26.16 m s^{-1}

Recall of ke = 1/2 mv^2 or ke = $p^2/2m$ **(1)**
Total ke before **(1)**
Total ke after **(1)**
Loss in ke **(1)**
Recall of work = force × distance **(1)**
Correct answer for force to 2 SF **(1)**

Example:
Total ke before = 1 138 000 J + 490 000 J = 1 627 938 J
Total ke after = 1 625 059 J
Loss of KE = 2879 J
Braking force = 2879/5 = 576 N Max 8

[8]

18. (a) Identify particle

Alpha (particle) / Helium nucleus/ ${}^4_2$He / He^4_2 / ${}^4_2\alpha$ /

α^4_2 / ${}^4_2$alpha/alpha$^4_2$ / α 1

(b) Momentum of particle

Momentum equation [In symbols or with numbers] **(1)**

Either

Correct substitution into $\frac{1}{2}mv^2$ = energy **(1)**

Use the relationship to determine the mass [6.6×10^{-27} kg] **(1)**

Answer [9.3×10^{-20} (kg m s^{-1}) Must be given to 2 sig fig. No unit error] **(1)**

Or

Rearrangement of $E_k = \frac{1}{2}mv^2$ to give momentum ie $\frac{2E_K}{v}$ **(1)**

Correct substitution **(1)**

Answer [9.3×10^{-20} kg m s^{-1}. Must be given to 2 sig fig. No unit error] **(1)**

Eg $\frac{1}{2}m(1.41 \times 10^7 \text{ m s}^{-1})^2 = 6.58 \times 10^{-13}$ J

$m = \frac{2 \times 6.58 \times 10^{-13} \text{ J}}{(1.41 \times 10^7 \text{ m s}^{-1})^2} = 6.6 \times 10^{-27}$ kg

momentum $= 6.6 \times 10^{-27} \text{ kg} \times 1.41 \times 10^7 \text{ m s}^{-1}$

$= 9.3 \times 10^{-20}$ (kg m s^{-1})

Or

Momentum = $\frac{2 \times 6.58 \times 10^{-13} \text{ J}}{1.41 \times 10^7 \text{ m s}^{-1}}$ = 9.3 × 10 (kg m s^{-1}) 4

(c) Consistent with the principle of conservation of momentum

(Since total) momentum before and after (decay) = 0 **(1)**

State or show momentum / velocity are in opposite directions **(1)**

[Values of momentum or velocity shown with opposite signs would get this mark]

Calculation ie $3.89 \times 10^{-25} \text{ kg} \times 2.4 \times 10^5 \text{ m s}^{-1} = 9(.3) \times 10^{-20}$ (kg m s^{-1}) **(1)**

Eg $3.89 \times 10^{-25} \text{ kg} \times 2.4 \times 10^5 \text{ m s}^{-1} = 9(.3) \times 10^{-20} \text{ kg m s}^{-1}$ 3

[8]

19. (a) Calculation of angular speed

Use of $\omega = 2\pi/T$ **(1)**
7.27×10^{-5} [2 sig fig minimum] **(1)** 2

$2\pi/(24\text{h} \times 3600 \text{ s h}^{-1}) = 7.27 \times 10^{5} \text{ rad s}^{-1}$

(b) (i) Calculation of acceleration
Use of $a = r\omega^2$ OR $v = r\omega$ and $a = v^2/r$ **(1)**
0.034/031 m s^{-2} **(1)** 2

$(6400 \times 10^{J} \text{ m})(7.27 \times 10^{-5} \text{ rad s}^{-1})^2$
$= 0.034 \text{ m s}^{-2}$

(ii) Direction of acceleration
Arrow to the left **(1)**
[No label needed on arrow. If more than one arrow shown, no mark unless correct arrow labelled acceleration] 1

(iii) Free-body diagram
Arrow to left labelled Weight/*W*/*mg*/pull of Earth/gravitational force **(1)**
Arrow to right labelled Normal reaction/*N*/*R*/push of Earth (OR ground)/(normal)contact force **(1)**

[Don’t accept “gravity” as label]
[More than two forces max 1]
[Diagram correct except rotated gets 1 out of 2] 2

(iv) How the acceleration is produced
N is less than *W* **(1)**
Resultant (OR net OR unbalanced) force towards centre **(1)**

[Accept downward / centripetal for towards the centre, but not as an alternative to “resultant”] 2

[9]

20. (a) recall of p = mv [eqn or sub] **(1)**
answer **(1)**

p = mv
= 2 × 0.024 × 0.88 (N s) = 0.042(24) N s OR kg m s^{-1} 2

(b) recall of KE = $1/2mv^2$ OR $p^2/2m$ [eqn or sub] **(1)**
answer **(1)**

KE = $1/2mv^2$
= 0.5 × 2 × 0.024 × 0.88 × 0.88 (J) = 0.0185(856) (J) 2

(c) (i) provided no external force acts **(1)**
OR balls do not interact with/transfer momentum to anything else 1

(ii) v = momentum/mass = 0.042(24)/0.072 = 0.5833 (0.5867) (m s^{-1}) **(1)** 1

(iii) 0.5 × 0.096 × 0.442 OR 0.5 * B9 * C9 * C9 **(1)** 1

(iv) 3 points from:
can't be one ball as too much KE **(1)**
collision pretty elastic/not much loss of energy **(1)**
so won't be 3 or 4 or 5 balls **(1)**
2 balls gives same energy **(1)** Max 3

(d) 2 points from
kinetic energy is lost (as sound/through deformation/to heat) **(1)**
OR collisions not perfectly elastic
Momentum still conserved **(1)**
as the total ke decreases (column D) more balls are in motion **(1)** Max 2

[12]

21. (a) 1 equating PE and KE **(1)**
2 recall of mv2/r **(1)**
3 find centripetal force = 2mg **(1)**
4 force on rider = centripetal force + weight OR force = 3mg **(1)**
5 hence "g-force" = 3 **(1)** 5

(b) height not a factor, so B is correct **(1)**
(some will reach this conclusion via much longer routes) 1

[6]

22. (a) <u>Table</u>

[Ignore crosses. If more than one tick in a line, no mark.]
Top line: To the left **(1)**
Bottom line: Downwards **(1)** 2

(b) Calculation of rotation period

Use of $T = 2\pi r/v$ or $T = 2\pi/\omega$ and $\omega = v/r$ **(1)**
Correct answer [0.084 s] **(1)**

e.g.

2π (0.28 m)/(21 m s^{-1})
= 0.084 s 2

(c) (i) How the angular speed is affected

ω is increased, plus correct supporting argument in formula or words **(1)**
i.e. Since $v = r\omega$ / T decreases / f increases / wheel must turn faster 1

(ii) Speedometer reading

Speedometer reading is too high because frequency **(1)**

(OR ω OR revs per second OR rate of rotation of wheel)
is increased
[Allow ecf from "ω decreased" in c (i)] 1

[6]

23. (a) Show that

See '$v = \frac{2\pi r}{T}$' OR '$\omega = \frac{2\pi r}{T}$' **(1)**

Substitution of (60 × 60 × 24)s or 86400s for T (giving 7.27×10^{-5}, no u.e.) **(1)**

Unit of ω

s^{-1}/rad s^{-1} **(1)** 3

(b) Height above Earth's surface

Statement / use of $\frac{GM_E m}{r^2} = \frac{mv^2}{r}$ OR $\frac{GM_E m}{r^2} = mr\omega^2$ **(1)**

[Equations may be given in terms of accelerations rather than forces]

[Third mark (from below) may also be awarded here if ($r_E + h$) is used for r]

Correct value for r, i.e. $4.2(3) \times 10^7$ m **(1)**

Use of h = their $r - R_E$ **(1)**

Correct answer = $(3.58 - 3.60) \times 10^7$ m [no ecf] **(1)**

Example of answer:

$$\frac{GM_E m}{r^2} = \frac{mv^2}{r}$$

$$\rightarrow \frac{GM_E}{r^2} = \frac{v^2}{r} = \frac{(\omega r)^2}{r} = \omega^2 r$$

$$\therefore GM_E = \omega^2 r^3$$

$$\therefore r = \sqrt[3]{GM_E / \omega^2} = \sqrt[3]{\frac{6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 5.98 \times 10^{24}\ \text{kg}}{(7.27 \times 10^{-5}\ \text{s}^{-1})^2}}$$

$= 4.23 \times 10^7$ m

$\therefore\ h = 4.23 \times 10^7 \text{ m} - 6.38 \times 10^6$ m

$= 3.59 \times 10^7$ m 4

[7]

24. (i) two correct arrows [ignore labelling] **(1)** 1

(ii) Some use of mv^2/r with v correctly subbed OR $mr\omega^2$ with v correctly used **(1)**

[subbing may happen later in answer]

$T \cos \theta = mg\ mg$

OR $T \sin \theta = mv^2/r$ [either gains **(1)**] **(1)**

$\Rightarrow \tan \theta = v^2/rg$ **(1)**

$\Rightarrow r = v^2/g \tan \theta$

$= 30 \times 30/9.81 \times \tan 20$ m

$= 252$ m **(1)** 4

[5]

25. (a) Expression for gravitational force:

$F = GMm/r^2$ **(1)** 1

(b) Expression for gravitational field strength:
g = force on 1 kg, so $g = GM/r^2$, or g = F/m so $g = GM/r^2$ 1

(c) Radius of geostationary orbit:
Idea that a = g, **and** suitable expression for a quoted [can be in terms of forces] **(1)**
substitution for velocity in terms of T **(1)**
algebra to obtain required result **(1)** 3

Example of derivation:
$g = v^2/r$ **or** $g = \omega^2 r$
and $v = 2\pi r/T$ ***or*** $\omega = 2\pi/T$
so $(2\pi r/T)^2/r = GM/r^2$ **or** $(2\pi/T)^2 r = GM/r^2$, leading to expression given

(d) Calculation of radius:
Substitution into expression given **(1)**
Correct answer [4.2×10^7 m] **(1)** 2

Example of calculation:
$r^3 = 6.67 \times 10^{-11}$ N m^2 kg^{-2} $\times 6.0 \times 10^{24}$ kg $\times (24 \times 60 \times 60\text{ s})^2 / 4\pi^2$
$= 7.6 \times 10^{22}$ m^3
So $r = 4.2 \times 10^7$ m

(e) (i) Satellite with greater mass:
Yes – because, in geostationary orbit, r constant so acceleration remains the same, regardless of mass **(1)**

(ii) Satellite with greater speed:
No + suitable argument **(1)** 2
[e.g. for geostationary orbit, T and r are fixed, so v cannot increase ($v = 2\pi r/T$)]

(f) Why satellite must be over equator:
Idea that centre of satellite's orbit must be the centre of the Earth (can be shown on diagram) **(1)**
there must be a common axis of rotation for the satellite and the Earth / the satellite's orbit must be at right angles to the spin axis of the Earth **(1)** 2

[11]

26. (a) <u>Momentum at impact</u>

$p = mv$ seen or used **(1)**

Answer [11 kg m s^{-1}] **(1)** 2

eg momentum = 0.42 kg × 27 m s^{-1}

= 11.34 kg m s^{-1}

(b) <u>Momentum at release</u>

Minus **(1)**

8.4 kg m s^{-1} **(1)** 2

(c) (i) <u>Average force(ecf momenta values)</u>

Use of $F = \frac{\Delta p}{\Delta t}$ ie for using a momentum value divided by **(1)**

0.22

Adding momentum values **(1)**

Answer [88.0 N – 89.8 N] **(1)**

$F = \frac{-8.4 \text{ kg m s}^{-1} - 11.3 \text{ kg m s}^{-1}}{0.22 \text{ s}}$

F = (–) 89.5 N

Or

Use of F = ma **(1)**

Adding velocities to calculate acceleration **(1)**

Answer [88.0 N – 89.8 N] **(1)**

Eg acceleration = $\frac{-20 \text{ m s}^{-1} - 27 \text{ m s}^{-1}}{0.22 \text{ s}}$ (= –213.6 m s^{-2})

Force = 0.42 kg × –213.6 m s^{-2} = (–)89.7(2) N 3

(ii) <u>Direction of force on diagram</u>

Right to left **(1)**

[Accept arrow drawn anywhere on the diagram. Label not required] 1

(d) <u>Difference and similarity</u>

Difference: opposite direction / acts on different object **(1)**

Similarity: same type of force / same size / acts along same line / **(1)**
act for same time / same **size** impulse
['Magnitude' and 'size' on their own is sufficient. 'They are equal' is OK. Accept; they are both contact forces; they are both electrostatic forces] 2

[10]

27. (a) E$_K$ of helium nucleus

Use of $E_K = \frac{1}{2}mv^2$ **(1)**

Answer [3.1×10^{-15} J. No ue. Min 2 sig fig required] **(1)** 2

eg $E_K = \frac{1}{2} \times 6.65 \times 10^{-27}$ kg $\times (9.65 \times 10^5$ m s$^{-1})^2$

$= 3.096 \times 10^{-15}$ J

(b) (i) Loss of E$_K$ of proton [ecf their value for EK of helium nucleus]

3×10^{-15} J or 3.1×10^{-15} J **(1)** 1

(ii) Speed of proton after collision

[ecf their value for loss of EK of proton, **but not if they have given it as zero**]

Calculation of initial E$_K$ of proton **(1)**

Subtraction of 3.1×10^{-15} J [= 1.7×10^{-15} J] **(1)**

Answer [(1.40 – 1.50) $\times 10^6$ m s^{-1}] **(1)**

eg $E_K = \frac{1}{2} 1.67 \times 10^{-27}$ kg $\times (2.4 \times 10^6$ m s$^{-1})^2$ (= 4.8×10^{-15} J)

E$_K$ after collision = 4.8×10^{-15} J – 3.1×10^{-15} J (= 1.7×10^{-15} J)

$v = \left(\frac{1.7 \times 10^{-15}\ \text{J}}{0.5 \times 1.67 \times 10^{-27}\ \text{kg}} \right) = 1.43 \times 10^6$ m s^{-1}

Or

Use of the principle of conservation of momentum. **(1)**

Correct expression for the total momentum after the collision **(1)**

Answer [(1.40 – 1.50) $\times 10^6$ m s^{-1}] **(1)**

Eg 1.67×10^{-27} kg $\times 2.4 \times 10^6$ m s^{-1}

$= 6.65 \times 10^{-27}$ kg $\times (9.65 \times 10^5$ m s$^{-1}) + 1.67 \times 10^{-27}$ kg $\times$ V

V = -1.44×10^6 m s^{-1}

[For both these solutions allow the second marking point to candidates who incorrectly write: 3

the mass of the proton as 1.6×10^{-27} kg or 1.7×10^{-27} kg,

or the mass of the helium as 6.6×10^{-27} kg or 6.7×10^{-27} kg

or the velocity as 9.6×10^5 m s^{-1} or 9.7×10^5 m s^{-1}]

(c) Other factor conserved

Momentum / mass / charge / total energy **(1)** 1

[7]

28. (a) *R* drawn [10° to vertical] **(1)**
D drawn [10° to horizontal] **(1)**
drag force *D* = 140 – 155 N [147.6 N by calc is OK] **(1)** 3

(b) Resolve vertically **(1)**
correct value **(1)**

eg $P \cos 40° = 850$ N
$\Rightarrow P = 1100$ N 2

(c) (i) velocity not constant / direction changing **(1)**
[NOT "if no force, goes straight"]
acceleration (towards centre of circle) **(1)** **(Any 2)**
$F = ma$ **(1)** 2

(ii) *P*/push of <u>ice</u> (on sled) **(1)**
horizontal component **(1)** 2
["additional centripetal force" = 0]

(d) Recall circular motion formula **(1)**
resolve horizontally **(1)**
correct value **(1)**
[incorrect force is eop]
[also possible: W.tan40 = mv^2/r **(1)(1)**]

eg $F = P \sin 40 = 713$ (643) (N) [formula or value]
$R = mv^2/F$
$= 87 \times 35^2 / 713$ (643) (m)
radius = 149 (166) m 3

[12]

29. (a) <u>Newton's Second Law of Motion</u>

(The) force (acting on a body) is proportional/equal to the rate of **(1)**
change of momentum **(1)**
and acts in the direction of the momentum change
[accept symbols if all correctly defined for the first of these marks]
[ignore any information that is given that is not contradictory] 2

(i) Calculate the mass

Correct calculation for volume of air reaching tree per second
[Do not penalise unit error or omission of unit] **(1)**
Correct value for mass of air to at least 3 sig fig [246 kg. No ue.] **(1)**
[If 1.23 × 10 × 20 = 246 kg is seen give both marks.
Any order for the numbers]

Example

$20\ \text{ms}^{-1} \times 10\text{m}^2 = 200\ \text{m}^3$
$1.23\ \text{kg m}^{-3} \times 200\ \text{m}^3 = 246\ \text{kg}$

(ii) Calculate the momentum

Answer: [($246\ \text{kg} \times 20\ \text{m s}^{-1}$ =) $4920\ \text{kg m s}^{-1}$]
[Accept ($250\ \text{kg} \times 20\ \text{m s}^{-1}$ =) $5000\ \text{kg m s}^{-1}$. Accept $4900\ \text{kg m s}^{-1}$. **(1)** 2
Ecf value for mass. Ignore signs in front of values.]

(iii) Magnitude of the force
Answer: [*F* = 4920 N or 5000 N or 4900 N.]
[Ecf value from b(ii). Ignore signs in front of values] **(1)** 2

[6]

30. Explanation

There is a resultant (or net or unbalanced) force **(1)**

Plus any 3 of following:–

Direction of motion is changing **(1)**
Velocity is changing **(1)**
Velocity change implies acceleration **(1)**
Force produces acceleration by *F* = *ma* (or N2) **(1)**
Force (or acceleration) is towards centre / there is a centripetal **(1)**
force (or acceleration) / no force (or acceleration) parallel to motion
No work done, so speed is constant **(1)** Max 3

[4]

31. <u>Speed of sphere</u>

Momentum conserved [stated or implied] □**(1)**

Correct subs L.H.S or R.H.S of conservation of momentum equation **(1)** 3

Correct answer [$\nu = 1.43(\text{m s}^{-1})$] **(1)**

Example of calculation:

$54 \times 2.57\ (+\ 0) = 54 \times \nu + 29 \times 2.12\ (\text{g m s}^{-1})$

$\Rightarrow\ 138.78 = 54 \times \nu + 61.48$

$\Rightarrow\ \nu = 1.43(\text{m s}^{-1})$

<u>Elastic or inelastic collision</u>

Recall K.E: $1/2mv^2$**(1)**

Correct values for both KEs [178(mJ), 120(mJ), no ue]**(1)**

Conclusion consistent with their results for KE**(1)** 3

[max 1 if only words used and inelastic ≡ energy lost implied]

Example of calculation:

$= ½ \times 54 \times 2.57^2 = 178$ mJ
Final total K.E: $½ \times 29 \times 2.12^2 + ½ \times 54 \times 1.43^2$ mJ
= 65 mJ + 55 mJ
= 120 mJ

⇒Inelastic

<u>Average speed of the spheres</u>

Recall $\nu = 2\pi r / t$ **(1)**

Correct answer [$2.9\ \text{m s}^{-1}$] **(1)** 2

Example of calculation:

$\nu = 2\pi r / t = \pi \times 0.17 \times 2\ \text{m} / 0.37\ \text{s}$

$= 2.9\ \text{m s}^{-1}$ or 290 cm/s

<u>Calculation of centripetal force</u>

Recall $F = m\nu^2 / r$ OR $mr\omega^2$ OR $m\ \nu\ \omega$ **(1)**
Correct answer [1.43 N, ecf for their ν] **(1)** 2

Example of calculation:

$F = m\nu^2 / r$
$= 0.029 \times 2.9^2 / 0.17$ N [watch out for 29 twice]
= 1.43 N [ecf]

Tension

Weight of sphere (= mg = 0.029 × 9.81 N =)0.28 N **(1)**

$T = F – W$ OR $F = T + W$ [using their values for F and T] **(1)** 2

Example of calculation:

= 1.43 – 0.28 (N)
⇒ T = 1.15 N

[12]

32. Smoke detectors

Recognition that mass alpha = 4 **(1)**
Idea of - 4 to find resulting nucleus mass [237] **(1)**

$Mu_{\text{daughter product}} = mv_{\text{alpha}}$ or momentum equations in context **(1)**

$v_{\text{alpha}} = 59(.25)\ u_{\text{daughter product}}$ [allow ecf incorrect masses eg 4 and 241 : 60.25] **(1)**

Use of ½ mv^2 To give ratio = 59(.25) [allow ecf as long as rounds **(1)**
to 60 ; must have speeds sub ; valid use of $p^2/2m$]

Energy:

$E = mc^2$ / energy must have come from mass **(1)**

Total mass after is a (little) less than before/mass loss/
mass defect/binding energy **(1)** max 6

[6]

33. (a) From what height?

Use of $mg\Delta h$ **and** ½ mv^2 **(1)**
[ignore power of 10 errors]

mg Δh = ½ mv^2 **(1)**

[shown as formulae without substitution, or as numbers substituted
into formulae]

Answer [0.8(2) m] **(1)**

[It is possible to get 0.8 m by a wrong method:

- If $v^2 = u^2 + 2as$ is used, award 0 marks
- If you see v^2/a then apply bod and up to 2/3 marks – the 2nd and 3rd marks. Note that v^2/g is correct and gains the first 2 marks, with the 3rd mark if 0.8 m is calculated] 3

$80 \times (10^{-3})\ \text{kg} \times 9.81\ \text{N kg}^{-1} \times \Delta h = \frac{1}{2} \times 80\ (\times 10^{-3})\ \text{kg} \times (4\ \text{m s}^{-1})^2$

$$h = \frac{0.5 \times 80 \times 10^{-3}\ \text{kg} \times (4\ \text{ms}^{-1})^2}{80 \times 10^{-3}\ \text{kg} \times 9.81\ \text{N kg}^{-1}}$$

= 0.8(2) m

(b) (i) Law of conservation of linear momentum

Provided no external [other/resultant/outside] force acts **(1)**
The total momentum (of a system) does not change / total momentum **(1)**
before(collision) = total momentum after (collision) 2
[Total seen at least once] [Ignore all references to elastic and inelastic]
[Do not credit simple statement that momentum is conserved]

(ii) Speed of trucks after collision

Any correct calculation of momentum **(1)**

Use of conservation of momentum leading to the answer 1.3(3) m s^{-1} **(1)**

$80 \times (10^{-3})\ \text{kg} \times 4\ \text{m s}^{-1} = 240 \times (10^{-3})\ \text{kg} \times u$, giving $u = 1.3(3)\ \text{m s}^{-1}$ 2

(c) Time for trucks to stop

[Do not penalise candidates for using a total frictional force of 0.36 N.
3/3 possible]

Either
Correct use of power = $f \times v$ and $\frac{1}{2} mv^2$ **(1)**
[Do not penalise power of 10 errors or not dividing by 2 in f × V equation]

Use of energy divided by power **(1)**

Answer in range 2.6 s to 2.7 s **(1)**
[ecf their value for *u*]

$P = 0.12\ \text{N} \times \frac{1.33}{2}\ \text{m s}^{-1} = 0.08\text{W}$

KE = ½ × (3) × 80 × (10^{-3}) kg × (1.33 m s^{-1})^2 = 0.21 J

$$\frac{\text{Energy}}{\text{power}} = \frac{0.21\,\text{J}}{0.08\,\text{W}}$$

t = 2.6(5) s

[accept 2.6 or 2.7 as rounding] 3

OR

Use of $F = ma$ ***(1)***

Use of **either** $v = u + at$ *i.e* **or** $a = \frac{\Delta v}{t}$ **(1)**

Answer in range 2.6 s to 2.7 s **(1)**

(–)0.12 N = (3) × 80 × (10^{-3}) kg × a (a = (–)0.5 m s^{-2})

0 = 1.33 m s^{-1} – 0.5 m s^{-2} × t **or** (–)0.5 m s^{-2} = $\frac{(-)1.33\,\text{m s}^{-1}}{t}$

t = 2.6(6) s

OR

Select $Ft = \Delta p$ **(1)**
Substitution (–)0.12t = (–3) × 80 × (10^{-3}) kg × 1.33 m s^{-1} **(1)**
Allow omission of any bracketed value]
Answer in range 2.6 s to 2.7 s **(1)**

[10]

34. (a) Radius of circular path

Correct use of $v = \frac{2\pi r}{T}$ (allow substitution of their T) **(1)**

Radius = 70 – 80 m (74.48 m) **(1)** 2

(b) Resultant force

$F = \frac{mv^2}{r}$ [seen or used] **(1)**

Force = 0.08 N (0.077 N) [Allow ecf of their radius.] **(1)**

Towards the centre of the circular path / towards hub. **(1)** 3

(c) Forces on the man

(i) Force P : Normal contact/reaction force / EM force / push of **(1)** capsule or floor on man

Force Q : Pull of Earth on man / weight / gravitational pull **(1)** 2

(ii) Resultant force (to centre) **(1)**
(at A provided by) friction **(1)** 2

(iii) at B resultant provided (by force Q being greater than P) **(1)** 1

[10]

35. Direction

Force → centre/perpendicular to velocity/motion **(1)** 1
[Accept sideways/inwards]

Why force required

2 of:

Changing direction /charging velocity **(1)**

Acceleration **(1)**

Reference to or explanation in terms of NI or NII **(1)** Max 2

What provides force

Friction between tyres and road surface **(1)** 1

Maximum speed

$F = mv^2/r$ [Accept $F = mr\omega^2$] **(1)**

$\Rightarrow v = \sqrt{\frac{Fr}{m}}$ **OR** $\sqrt{\frac{470 \times 14}{160}}$ **(1)**

$= 6.4 \text{ m s}^{-1}$ **(1)** 3

Why skid occurs

Smaller r **(1)**

$\Rightarrow F(mv^2/r)$ (required) increases / use of $F = mv^2/r$ to deduce v decreases **(1)**

Only 470 N (available) / the force is the same **(1)** 3

Explanation

(m increased ⇒) F (needed) increases **(1)**

EITHER only 470 N available or the force is the same ⇒ NO
OR friction increases as mass increases(⇒YES) **(1)** 2

[12]

36. (a) Resultant force required

The direction of speed OR velocity is changing **(1)**
There is an acceleration/rate of change in momentum **(1)** 2

(b) (i) Angular speed

Use of an angle divided by a time **(1)**
7.3×10^{-5} rad s^{-1} OR 0.26 rad h^{-1} OR 4.2×10^{-3} $^{\circ}$ s^{-1} OR 15° h^{-1} **(1)** 2

(ii) Resultant force on student

Use of $F = mr\omega^2$ OR $v = r\omega$ with $F = \frac{mv^2}{r}$ **(1)**

2.0 N **(1)** 2

(iii) Scale reading

Evidence of contact force = mg − resultant force **(1)**
Weight of girl = 588 (N) OR 589 (N) OR 60 × 9.81 (N) **(1)**
Scale reading = 586 N OR 587 N [ecf their mg − their F] **(1)** 3

[9]

37. Speed of car 2

$\upsilon^2 - u^2 = 2as$

⇒ $(-)u^2 = (-)\ 2 \times 3.43 \times 23.9$ [substitution or rearrange] (m s^{-1}) **(1)**

⇒ $u = 12.8$ (m s^{-1}) [value] **(1)** 2

Magnitude of the momentum of car 2

$p = m\upsilon$ **(1)**

= 1430 × 12.8 (13) (kg m s^{-1})

= 18 300 (18 600) N s or kg m s^{-1} **(1)** 2

Calculation of easterly component of momentum

Component = momentum × cos θ **(1)**

Car 1: 23 800 Ns × cos 45

= 16 800 N s **(1)**

Car 2: 18 300 (18 600) N s × cos 30 = 15 800 (16 100) N s **(1)** 3

Whether car 1 was speeding before accident

(Sum of two easterly components) ~ 33 000 N s [ecf] **(1)**

(÷ mass of car 1) ⇒ ~ 16.8 m s^{-1} [ecf] **(1)**

Conclusion related to speed limit (17.8 m s^{-1}) **(1)** 3

Explanation of how investigator could use conservation law

Any two from:

- Momentum conservation
- After collision there is significant northerly momentum
- Before collision car 1 had no northerly momentum/only car 2 had northerly momentum **(1) (1)** 2

[12]

38. Momentum of neutron

Use of $p = m\upsilon$ **(1)**

$p = 5.03 \times 10^{-20}$ N s/kg m s^{-1} **(1)** 2

Speed of nucleus

Total mass attempted to be found **(1)**
Conservation of momentum used **(1)**
$\upsilon = 2.01 \times 10^{6}$ m s^{-1} [ecf from p above only] **(1)** 3

Whether collision was elastic

Use of k.e. = ½ $m\upsilon^2$ **(1)**

ke = 7.45×10^{-13} (J) / 5.06×10^{-14} (J) (ecf) **(1)**

A correct comment based on their two values of ke. **(1)** 3

[8]

39. <u>Resultant force</u>

Direction of travel changing **(1)**

Velocity changing/accelerating **(1)**

<u>Force</u> is towards centre of circle **(1)** 3

<u>Why no sharp bends</u>

Relate sharpness of bend to *r* **(1)**

Relate values of υ, *r* and *F* **(1)** 2

[e.g. if *r* large, υ can be large without force being too large/if *r* small, υ must be small to prevent force being too large]

<u>Bobsleigh</u>

$N\cos\theta = mg$ **(1)**

$N\sin\theta$ **(1)**

$= m\upsilon^2/r$ or ma **(1)**

Proof successfully completed [consequent on using correct formula] **(1)** 4

<u>Calculation of angle</u>

77 – 78° **(1)** 1

[10]

40. Discussion of type of collision

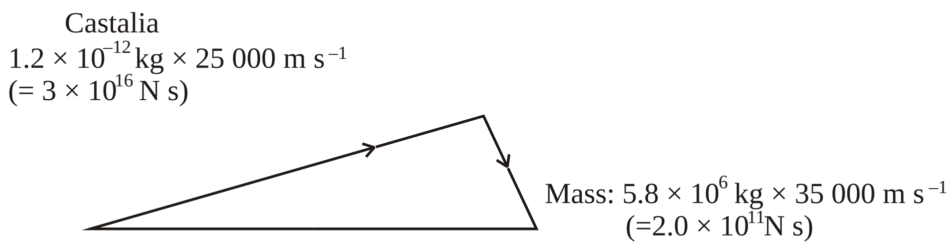
Inelastic **(1)**

Energy → heat at impact/plastic deformation **(1)** 2

<u>Momentum vector diagram</u>

Diagram [right–angle triangle with arrows on two perpendicular sides] **(1)**

Labelling **(1)** 2



Calculation of change in direction

θ /sinθ /tan $\theta = \dfrac{5.8 \times 10^6 \times 35\,000}{1.2 \times 10^{12} \times 25\,000}$

$= 6.77 \times 10^{-6}$ **(1)**

$\theta = 6.8 \times 10^{-6}$ rad OR 3.9×10^{-4} degrees OR 1.4 seconds **(1)** 2

Formula for net force in terms of momentum

F = d/dt ($m\upsilon$) OR words **(1)** 1

Calculation of number of rockets required

$N \times F \times t = 2 \times 10^{11}$ OR $N = 2 \times 10^{11} / (7 \times 10^6 \times 130)$ **(1)**

N = 220 [must be a whole number] **(1)** 2

[9]

41. Speed of rim of drum

$v = r\omega$ or $v = 2\pi r/T$ [either used] **(1)**

$\omega = \dfrac{2\pi \times 800 \text{ rev min}^{-1}}{60 \text{ s}}$ OR $T = \dfrac{60\text{s}}{800 \text{ rev min}^{-1}}$ **(1)**

= 18.4 m s^{-1} [3 sf min.] (no ue) **(1)** 3

Acceleration

Use of $a = r\omega^2$ OR $a = v^2/r$ **(1)**
1.5×10^3 ms^{-2} **(1)** 2

Addition of arrow and explanation

Arrow labelled A towards centre of drum **(1)**
Push of drum on clothing/normal contact exerted by drum on clothing **(1)** 2
[Normal reaction accepted]

Arrow of path

Arrow labelled B tangential to drum, from P, in anticlockwise direction **(1)** 1

[8]

42. <u>Mass of head of mallet</u>

Selecting density x volume **(1)**
Correct substitutions **(1)**
Mass = 1.15 (kg) [3 significant figures, minimum] **(1)** 3

<u>Momentum change</u>

$p = m\upsilon$ used **(1)**
Δp = 1.15 or 1.2 kg (4.20 + 0.58) m s^{-1} **(1)**
= 5.50 / 5.74 kg m s^{-1}/N s **(1)** 3

<u>Average force</u>

Their above / 0.012 s **(1)**

F = 458/478 N [e.c.f. Δp above] **(1)** 2

<u>Value for force</u>

Handle mass/weight/ head weight/force exerted by user (handle) neglected **(1)** 1

<u>Effectiveness of mallet with rubber head</u>

Δt goes up/Δp goes up **(1)**

⇒ *less* force, *less* effective/*more* force, *more* effective [consequent] **(1)** 2

[11]

43. <u>Homogeneity</u>

p = mass × velocity **(1)**
p units N s or kg m s^{-1} [This alone implies above mark] **(1)**
E unit (J) N m or kg m^2 s^{-2} **(1)**
c unit m s^{-1} **(1)** 4

[4]

44. Magnitude of F

$F = m\upsilon^2 / r$ **(1)**
Towards the centre **(1)** 2

Calculation

(i) 9.07×10^3 N **(1)**

(ii) $R = mg - m\upsilon^2 / r$ **(1)**
Substitutions **(1)**
5.37×10^3 N

[Calculation of $m\upsilon^2 / r$ max 1] **(1)** 4

Explanation

Required centripetal force > mg (so cannot be provided) **(1)** 1

Critical speed
Use of $(m)g = (m)\upsilon^2 / r$ **(1)**
15.7 m s^{-1} **(1)** 2

Apparently weightless
This means no force exerted on/by surroundings OR $R = 0$ OR only force acting is weight **(1)**
When car takes off it is in free fall [consequent] **(1)** 2

[11]

45. Direction of centripetal acceleration

Towards centre/downwards/inwards **(1)** 1

Explanation

$F=ma$
a and F in same direction **(1)** 1

Resultant force

$\upsilon = \frac{2\pi r}{T} = \frac{2\pi \times 8}{4.5}$ [Equation OR substitution] **(1)**

$= 11.2 \text{ m s}^{-1}$ **(1)**

$F = \frac{mv^2}{r} = \frac{60 \times 11.2^2}{8}$ [Equation OR substitution] **(1)**

= 936 N **(1)**

OR $w = \frac{2\pi}{T} = \frac{2\pi}{4.5}$ [Equation OR substitution] **(1)**

$= 1.396 \text{ rad s}^{-1}$ **(1)**

$F = mrw^2$ (*)

$= 60 \times 8 \times 1.4^2$ (*) [(*) Equation OR substitution] **(1)**

= 936 N **(1)** 4

Calculation of weight

$W = mg = 60 \times 9.81$

= 589 N **(1)** 1

Calculation of magnitude of push

$F_{net} = W + P$

$P = F - W = 936 - 589$

= 347 N **(1)** 1

Diagram

$W\downarrow$ **(1)**

$P\uparrow$ **(1)** 2

[10]

46. Deceleration of Earth

$F = m\Delta \upsilon / \Delta t = 7 \times 3 \times 10^4$ N [Equation or substitution] **(1)**
$= 2.1 \times 10^5$ N **(1)**
$a = F/m = 2.1 \times 10^5 / 6.0 \times 10^{24}$ [Equation or substitution] **(1)**
$= 3.5 \times 10^{-20}$ m s^{-2} **(1)** 4

OR
in 1 second: $\Delta\upsilon$ for debris $= 3 \times 10^4$ m s^{-1}

$\Rightarrow a = 3 \times 10^4$ m s^{-2}

$F = ma = 7$ kg $\times 3 \times 10^4$ ms^{-2}
$= 2.1 \times 10^5$ N **(1) (1)**

F on Earth = F on debris

$\Rightarrow a_{\text{earth}} = F/m = \dfrac{2.1 \times 10^5 \text{ N}}{6 \times 10^{24} \text{ kg}}$

$= 3.5 \times 10^{-20}$ m s^{-2} **(1) (1)**
OR Conservation of momentum } **(1)**
or $m_1u_1 + m_2\upsilon_2 = m_3\upsilon_3$ etc }
$6 \times 10^{24} \times 3 \times 10^4 (+ 7 \times 0) = (6 \times 10^{24} + 7) \times \upsilon_3$ **(1)**
OR An answer (3.5×10^{-20} m s^{-2}) calculated from any specific **(1) (1) (1)**
arbitrary time] **(1)**
Comment: negligible **(1)** 1
[OR energy loss negligible]

[5]

47. Momentum and its unit

Momentum = mass × velocity 1

kg m s^{-1} or N s 1

Momentum of thorium nucleus before the decay

Zero 1

Speed of alpha particle/radium nucleus and directions of travel

Alpha particle because its mass is smaller/lighter 1

So higher speed for the same (magnitude of) momentum
OR N3 argument 1

Opposite directions/along a line 1

[6]

48. Angular speed

Use of $\omega = 2\pi/T$ 1

$\omega = 1.2 \times 10^{-3}$ [min 2 significant figures) [No ue as units given] 1

Free-body force diagram

Pull of Earth/Weight/mg/Gravitational Pull 1

Why satellite is accelerating

Resultant/Net/Unbalanced force on satellite must have an acceleration OR $\Sigma F = ma$. 1

-

Magnitude of acceleration

Use of $a = \omega^2 r$ OR $\upsilon^2 \div r$ 1

a = 9.36-9.42 OR 6.5 m s^{-2} 1

[Depends on which ω value used]

[6]

49. Why person moving in a circle must have an acceleration

Acceleration due to changing direction
OR
If not it would continue in straight line **(1)** 1

Centripetal acceleration

$a = \frac{v^2}{r}$ OR rw^2 **(1)**

$$v = \frac{2\pi r}{T} = \frac{2\pi \times 6.4 \times 10^6}{24 \times 60 \times 60} = 465 (\text{ms}^{-1})$$

OR

$$w = 7.3 \times 10^{-5} (\text{rad s}^{-1})$$

(1)

$\Rightarrow a$ = 0.034 (m s^{-2}) [no u.e.] **(1)** 3

Which force is the larger

mg is larger than *R*/*R* is smaller than *mg* **(1)**

mg – *R* / centripetal/accelerating/resultant force acts towards centre **(1)** 2

Differing apparent field strength

(0.034 ÷ 9.81) × 100%

= 0.35%

OR (0.03 ÷ 9.81) × 100% = 0.31 % [NOT 0.3%] **(1)** 1

[6]

50. Explanation of Pelton wheel

Quote of $F = \Delta m\upsilon/t$ [or in words] **(1)**

Negative moment/velocity after **(1)**

Increased (twice) momentum / velocity change/$m\upsilon$ - mu compared with falling off plane paddle **(1)**

Idea of doubled **(1)** Max 3

Percentage efficiency of station

Energy available = *mgh* **(1)**

Power input = 270 × 9.8 × 250 **(1)**

Efficiency = 500 000 × 100 / 661 500 = 76 (%) **(1)** 3

Other desirable properties

For example:

Hard – does not wear/scratch/dent **(2)**

Tough – can withstand dynamic loads/plastic deformation **(2)**

Strong – high breaking stress/force **(2)**

Smooth – low friction surface **(2)**

Durable – properties do not worsen with time **(2)** Max 4

Time to repay initial investment

Each hour worth 500 × 0.0474 = £23.70 OR total no of kW h required 1.000000/0.0474 = 2.1×10^7

No. of hours to repay = 1 000 000 /23.70 OR 2.1×10^7 /500

24 × 365 = 4.8 years to repay debt **(1)**

Assumption

Constant power production / no interest charges / no repair costs no wages for employees **(1)** 4

[14]

51. Angular speed

Conversion of 91 into seconds – here or in a calculation **(1)**

Use of $T = 2\pi/\omega$ allow $T = 360/\omega$

ω = 1.15 – 1.20 × 10^{-3} rad s^{-1} /6.9 × 10^{-2} rad min^{-1} /0.066 deg s^{-1} **(1)** 3

Acceleration

Use of $a = r\omega^2$ / υ^2 / r **(1)**

Adding 6370 (km) to 210 (km)/ 6580 (km) **(1)**

a = 8.5 to 9.5 m s^{-2} [No e.c.f. for 210 missed but allow for ω in rad s^{-1}] **(1)** 3

Resultant force

Recall/Use of $F = ma$ **(1)**

F = 35 –39 N [Allow e.c.f their a above only] **(1)**

Towards (centre of the) Earth **(1)** 3

[9]

52. How ions are accelerated

Electric field exists between +, – electrodes **(1)**

⇒ force on ions / force → acceleration **(1)** 2

Speed of xenon atom

eV = ½ $m\upsilon^2$/eV = E_k **(1)**

$\Rightarrow \upsilon = \sqrt{2eV/m}$ **(1)**

$= \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times (1060 + 225)}{2.2 \times 10^{-25}}}\,ms^{-1}$ **(1)**

= 4.3 ×10^4 m s^{-1} [No u.e.] **(1)** 4

Thrust on space probe

Force = rate of change of momentum **(1)**

= 2.1 × 10^{-6} × 43 000 N **(1)**

= 0.090 N **(1)** 3

[Using 4 × 10^4 m s^{-1} gives F = 0.084 N]

Reason for reduced thrust

Xenon ions attracted back OR similar **(1)** 1

Why ion drives maybe preferable

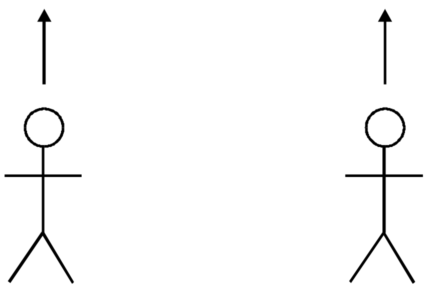
Any two from:

- less fuel required in total
- for example, 66 kg for a year
- thrust provided for longer/fuel lasts longer/accelerates for longer
- lower payload for initial launch/ion drive lighter **(1)** **(1)** 2

[12]

53. Diagrams showing forces:

Diagram 1 Diagram 2



(1) **(1)** 2

[Each diagram, one arrow only]

Discussion re artificial gravity

Any four from:

- centripetal force, in context
- forces felt by astronaut both "upward"
- so feels like weight/gravity
- a υ^2/r / $F = m\upsilon^2 / r$ / $a = \omega^2 r$ / $F = m\omega^2 r$ / $F = m\,\upsilon\,\omega$
- $= \left(\frac{2\pi r}{t}\right)^2 / r = \frac{4\pi^2 r}{t^2} = \frac{4\pi^2 \times (10/2)}{10^2}$ [Any one] or calculate υ or ω
- = 2.0 m s^{-2} [No u.e.]
- artificial field varies with / α radius **(1) (1) (1) (1)** 4

≡ 1.6 N kg^{-1} [to one significant figure] OR other justification [e.c.f] **(1)** 1

[7]

54. Experiment
2 light gates **(1)**
Gate gives time trolley takes to pass [not just 'the time'] **(1)**
Speed = length of 'interrupter'/time taken **(1)**

OR

2 ticker timers **(1)**
Dots at known time intervals **(1)**
Speed = length of tape section/time taken **(1)** 3
[ruler + clock could obtain third mark only, specifying a length/time]

Total momentum of trolleys
Zero **(1)**
It was zero initially **or** momentum is conserved [consequent] **(1)** 2

Speed *v* of A
Use of momentum = mass × velocity **(1)**
Use of mass × speed (A) = mass × speed (B) **(1)**
1.8 m s^{-1} [ignore -ve signs] **(1)** 3

[8]

55. Magnitude of charges

Value of v or ω (v = 1023 ms^{-1}, $\omega = 2.7 \times 10^{-6}\ s^{-1}$) **(1)**

Value of a ($a = 2.7 \times 10^{-3}\ ms^{-2}$) **(1)**

$F = \frac{m\upsilon^2}{r}$ **(1)**

Value of F (F = 2 × 10^{20} N) **(1)**

$F = \frac{kQ_1Q_2}{r^2}$ **(1)**

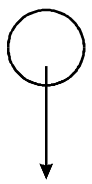
Charge = 5.7 × 10^{13} C **(1)** 6

[Use of $\frac{GMm}{r^2}$ to calculate F:

Allow M_e in range 10^{24} – 10^{25} kg without penalty, otherwise max 4 for question.]

56. Discussion:
No equilibrium or there is a resultant force **(1)**
Direction changing or otherwise would move in a straight line
(or off at an tangent) **(1)**
acceleration or velocity changing **(1)**
Force towards centre or centripetal **(1)**
The tension provides this force [consequent] **(1)**
[OR for last 2 marks: weight of ball acts downwards **(1)**
vertical component of tension balances it **(1)**] 5

Free-body diagram:



W/weight/mg/gravitational 'attraction' [not 'gravity'] **(1)** 1

[6]

57. Calculation of total momentum:

In 1 s, p = 1400 J /3 × 10^8 m s^{-1}

= 4.7 × 10^{-6} N s (kg m s^{-1})

[No u.e.] 2

Force exerted on whole sail:

Momentum change/time [OR symbols] **(1)**

= 4.7 × 10^{-6} × 1.5 × 10^6

= 7.0 (7.1) N **(1)** 2

Explanation of why force is doubled:

Photons bounce back **(1)**

So their change of momentum is doubled **(1)** 2

Calculation of maximum increase in speed:

$a = F/m$ = 7/1200 m s^{-2} [allow e.c.f.] **(1)**

(= 0.006 m s^{-2})

$\Delta \upsilon = a \Delta t$ = 0.006 m s^{-2} × 604 800 s **(1)**

= 3500 m s^{-1} **(1)** 3

[9]

58. Calculation of minimum height x:

$a = \frac{\upsilon^2}{r}$ **(1)**

$\Rightarrow \frac{\upsilon^2}{r} \geq g$ at top **(1)**

At top: ½ $m\upsilon^2 = mgx$ [OR mgh 1 mark] **(2)**

$\Rightarrow \upsilon^2 = 2gx$ (Note: derived from $\upsilon^2 = u^2 + 2as = 0$)

[For $\upsilon^2 = 2g(x + 1)$ **(1)**(speed at bottom)]

$\Rightarrow 2gx/r \geq g$ at top

$\Rightarrow x \geq r/2$

$\Rightarrow x \geq 0.25$ m

[≥ or =] **(1)**

[5]

59. Principle of conservation of linear momentum:

[Not just equation – symbols must be defined]

Sum of momenta/*total* momentum remains constant **(1)**

[Equation can indicate]

[Not "conserved"]

If no (resultant) external force acts **(1)**

[**Not** "closed/isolated system"]

2

Laws of Motion:

2^{nd} and 3^{rd} laws **(1)**

1

Description:

Measure velocities/speeds before and after collision **(1)**

Suitable technique for measuring velocity

e.g. ticker tape/ticker timer

light gate(s)

motion sensor **(1)**

[Not stop clock or just datalogger]

How velocity is found from **their** technique

[Need distance ÷ time + identify distance and time. Could get with stopclock method.] **(1)** **(1)**

$\upsilon_{after} = \frac{1}{2}\,\upsilon_{before}$/ calculate $m\upsilon$ before and after/check e.g. $m_1\upsilon_1 = (m_1 + m_2)\,\upsilon_2$

4

Reason for discrepancy:

Friction/air resistance **(1)**

[Ignore any reference to energy] **(1)**

Explanation:

The Earth (plus car) recoils **(1)**

With same momentum as the car had **(1)**

2

[10]

60. Momentum of driver:

Correct use of $p = mv$ [OR with numbers] **(1)**

= 1500 N s OR 1500 kg m s^{-1} **(1)** 2

Average resultant force:

Correct choice of $F \times t = \Delta p$	OR	$F = ma$ **(1)**
$F \times 0.07$ (s) = 1500 (N s)		$F = 50 \times 429/50 \times 30/0.07$ **(1)**
= 21 kN		= 21 kN **(1)** 3

[Ignore sign of answer]

Why resultant force is not the same as force exerted on driver by seatbelt:

Air bags /floor/friction/seat/steering wheel **(1)**
[Named force other than weight/reaction] 1

[6]

61. Momentum: mass × velocity [accept defined symbols] 1

Physical quantity:

(Net) force **(1)**

on lorry **(1)** 2

[“Rate of change of momentum” scores one only]

Magnitude:

$$\frac{61\text{Ns}}{40\,\text{s}} = 1.5\ (3) \times 10^4\ \text{N}$$

Gradient measurements **(1)**

Correct calculation **(1)** 2

[Accept 1.4 – 1.7 to 2 s.f.]

Explanation of shape:

Force decreases as speed increases **(1)**

[Allow “rate of change of momentum”]

Any one of:

- Air resistance increases
- Transmission friction increases
- Engine force reduces 2

[7]

62. Demonstration of how statement leads to equation:

Momentum	=	mass × velocity **(1)**
Therefore force	$\propto$	mass × rate of change of velocity **(1)**
Therefore force	$\propto$	mass × acceleration **(1)**

Definition of newton or choice of units makes the proportionality constant equal 1 **(1)** 4

[Standard symbols, undefined, OK; "=" throughout only loses mark 4. No marks for just manipulating units. If no $\Delta\ \upsilon$(e.g. $m\upsilon/t$),can only get marks 1 and 4]

Effect on time:

Time increases **(1)** 1

Explanation:

Acceleration smaller/momentum decreases more slowly/$F = \frac{\Delta p}{\Delta t}$ **(1)**

[Need not say Δp = constant]

So force is smaller **(1)** 2

[Independent mark, but must be consistent with previous argument]
[If *no* previous argument, this becomes fully independent mark] 7]

63. Explanation:

Changing direction/with no force goes straight on (along tangent) **(1)**

Acceleration/velocity change/momentum change **(1)** 2

Identification of bodies:

A: Earth [*Not* Earth's gravitational field] **(1)**

B: scales [*Not* Earth/ground] **(1)** 2

Calculation of angular speed:

Angular speed = correct angle ÷ correct time [any correct units] **(1)**

$= 4.4 \times 10^{-3}$rad min^{-1} / 0.26 rad h^{-1}/ 2πrad day^{-1} etc **(1)** 2

Calculation of resultant force:

Force $= mr\omega^2$ **(1)**

$= 55\text{ kg} \times 6400 \times 10^3\text{ m} \times (7.3 \times 10^{-5}\text{ rad s}^{-1})^2$ **(1)**

$= 1.9$ N **(1)** 3

[No e.c.f here unless ω in rad s^{-1}]

Calculation of value of force B:

Force B = 539N – 1.9N **(1)**

= 537 N **(1)** 2

[e.c.f. except where R.F = 0]

Force:

Scales read 537 N (same as B) [allow e.c.f.]

Newton's 3rd law/force student exerts on scales **(1)** 1

[12]

64. Calculation of how long wheel takes to complete one revolution:

Time = $2\pi \times 60$ m/0.20 m s^{-1} **(1)**

= 1900 s/1884 s/31.4 min **(1)** 2

Change in passenger's velocity:

Direction changes OR up (N) → down (S) OR + → – **(1)**

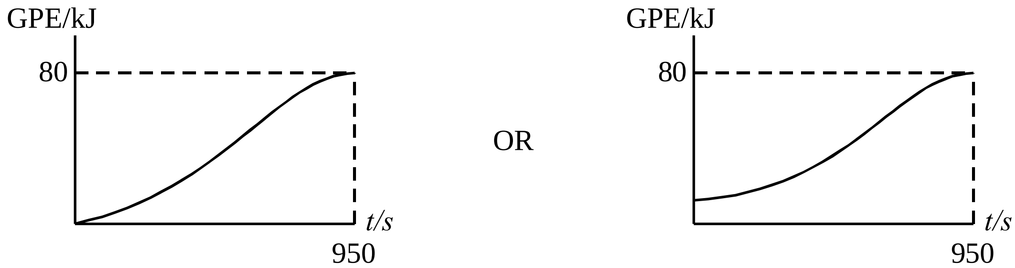
OR 180° **(1)** 2

0.40 m s^{-1}
[0.40 m s^{-1} without direction = 2/2]

Calculation of mass:

(G)pe = mgh
$m = 80 \times 10^3$ J/9.81 m $s^{-2} \times 120$ m) **(1)**
[This mark is for rearranging the formula; accept 10 instead **(1)**
of 9.81 and 60 instead of 120 but do not e.c.f. to next mark]
m = 68 kg **(1)** 3

Sketch graph:



Labelled axes and line showing PE increasing with time
Sinusoidal shape **(1)**
(950 s, 80 kJ) **(1)**
[Accept half the time they calculated at start of question **(1)**
instead of 950 s as e.c.f.]
[PE v h 0/3] 3

Whether it is necessary for motor to supply the gpe:

No, because passenger on other side is losing gpe **(1)**
If wheel equally loaded OR balanced with people **(1)**

OR
Yes, because no other passengers **(1)**
so unequally loaded **(1)** 2

[12]

65. Definition of linear momentum:

Mass × velocity [Words or defined symbols; NOT *ft*] **(1)** 1

Newton's second law:

Line 3 only **(1)** 1

Newton's third law:

Line 2 OR 1& 2 **(1)** 1

Assumption:

No (net) external forces/no friction/drag **(1)**

In line 3 (he assumes the force exerted by the other trolley is
the resultant force) [Only if 1st mark earned] **(1)** 2

Description of how it could be checked experimentally that momentum is conserved in a collision between two vehicles:

Suitable collision described and specific equipment to
measure velocities [e.g. light gates] **(1)**

Measure velocities before and after collision **(1)**

How velocities calculated [e.g. how light gates used] **(1)**

Measure masses / use known masses/equal masses **(1)**

Calculate initial and final moment a and compare OR
for equal trolleys in inelastic collision, then $v_1 = ½ v_2$ **(1)** Max 4

[9]

66. Demonstration that water must be thrown backwards at about 13 m s^{-1}:

$$\text{Force} = \frac{\Delta(\textit{momentum of water})}{\Delta t}$$ **(1)**

8×10^5 N = $6 \times 10^4 \times \Delta V$ **(1)**

$$\Delta V = \frac{8 \times 10^5}{6 \times 10^4} = 13 \text{ m s}^{-1}$$ **(1)** 3

Calculation of power expended:

$P = F \times \upsilon = 8.0 \times 10^5$ N × 20 m s^{-1} **(1)**

1.6×10^7 W OR 15 MW **(1)** 2

Calculation of rate at which water gains kinetic energy:

$\frac{1}{2} \times m/t \times \upsilon^2 = \frac{1}{2}\ 6 \times 10^4$ kg/s × (13 M $s^{-1})^2$ **(1)**

= 5.07×10^6 W OR 5.1 MW **(1)**

[Allow 5.3 MW if 13.33 m s^{-1} used] 2

Overall efficiency:

$$\text{Power in} = 1.6\ \frac{l}{s} \times 3.4 \times 10^7\ \frac{J}{l} = 5.44 \times 10^7 \text{ W}$$ **(1)**

[Intermediate value not explicitly needed]

Power out = $16.0 \times 10^6 + 5.4 \times 10^6 = 21.4 \times 10^6$ **(1)**

$$\text{Efficiency} = \frac{21.4}{54.5} = 0.39\ (39\%)$$ **(1)** 3

[10]

67. A satellite orbits the Earth once every 120 minutes. Calculate the satellite's angular speed.

Correct substitution into angle/time (1)

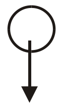
Answer with correct unit (1)

r.p.m. etc. not allowed

Angular speed = **e.g. 0.052 rad min^{-1} 180°h^{-1}**

(2 marks)

Draw a free-body force diagram for the satellite.



(1 mark)

(If the Earth is shown, then the direction must be correct)

The satellite is in a state of free fall. What is meant by the term *free fall?* How can the height of the satellite stay constant if the satellite is in free fall?

Free fall – when gravitational force is the <u>only</u> force acting on an object (1)

Height – (1) for each clear and relevant physics statement (1) + (1)

(3 marks)
[Total 6 marks]