Further Mechanics MS

1. C

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

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 / \( \Delta mv/t \) /ma to bacteria (1)
(Bacteria) moves in opposite direction [backwards or forwards OK] (1) Max 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:

\[ T = \frac{25 \times 60 \times 60s}{15} = 5760s \]

\[ v = \frac{2\pi r}{T} = \frac{2\pi \times 6.94 \times 10^6 m}{5760s} = 7.57 \times 10^3 \text{ ms}^{-1} \]

\[ a = \frac{v^2}{r} = \frac{(7.6 \times 10^4 \text{ ms}^{-1})^2}{6.94 \times 10^6 m} = 8.26 \text{ms}^{-2} \]

OR

\[ \omega = \frac{2\pi}{T} = \frac{2\pi}{5760s} = 1.09 \times 10^{-3} \text{ ms}^{-1} \]

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

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

\[ g (= a) = 8.3 \text{ ms}^{-2} \] substituted (1)

Correct answer (1)

Example of calculation:

\[ mg = \frac{GMm}{r^2} \]

\[ \therefore 8.3 \text{ms}^{-2} = \frac{6.67 \times 10^{-11} \text{Nm}^2 \text{kg}^{-2} M}{(6.94 \times 10^6 m)^2} \]

\[ \therefore M = \frac{8.3 \text{ms}^{-1} \times (6.94 \times 10^6 m)^2}{6.67 \times 10^{-11} \text{Nm}^{-2} \text{kg}^{-2}} = 6.0 \times 10^{24} \text{kg} \]

(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 \( v = H_0 \) to show) \( H_0 = \frac{1}{t} \) \( \text{(1)} \)  

Correct answer \( \text{(1)} \)  

Example of calculation:

\[
H_0 = \frac{1}{t} = \frac{1}{12 \times 3.15 \times 10^{10} \text{s}} = 2.65 \times 10^{-18} \text{s}^{-1}
\]

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

There is considerable uncertainty in the value of the Hubble constant \( \text{(1)} \)

QWC

Any sensible reason for uncertainty \( \text{(1)} \)

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 \( \text{(1)} \)  

5. B  

6. A  

7. D  

8. A  

9. (a) Use of \( F = mv/t \) or \( F = ma \) \( \text{(1)} \)

Answer = \( 2.0 \times 10^5 \text{ N} \) \( \text{(1)} \)

\( E_G F = 12000 \times 57 / 3.5 \) \( \text{2} \)
(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)

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

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

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

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

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

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

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

(b) Conversion of G (1)
Conversion of either eV or divided by c$^2$ (1)
$2.5 \times 10^{-28}$ (kg) (1)

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

Electric field gives energy to / work done / \[ E = qV \] accelerate protons (1)

**Magnetic fields:**

Force on moving charge/proton (1)

Produces circular path/centripetal force (1)

 labelled diagram showing Dees with E field indicated across gap OR B field through Dees (1)

E field is reversed/alternates (1) Max 1

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(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

---

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 \( 9.1 \times 10^{-21} - 1.4 \times 10^{-20} \text{ N s or kg m s}^{-1} \)

[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 \(9.11 \times 10^{-31}\) 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

12. B

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

14. (a) Total (linear) momentum of a system is constant, (1)
provided no (resultant) external 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 and after (1) 2
15. (a) (i) Use of $A = \pi r^2$ leading to 0.87 (m) (1)

(ii) Correct use of $\omega = \frac{2\pi}{t}$ leading to 62.8 (rad s$^{-1}$) (1)

(iii) Correct use of $v = r\omega = 55$ m s$^{-1}$ [allow use of show that value] (1)

(b) (i) Substitution into $p = \frac{1}{2} \rho Av^3$ (1)

3047 (W) (1)

(ii) Air is hitting at an angle/all air not stopped by blades (1)
Energy changes to heat and sound (1)

(c) (i) Attempts to find volume per second ($A \times v$) (1)

44 kg s$^{-1}$ (1)

(ii) Use of $F = \Delta mv/\Delta t$ (1)

$F = 610$ N (1)

(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

Example:
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]
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)

(ii) Why it accelerates
   Direction (of motion) is changing (1)
   Acceleration linked to a change in velocity (1)

(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:
   $v = \sqrt{(2.7 \times 10^7 \text{ m} \times 0.56 \text{ m s}^{-2})}$
   [Allow 1 mark for $\omega = 1.4 \times 10^{-4} \text{ rad s}^{-1}$] (2)

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:
   $1250 \times 28.0 + 3500 \times 25.5 = (1250 + 3500) v$
   $v = 26.16 \text{ m s}^{-1}$
   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
18. (a) **Identify particle**

Alpha (particle) / Helium nucleus \( ^4_2 \text{He} \) / 2He / \( \alpha \) / 2He / \( ^4_2 \alpha \) / 2He

(b) **Momentum of particle**

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

**Either**

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

Use the relationship to determine the mass [6.6 \times 10^{-27} \text{ kg}] (1)

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

\[
\begin{align*}
\text{Eg} & \quad \frac{1}{2} m(1.41 \times 10^7 \text{ m s}^{-1})^2 = 6.58 \times 10^{-13} \text{ J} \\
m & = \frac{2 \times 6.58 \times 10^{-13} \text{ J}}{(1.41 \times 10^7 \text{ m s}^{-1})^2} = 6.6 \times 10^{-27} \text{ kg} \\
\text{momentum} & = 6.6 \times 10^{-27} \text{ kg} \times 1.41 \times 10^7 \text{ m s}^{-1} \\
& = 9.3 \times 10^{-20} \text{ (kg m s}^{-1})
\end{align*}
\]

**Or**

\[
\begin{align*}
\text{Momentum} & = \frac{2 \times 6.58 \times 10^{-13} \text{ J}}{1.41 \times 10^7 \text{ m s}^{-1}} = 9.3 \times 10 \text{ (kg m s}^{-1})
\end{align*}
\]

(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} \text{ (kg m s}^{-1}) \] (1)

\[
\begin{align*}
\text{Eg} & \quad 3.89 \times 10^{-25} \text{ kg} \times 2.4 \times 10^5 \text{ m s}^{-1} = 9.3 \times 10^{-20} \text{ kg m s}^{-1}
\end{align*}
\]

9
19. (a) **Calculation of angular speed**

Use of \( \omega = \frac{2\pi}{T} \) (1)

\[ 7.27 \times 10^{-5} \text{ [2 sig fig minimum]} \text{ (1)} \]

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

(b) (i) **Calculation of acceleration**

Use of \( a = r\omega^2 \) OR \( v = r\omega \) and \( a = \frac{v^2}{r} \) (1)

\[ 0.034/031 \text{ m s}^{-2} \text{ (1)} \]

\[ (6400 \times 10^4 \text{ m})(7.27 \times 10^{-5} \text{ rad s}^{-1})^2 \]

= 0.034 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/\( W \)/pull of Earth/gravitational force (1)

Arrow to right labelled Normal reaction/\( N \)/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

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

answer (1)

\[ p = mv \]

\[ = 2 \times 0.024 \times 0.88 \text{ (N s)} = 0.042(24) \text{ N s OR kg m s}^{-1} \]

(b) **recall of KE = \frac{1}{2}mv^2 \text{ OR } p^2/2m [eqn or sub] (1)**

answer (1)

\[ KE = \frac{1}{2}mv^2 \]

\[ = 0.5 \times 2 \times 0.024 \times 0.88 \times 0.88 \text{ (J)} = 0.0185(856) \text{ (J)} \]
(c) (i) provided no external force acts (1)
    OR balls do not interact with/transfer momentum to anything else 1

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

    (iii) \( 0.5 \times 0.096 \times 0.442 \text{ OR } 0.5 \times B9 \times C9 \times C9 \) (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

21.  (a) 1 equating PE and KE (1)
    2 recall of \( mv^2/r \) (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

22.  (a) Table
    [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 \( T = \frac{2\pi r}{v} \) or \( T = \frac{2\pi}{\omega} \) and \( \omega = \frac{v}{r} \) \( (1) \)

Correct answer [0.084 s] \( (1) \)

e.g.

\[
2\pi \left( \frac{0.28 \text{ m}}{21 \text{ m s}^{-1}} \right) = 0.084 \text{ s}
\]

(c)  

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

\( \omega \) 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 \( \omega \) OR revs per second OR rate of rotation of wheel)

is increased

[Allow ecf from “\( \omega \) decreased” in c (i)] \( 1 \)  

[6]

23. **(a) Show that**

See ‘\( v = \frac{2\pi r}{T} \)’ OR ‘\( \omega = \frac{2\pi}{T} \)’ \( (1) \)

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

Unit of \( \omega \)

\( \text{s}^{-1} \)/rad \( \text{s}^{-1} \) \( (1) \)  

3
(b) Height above Earth’s surface

Statement / use of \( \frac{GM_E m}{r^2} = \frac{mv^2}{r} \) OR \( \frac{GM_E m}{r^2} = mro^2 \) (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. \(4.2(3) \times 10^7 \text{ m}\) (1)
Use of \(h = r - R_E\) (1)
Correct answer = \((3.58 - 3.60) \times 10^7 \text{ m} \) [no ecf] (1)

Example of answer:
\[
\frac{GM_E m}{r^2} = \frac{mv^2}{r} \\
\rightarrow \frac{GM_E}{r^2} = \frac{v^2}{r} = \frac{(\omega r)^2}{r} = \omega^2 r \\
\therefore GM_E = \omega^2 r^3 \\
\therefore r = \sqrt[3]{\frac{GM_E}{\omega^2}} = \sqrt[3]{\frac{6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 5.98 \times 10^{24} \text{ kg}}{(7.27 \times 10^{-5} \text{ s}^{-1})^2}} \\
= 4.23 \times 10^7 \text{ m} \\
\therefore h = 4.23 \times 10^7 \text{ m} - 6.38 \times 10^6 \text{ m} \\
= 3.59 \times 10^7 \text{ m} \\
\]

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

(ii) Some use of \(mv^2/r\) with \(v\) correctly subbed OR \(mro^2\) with \(v\) correctly used (1)
[subbing may happen later in answer]
\[T \cos \theta = mg \]
OR \(T \sin \theta = \frac{mv^2}{r}\) [either gains] (1)
\[\Rightarrow \tan \theta = \frac{v^2}{rg} \] (1)
\[\Rightarrow r = \frac{v^2}{g} \tan \theta \]
\[= 30 \times 30/9.81 \times \tan 20 \text{ m} \]
\[= 252 \text{ m} \] (1)

25. (a) Expression for gravitational force:
\[F = GMm/r^2 \] (1)

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(b) Expression for gravitational field strength:
\[ g = \text{force on 1 kg, so } g = \frac{GM}{r^2}, \text{ or } g = \frac{F}{m} \text{ so } g = \frac{GM}{r^2} \]

(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)
Example of derivation:
\[ g = \frac{v^2}{r} \text{ or } g = \omega^2r \]
and \( v = \frac{2\pi r}{T} \text{ or } \omega = \frac{2\pi}{T} \)
so \( \frac{(2\pi r/T)^2}{r} = \frac{GM}{r^2}, \text{ leading to expression given } \]

(d) Calculation of radius:
Substitution into expression given (1)
Correct answer \([4.2 \times 10^7 \text{ m}] \) (1)
Example of calculation:
\[ r^3 = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times \frac{6.0 \times 10^{24} \text{ kg}}{(24 \times 60 \times 60 \text{ s})^2} / 4\pi^2 \]
\[ = 7.6 \times 10^{22} \text{ m}^3 \]
So \( r = 4.2 \times 10^7 \text{ m} \)

(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)
[e.g. for geostationary orbit, \( T \) and \( r \) are fixed, so \( v \) cannot increase (\( v = \frac{2\pi r}{T} \))]

(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)
26. (a) **Momentum at impact**

\[ p = mv \]

Answer \([11 \text{ kg m s}^{-1}]\) \(\text{(1)}\)

eg momentum = \(0.42 \text{ kg} \times 27 \text{ m s}^{-1}\)

\[ = 11.34 \text{ kg m s}^{-1} \]

(b) **Momentum at release**

Minus \(\text{(1)}\)

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

(c) (i) **Average force** (ecf momenta values)

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

0.22

Adding momentum values \(\text{(1)}\)

Answer \([88.0 \text{ N} – 89.8 \text{ N}] \text{(1)}\)

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

\[ F = (-) 89.5 \text{ N} \]

**Or**

Use of \(F = ma\) \(\text{(1)}\)

Adding velocities to calculate acceleration \(\text{(1)}\)

Answer \([88.0 \text{ N} – 89.8 \text{ N}] \text{(1)}\)

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

Force = \(0.42 \text{ kg} \times -213.6 \text{ m s}^{-2} = (-) 89.7\) \(\text{(2)} \text{N}\)

(ii) **Direction of force on diagram**

Right to left \(\text{(1)}\)

[Accept arrow drawn anywhere on the diagram. Label not required] \(\text{1}\)

(d) **Difference and similarity**

Difference: opposite direction / acts on different object \(\text{(1)}\)

Similarity: same type of force / same size / acts along same line / \(\text{(1)}\)

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] \(\text{2}\)

\[\text{[10]}\]
27. (a) **E\text{K} of helium nucleus**

Use of \(E\text{K} = \frac{1}{2} mv^2\) (1)

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

\[E\text{K} = \frac{1}{2} \times 6.65 \times 10^{-27} \text{ kg} \times (9.65 \times 10^5 \text{ m s}^{-1})^2\]
\[= 3.096 \times 10^{-15} \text{ J}\]

(b) (i) **Loss of E\text{K} of proton** [ecf their value for E\text{K} of helium nucleus]

\[3 \times 10^{-15} \text{ J or } 3.1 \times 10^{-15} \text{ J} \text{ (1)}\]

(ii) **Speed of proton after collision**
[ecf their value for loss of E\text{K} of proton, but not if they have given it as zero]

Calculation of initial \(E\text{K}\) of proton (1)

Subtraction of \(3.1 \times 10^{-15} \text{ J} = 1.7 \times 10^{-15} \text{ J}\) (1)

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

\[E\text{K} = \frac{1}{2} \times 1.67 \times 10^{-27} \text{ kg} \times (2.4 \times 10^6 \text{ m s}^{-1})^2 = 4.8 \times 10^{-15} \text{ J}\]

\[E\text{K after collision} = 4.8 \times 10^{-15} \text{ J} – 3.1 \times 10^{-15} \text{ J} = 1.7 \times 10^{-15} \text{ J}\]

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

Or

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

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

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

\[V = -1.44 \times 10^6 \text{ m s}^{-1}\]

[For both these solutions allow the second marking point to candidates who incorrectly write: the mass of the proton as \(1.6 \times 10^{-27} \text{ kg}\) or \(1.7 \times 10^{-27} \text{ kg}\), or the mass of the helium as \(6.6 \times 10^{-27} \text{ kg}\) or \(6.7 \times 10^{-27} \text{ kg}\) or the velocity as \(9.6 \times 10^5 \text{ m s}^{-1}\) or \(9.7 \times 10^5 \text{ m s}^{-1}\)]

(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 \([147.6 \text{ N by calc is OK}]\) (1)

(b) Resolve vertically (1)
correct value (1)
\[ \text{eg } P \cos 40° = 850 \text{ N} \]
\[ \Rightarrow P = 1100 \text{ N} \]

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

(ii) \( P \)/push of ice (on sled) (1)
horizontal component (1)
[“additional centripetal force” = 0]

(d) Recall circular motion formula (1)
resolve horizontally (1)
correct value (1)
[incorrect force is eop]
[also possible: \( W \tan 40 = \frac{mv^2}{r} \) (1)]
\[ \text{eg } F = P \sin 40 = 713 (643) \text{ (N)} \] [formula or value]
\[ R = \frac{mv^2}{F} \]
\[ = 87 \times 35^2 / 713 (643) \text{ (m)} \]
radius = 149 (166) m

29. (a) Newton’s Second Law of Motion
(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]
(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 ms\(^{-1}\) \times 10\(\text{m}^2\) = 200 \(\text{m}^3\)  
1.23 kg \(\text{m}^{-3}\) \times 200 \(\text{m}^3\) = 246 kg

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

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

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

[6]
31. **Speed of sphere**

Momentum conserved [stated or implied] \(\square (1)\)

Correct subs L.H.S or R.H.S of conservation of momentum equation \(\text{(1)}\) \(\square 3\)

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

Example of calculation:

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

\[\Rightarrow 138.78 = 54 \times v + 61.48\]

\[\Rightarrow v = 1.43 \text{ m s}^{-1}\]

**Elastic or inelastic collision**

Recall K.E: \(\frac{1}{2}mv^2\) \(\text{(1)}\)

Correct values for both KEs \([178 \text{ (mJ)}, 120 \text{ (mJ)}, \text{ no } \text{ue}](\text{1})\)

Conclusion consistent with their results for KE \(\text{(1)}\) \(\square 3\)

[max 1 if only words used and inelastic \(\equiv\) energy lost implied]

Example of calculation:

\[= \frac{1}{2} \times 54 \times 2.57^2 = 178 \text{ mJ}\]

Final total K.E: \(\frac{1}{2} \times 29 \times 2.12^2 + \frac{1}{2} \times 54 \times 1.43^2 \text{ mJ}\)

\[= 65 \text{ mJ} + 55 \text{ mJ}\]

\[= 120 \text{ mJ}\]

\[\Rightarrow \text{Inelastic}\]

**Average speed of the spheres**

Recall \(v = \frac{2\pi r}{t}\) \(\text{(1)}\)

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

Example of calculation:

\[v = \frac{2\pi r}{t} = \pi \times 0.17 \times 2 \text{ m} / 0.37 \text{ s}\]

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

**Calculation of centripetal force**

Recall \(F = \frac{mv^2}{r}\) OR \(mro^2\) OR \(m \nu \omega\) \(\text{(1)}\)

Correct answer \([1.43 \text{ N, ecf for their } v]\) \(\text{(1)}\) \(\square 2\)

Example of calculation:

\[F = \frac{mv^2}{r}\]

\[= 0.029 \times 2.9^2 / 0.17 \text{ N [watch out for 29 twice]}\]

\[= 1.43 \text{ N [ecf]}\]
Tension
Weight of sphere \( (= mg = 0.029 \times 9.81 \text{ N} = )0.28 \text{ N} \) (1)

\[ T = F - W \text{ OR } F = T + W \left[ \text{using their values for } F \text{ and } T \right] \) (1)

Example of calculation:
\[ = 1.43 - 0.28 \text{ (N)} \]
\[ \Rightarrow T = 1.15 \text{ N} \]

\[ \square 32. \quad \text{Smoke detectors} \]
Recognition that mass alpha = 4 (1)
Idea of - 4 to find resulting nucleus mass [237] (1)

\[ M_{\text{daughter product}} = m_{\text{alpha}} \text{ or momentum equations in context (1)} \]

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

Use of \( \frac{1}{2} mv^2 \) 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

\[ \square 33. \quad \text{(a)} \quad \text{From what height?} \]

Use of \( mg \Delta h \text{ and } \frac{1}{2} mv^2 \) (1)
[ignore power of 10 errors]

\[ mg \Delta h = \frac{1}{2} 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]

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

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

\[= 0.8(2) \text{ m} \]

(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)

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

(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 \( f \times V \) 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 = \frac{1}{2} \times (3) \times 80 \times (10^{-3}) \text{ kg} \times (1.33 \text{ m s}^{-1})^2 = 0.21 \text{ J}

\text{Energy} = \frac{0.21 \text{ J}}{0.08 \text{ W}}

t = 2.6(5) \text{ s}

[accept 2.6 or 2.7 as rounding]

\text{OR}

Use of } F = ma \ (I)

Use of \text{either } v = u + at \text{ i.e } a = \frac{\Delta v}{t} \ (I)

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

\begin{align*}
(-)0.12 \text{ N} &= (3) \times 80 \times (10^{-3}) \text{ kg} \times a \ (a = (-)0.5 \text{ m s}^{-2}) \\
0 &= 1.33 \text{ m s}^{-1} - 0.5 \text{ m s}^{-2} \times t \text{ or } (-)0.5 \text{ m s}^{-2} = \frac{(-)1.33 \text{ m s}^{-1}}{t} \\
t &= 2.6(6) \text{ s}
\end{align*}

\text{OR}

Select } Ft = \Delta p \ (I)

\text{Substitution } (-)0.12t = (-3) \times 80 \times (10^{-3}) \text{ kg} \times 1.33 \text{ m s}^{-1} \ (1)

\text{Allow omission of any bracketed value]}

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

34. (a) \text{Radius of circular path}

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

Radius = 70 – 80 m (74.48 m) \ (1)

(b) \text{Resultant force}

\begin{align*}
F &= \frac{mv^2}{r} \ [\text{seen or used}] \ (1) \\
\text{Force} &= 0.08 \text{ N (0.077 N)} \ [\text{Allow ecf of their radius.}] \ (1) \\
\text{Towards the centre of the circular path / towards hub.} \ (1)
\end{align*}
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)

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

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

35. Direction

Force → centre/perpendicular to velocity/motion (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)

Maximum speed

\[ F = \frac{mv^2}{r} \] [Accept \( F = m\omega^2 \)] (1)

\[ \Rightarrow v = \sqrt{\frac{Fr}{m}} \quad \text{OR} \quad \sqrt{\frac{470 \times 14}{160}} \] (1)

\[ = 6.4 \, \text{m} \, \text{s}^{-1} \] (1)

Why skid occurs

Smaller \( r \) (1)

\[ \Rightarrow F(\frac{mv^2}{r}) \] (required) increases / use of \( F = \frac{mv^2}{r} \) to deduce \( v \) decreases (1)

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

$(m \text{ increased} \Rightarrow F \text{ (needed)} \text{ increases}) (1)$

EITHER only 470 N available or the force is the same $\Rightarrow$ NO
OR friction increases as mass increases($\Rightarrow$ YES) (1)

36. (a) Resultant force required

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

(b) (i) Angular speed
Use of an angle divided by a time (1)
$7.3 \times 10^{-5} \text{ rad s}^{-1}$ OR $0.26 \text{ rad h}^{-1}$ OR $4.2 \times 10^{-3} \text{ o s}^{-1}$ OR $15 \text{ o h}^{-1}$ (1)

(ii) Resultant force on student
Use of $F = mr^2$ OR $v = r\omega$ with $F = \frac{mv^2}{r}$ (1)
$2.0 \text{ N}$ (1)

(iii) Scale reading
Evidence of contact force = $mg - \text{resultant force}$ (1)
Weight of girl = 588 (N) OR 589 (N) OR 60 $\times$ 9.81 (N) (1)
Scale reading = 586 N OR 587 N [efc their $mg - \text{their } F$] (1)

37. Speed of car 2

$v^2 - u^2 = 2as$

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

$\Rightarrow u = 12.8 \text{ (m s}^{-1}) \text{ [value] (1)}$

Magnitude of the momentum of car 2

$p = mv \text{ (1)}$

$= 1430 \times 12.8 \text{ (13) (kg m s}^{-1})$

$= 18\,300 \text{ (18 600) N s or kg m s}^{-1} \text{ (1)}$
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)

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)

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)

38. Momentum of neutron

Use of $p = mv$ (1)

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

Speed of nucleus

Total mass attempted to be found (1)
Conservation of momentum used (1)
$v = 2.01 \times 10^6$ m s⁻¹ [ecf from $p$ above only] (1)

Whether collision was elastic

Use of $k.e. = \frac{1}{2} mv^2$ (1)

$ke = 7.45 \times 10^{-13}$ (J) / $5.06 \times 10^{-14}$ (J) (ecf) (1)

A correct comment based on their two values of $ke$. (1) 3
39. Resultant force
   Direction of travel changing (1)
   Velocity changing/accelerating (1)
   Force is towards centre of circle (1)
   Why no sharp bends
   Relate sharpness of bend to $r$ (1)
   Relate values of $\nu$, $r$ and $F$ (1)
   \[ \text{[e.g. if } r \text{ large, } \nu \text{ can be large without force being too large/if } r \text{ small,}
   \nu \text{ must be small to prevent force being too large]} \]
   Bobsleigh
   \[ N \cos \theta = mg \] (1)
   \[ N \sin \theta = \frac{mv^2}{r} \text{ or } ma \] (1)
   Proof successfully completed [consequent on using correct formula] (1)
   Calculation of angle
   $77 - 78^\circ$ (1)

40. Discussion of type of collision
   Inelastic (1)
   Energy $\rightarrow$ heat at impact/plastic deformation (1)
   Momentum vector diagram
   Diagram [right–angle triangle with arrows on two perpendicular sides] (1)
   Labelling (1)
   \[ \text{Castalia} \]
   \[ 1.2 \times 10^{12} \text{ kg } \times 25 \text{ 000 m s}^{-1} \]
   \[ (= 3 \times 10^{16} \text{ N s}) \]
   \[ \text{Mass: } 5.8 \times 10^6 \text{ kg } \times 35 \text{ 000 m s}^{-1} \]
   \[ (= 2.0 \times 10^{18} \text{ N s}) \]
Calculation of change in direction

\[
\theta / \sin \theta / \tan \theta = \frac{5.8 \times 10^6 \times 35000}{1.2 \times 10^{12} \times 25000}
\]

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

\theta = 6.8 \times 10^{-6} \text{ rad OR } 3.9 \times 10^{-4} \text{ degrees OR } 1.4 \text{ seconds} \quad (1)

Formula for net force in terms of momentum

\[ F = \frac{\text{d}p}{\text{d}t} \text{ OR words} \quad (1) \]

Calculation of number of rockets required

\[ N \times F \times t = 2 \times 10^{11} \text{ OR } N = \frac{2 \times 10^{11}}{7 \times 10^6 \times 130} \quad (1) \]

\[ N = 220 \text{ [must be a whole number]} \quad (1) \]

41. Speed of rim of drum

\[ v = r \omega \text{ or } v = \frac{2\pi r}{T} \text{ [either used]} \quad (1) \]

\[ \omega = \frac{2\pi \times 800 \text{ rev min}^{-1}}{60s} \quad \text{OR} \quad T = \frac{60s}{800 \text{ rev min}^{-1}} \quad (1) \]

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

Acceleration

Use of \( a = r \omega^2 \) \text{ OR } \[ a = \frac{v^2}{r} \quad (1) \]

\[ 1.5 \times 10^3 \text{ m s}^{-2} \quad (1) \]

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 \( (1) \)

[Normal reaction accepted]

Arrow of path

Arrow labelled B tangential to drum, from P, in anticlockwise direction \( (1) \)
42. **Mass of head of mallet**
   Selecting density x volume (1)
   Correct substitutions (1)
   Mass = 1.15 (kg) [3 significant figures, minimum] (1)  
   
   **Momentum change**
   
   \[ p = m \nu \text{ used (1)} \]
   \[ \Delta p = 1.15 \text{ or } 1.2 \text{ kg } (4.20 + 0.58) \text{ m s}^{-1} \text{ (1)} \]
   \[ = 5.50 \text{ or } 5.74 \text{ kg m s}^{-1} / \text{N s (1)} \]
   
   **Average force**
   
   Their above / 0.012 s (1)
   \[ F = 458/478 \text{ N [e.c.f. } \Delta p \text{ above] (1)} \]
   
   **Value for force**
   
   Handle mass/weight/ head weight/force exerted by user (handle) neglected (1)  
   
   **Effectiveness of mallet with rubber head**
   
   \[ \Delta t \text{ goes up/} \Delta p \text{ goes up (1)} \]
   
   \[ \Rightarrow \text{ less force, less effective/more force, more effective [consequent] (1)} \]

43. **Homogeneity**
   
   \[ p = \text{ mass } \times \text{ velocity (1)} \]
   
   \[ p \text{ units N s or kg m s}^{-1} [\text{This alone implies above mark} \text{ (1)}] \]
   
   \[ E \text{ unit (J) N m or kg m}^{2} \text{ s}^{-2} \text{ (1)} \]
   
   \[ c \text{ unit m s}^{-1} \text{ (1)} \]
44. **Magnitude of \( F \)**

\[
F = \frac{mv^2}{r} \quad (1)
\]

Towards the centre \( (1) \)

Calculation

(i) \( 9.07 \times 10^3 \) N \( (1) \)

(ii) \( R = mg - \frac{mv^2}{r} \quad (1) \)

Substitutions \( (1) \)

\[ 5.37 \times 10^3 \text{ N} \]

[Calculation of \( \frac{mv^2}{r} \text{ max 1} \) \( (1) \) \]

Explanation

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

Critical speed

Use of \( (m)g = \frac{(m)v^2}{r} \quad (1) \)

\[ 15.7 \text{ m s}^{-1} \quad (1) \]

**Apparent weightless**

This means no force exerted on/by surroundings \( \text{OR} \ R = 0 \ \text{OR only} \)

force acting is weight \( (1) \)

When car takes off it is in free fall [consequent] \( (1) \)

\[ [11] \]

45. **Direction of centripetal acceleration**

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

Explanation

\[
F=ma
\]

\( a \) and \( F \) in same direction \( (1) \)

\[ 1 \]
Resultant force

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

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

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

= 936 N (1)

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

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

\[ F = mrw^2 \quad (*) \]

= 60 \times 8 \times 1.4^2 \quad (*) \quad [(*) \text{ Equation OR substitution] (1)} \]

= 936 N (1)

Calculation of weight

\[ W = mg = 60 \times 9.81 \]

= 589 N (1)

Calculation of magnitude of push

\[ F_{\text{net}} = W + P \]

\[ P = F - W = 936 - 589 \]

= 347 N (1)

Diagram

\[ W \downarrow \text{ (1)} \]

\[ P \uparrow \text{ (1)} \]

[10]
46. **Deceleration of Earth**

\[ F = \frac{m \Delta \upsilon}{\Delta t} = 7 \times 3 \times 10^4 \text{ N} \]  
\[ = 2.1 \times 10^5 \text{ N} \quad (1) \]

\[ a = \frac{F}{m} = 2.1 \times 10^5 / 6.0 \times 10^{24} \]  
\[ = 3.5 \times 10^{-20} \text{ m s}^{-2} \quad (1) \]

OR

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

\[ \Rightarrow a = 3 \times 10^4 \text{ m s}^{-2} \]

\[ F = ma = 7 \text{ kg} \times 3 \times 10^4 \text{ m s}^{-2} \]

\[ = 2.1 \times 10^5 \text{ N} \quad (1) \quad (1) \]

\[ F \text{ on Earth} = F \text{ on debris} \]

\[ \Rightarrow a_{\text{earth}} = \frac{F}{m} = \frac{2.1 \times 10^5 \text{ N}}{6 \times 10^{24} \text{ kg}} \]

\[ = 3.5 \times 10^{-20} \text{ m s}^{-2} \quad (1) \quad (1) \]

OR Conservation of momentum

\[ m_1 \upsilon_1 + m_2 \upsilon_2 = m_3 \upsilon_3 \text{ etc} \quad (1) \]

\[ 6 \times 10^{24} \times 3 \times 10^4 (+ 7 \times 0) = (6 \times 10^{24} + 7) \times \upsilon_3 \quad (1) \]

OR An answer (3.5 \times 10^{-20} \text{ m s}^{-2}) calculated from any specific \( \text{arbitrary time} \) \( (1) \)

Comment: negligible \( (1) \)

[OR energy loss negligible]

47. **Momentum and its unit**

Momentum = mass \times velocity

kg m s\(^{-1}\) or N s

Momentum of thorium nucleus before the decay

Zero

Speed of alpha particle/radium nucleus and directions of travel

Alpha particle because its mass is smaller/lighter

So higher speed for the same (magnitude of) momentum

OR N3 argument

Opposite directions/along a line

48. **Angular speed**

Use of \( \omega = 2\pi / T \)

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

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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 $\frac{v^2}{r}$ 1

$\begin{align*}
a & = 9.36 - 9.42 \text{ OR } 6.5 \text{ m s}^{-2} \\
\text{[Depends on which } \omega \text{ value used]} &
\end{align*}$ 1

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

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

$$\begin{align*}
v &= \frac{2\pi r}{T} = \frac{2\pi \times 6.4 \times 10^6}{24 \times 60 \times 60} = 465(\text{ms}^{-1}) \\
\text{OR} \\
w &= 7.3 \times 10^{-5} \text{ (rad s}^{-1})
\end{align*}$$

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

Differing apparent field strength

\((0.034 \div 9.81) \times 100\%\)

= 0.35\%

OR \((0.03 \div 9.81) \times 100\% = 0.31\% \) [NOT 0.3\%] \( (1) \)

50. **Explanation of Pelton wheel**

Quote of \( F = \Delta mv/t \) [or in words] \( (1) \)

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

Increased (twice) momentum / velocity change/\( mv - mu \) compared with falling off plane paddle \( (1) \)

Idea of doubled \( (1) \)

Max 3

Percentage efficiency of station

Energy available = \( mgh \) \( (1) \)

Power input = \( 270 \times 9.8 \times 250 \) \( (1) \)

Efficiency = \( 500000 \times 100 \div 661500 = 76\% \) \( (1) \)

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 $500 \times 0.0474 = £23.70$ OR total no of kW h required $1.000000/0.0474 = 2.1 \times 10^7$

No. of hours to repay $= 1\,000\,000/23.70$ OR $2.1 \times 10^7/500$

$24 \times 365 = 4.8$ years to repay debt (1)

**Assumption**

Constant power production / no interest charges / no repair costs

no wages for employees (1)

---

**Angular speed**

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

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

$\omega = 1.15 - 1.20 \times 10^{-3} \text{ rad s}^{-1}$ / $6.9 \times 10^{-2} \text{ rad min}^{-1}$ / $0.066 \text{ deg s}^{-1}$ (1)

**Acceleration**

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

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

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

**Resultant force**

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

$F = 35 - 39 \text{ N}$ [Allow e.c.f their $a$ above only] (1)

Towards (centre of the) Earth (1)

---

**How ions are accelerated**

Electric field exists between $+,-$ electrodes (1)

$\Rightarrow$ force on ions / force $\rightarrow$ acceleration (1)
Speed of xenon atom
\[ eV = \frac{1}{2} m v^2/eV = E_k \] (1)
\[ \Rightarrow v = \sqrt{2eV/m} \] (1)
\[ = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times (1060 + 225)}{2.2 \times 10^{-25}}} \text{ ms}^{-1} \] (1)
\[ = 4.3 \times 10^4 \text{ m s}^{-1} \] [No u.e.] (1)

Thrust on space probe
Force = rate of change of momentum (1)
\[ = 2.1 \times 10^{-6} \times 43000 \text{ N} \] (1)
\[ = 0.090 \text{ N} \] (1)
[Using \( 4 \times 10^4 \text{ m s}^{-1} \) gives \( F = 0.084 \text{ N} \)]

Reason for reduced thrust
Xenon ions attracted back OR similar (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

53. Diagrams showing forces:

Diagram 1  Diagram 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/weight
- \[ a \frac{\upsilon^2}{r} / F = m \frac{\upsilon^2}{r} / a = \omega^2 r / F = m \omega^2 r \]
- \[ a \frac{\upsilon^2}{r} / F = \frac{2\pi r}{t} \]
- \[ \frac{4\pi^2 r}{t^2} = \frac{4\pi^2 \times (10/2)}{10^2} \]
- \[ a = 2.0 \text{ m s}^{-2} \] [No u.e.]
- artificial field varies with / \( \alpha \) radius

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

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)
[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 \( \upsilon \) of A
Use of momentum = mass \( \times \) velocity (1)
Use of mass \( \times \) speed (A) = mass \( \times \) speed (B) (1)
1.8 m s\(^{-1} \) [ignore -ve signs] (1) 3

55. Magnitude of charges

Value of \( \upsilon \) or \( \omega \) (\( \upsilon = 1023 \text{ ms}^{-1}, \omega = 2.7 \times 10^{-6} \text{ s}^{-1} \)) (1)

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

\[ F = \frac{mv^2}{r} \] (1)
Value of $F$ ($F = 2 \times 10^{20}$ N) (1)

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

Charge = $5.7 \times 10^{13}$ C (1)

[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)]

Free-body diagram:

[Diagram of a ball with an arrow pointing downwards labeled W/weight/mg/gravitational ‘attraction’ [not ‘gravity’] (1)]

57. Calculation of total momentum:
In 1 s, $p = 1400$ J / $3 \times 10^8$ m s$^{-1}$
$= 4.7 \times 10^{-6}$ N s (kg m s$^{-1}$)
[No u.e.] 2

Force exerted on whole sail:
Momentum change/time [OR symbols] (1)
$= 4.7 \times 10^{-6} \times 1.5 \times 10^6$
$= 7.0$ (7.1) N (1) 2
Explanation of why force is doubled:
Photons bounce back (1)
So their change of momentum is doubled (1)  

Calculation of maximum increase in speed:
\[ a = \frac{F}{m} = \frac{7}{1200} \text{ m s}^{-2} \] [allow e.c.f.] (1)
\[ (= 0.006 \text{ m s}^{-2} ) \]
\[ \Delta v = a \Delta t = 0.006 \text{ m s}^{-2} \times 604800 \text{ s} \]
\[ = 3500 \text{ m s}^{-1} \] (1)  

58. Calculation of minimum height \( x \):
\[ a = \frac{v^2}{r} \] (1)
\[ \Rightarrow \frac{v^2}{r} \geq g \text{ at top} \] (1)
At top: \( \frac{1}{2} m v^2 = mgx \) [OR \( mgh \) 1 mark] (2)
\[ \Rightarrow v^2 = 2gx \] (Note: derived from \( v^2 = u^2 + 2as = 0 \))
[For \( v^2 = 2g(x + 1) \) (1)(speed at bottom)]
\[ \Rightarrow 2gx/r \geq g \text{ at top} \]
\[ \Rightarrow x \geq r/2 \]
\[ \Rightarrow x \geq 0.25 \text{ m} \]
\[ \geq \text{ or } = \] (1)  

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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”]

Laws of Motion:
2\(^{nd}\) and 3\(^{rd}\) laws (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.]
\(v_{after} = \frac{1}{2} v_{before}\) calculate \(mv\) before and after/check e.g. \(m_1v_1 = (m_1 + m_2) v_2\)

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)
60. Momentum of driver:

Correct use of \( p = m \nu \) [OR with numbers] (1)

\[ p = 1500 \text{ N s OR } 1500 \text{ kg m s}^{-1} \] (1)

Average resultant force:

Correct choice of \( F \times t = \Delta p \) OR \( F = ma \) (1)

\[ F \times 0.07 \text{ (s)} = 1500 \text{ (N s)} \quad F = 50 \times 429/50 \times 30/0.07 \] (1)

\[ = 21 \text{ kN} \] (1)

[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

61. Momentum: mass \times velocity [accept defined symbols]

Physical quantity:

(Net) force (1)

on lorry (1)

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

Magnitude:

\[ \frac{61 \text{ Ns}}{40 \text{ s}} = 1.5 \times 10^4 \text{ N} \]

Gradient measurements (1)

Correct calculation (1)

[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
62. Demonstration of how statement leads to equation:

Momentum = mass × velocity (1)

Therefore force ∝ mass × rate of change of velocity (1)

Therefore force ∝ mass × acceleration (1)

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

[Standard symbols, undefined, OK; “=” throughout only loses mark 4. No marks for just manipulating units. If no ∆υ (e.g. \( m \frac{\Delta v}{t} \)), can only get marks 1 and 4]

Effect on time:

Time increases (1)

Explanation:

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

[Need not say \( \Delta p = \text{constant} \)]

So force is smaller (1)

[Independent mark, but must be consistent with previous argument]

[If no previous argument, this becomes fully independent mark]

63. Explanation:

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

Acceleration/velocity change/momentum change (1)

Identification of bodies:

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

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

Calculation of angular speed:

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

\[ \text{Angular speed} = \frac{4.4 \times 10^{-3} \text{rad min}^{-1}}{0.26 \text{ rad h}^{-1}/2\pi \text{ rad day}^{-1} \text{ etc}} \] (1)

Calculation of resultant force:

\[ \text{Force} = mro^2 \] (1)

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

\[ = 1.9 \text{ N} \] (1)

[No e.c.f here unless \( \omega \) in rad s\(^{-1} \)]
Calculation of value of force B:

\[
\text{Force B} = 539\text{N} - 1.9\text{N} \quad (1)
\]
\[
= 537\text{ N} \quad (1)
\]

[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:

\[
\text{Time} = 2\pi \times 60\text{ m}/0.20\text{ m s}^{-1} \quad (1)
\]
\[
= 1900\text{ s}/1884\text{ s}/31.4\text{ min} \quad (1)
\]

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:

\[(G)pe = mgh\]

\[m = 80 \times 10^3 \text{ J}/9.81 \text{ m s}^{-2} \times 120 \text{ m} \quad (1)\]

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

\[m = 68 \text{ kg} \quad (1)\]

Sketch graph:

\[
\begin{array}{c}
\text{GPE/kJ} \\
\hline
\text{GPE/kJ} \\
\hline
80 \\
950 \\
\hline
\end{array}
\]

OR

\[
\begin{array}{c}
\text{GPE/kJ} \\
\hline
\text{GPE/kJ} \\
\hline
80 \\
950 \\
\hline
\end{array}
\]
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]  

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)  

65. Definition of linear momentum:  

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

Newton’s second law:  

Line 3 only (1)  

Newton’s third law:  

Line 2 OR 1 & 2 (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)  

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 \( v_1 = \frac{1}{2} v_2 \) (1)  

Max 4
66. Demonstration that water must be thrown backwards at about 13 m s\(^{-1}\):

\[
\text{Force} = \frac{\Delta (\text{momentum of water})}{\Delta t} \quad (1)
\]

\[
8 \times 10^5 \text{ N} = 6 \times 10^4 \times \Delta V \quad (1)
\]

\[
\frac{8 \times 10^5}{6 \times 10^4} = 13 \text{ m s}^{-1} \quad (1)
\]

Calculation of power expended:

\[
P = F \times \nu = 8.0 \times 10^5 \text{ N} \times 20 \text{ m s}^{-1} \quad (1)
\]

\[
1.6 \times 10^7 \text{ W OR } 15 \text{ MW} \quad (1)
\]

Calculation of rate at which water gains kinetic energy:

\[
\frac{1}{2} \times \frac{m}{t} \times \nu^2 = \frac{1}{2} \times 6 \times 10^4 \text{ kg/s} \times (13 \text{ M s}^{-1})^2 \quad (1)
\]

\[
= 5.07 \times 10^6 \text{ W OR } 5.1 \text{ MW} \quad (1)
\]

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

Overall efficiency:

\[
\text{Power in} = 1.6 \times 3.4 \times 10^7 = 5.44 \times 10^7 \text{ W} \quad (1)
\]

[Intermediate value not explicitly needed]

\[
\text{Power out} = 16.0 \times 10^6 + 5.4 \times 10^6 = 21.4 \times 10^6 \quad (1)
\]

\[
\text{Efficiency} = \frac{21.4}{54.5} = 0.39 \text{ (39\%)} \quad (1)
\]

[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)

\text{r.p.m. etc. not allowed}

Angular speed \(= \text{e.g. } 0.052 \text{ rad min}^{-1} \text{ 180}^\circ \text{h}^{-1} \quad (2 \text{ marks})
Draw a free-body force diagram for the satellite.

(If the Earth is shown, then the direction must be correct) (1 mark)

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 *only* force acting on an object (1)
- **Height** – (1) for each clear and relevant physics statement (1) + (1)

(3 marks)

[Total 6 marks]