

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

$$20 \text{ revolutions} = 20 \times 2\pi / 60 (= 2.1 \text{ rads s}^{-1})$$

- (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 / $\Delta mv/t$ / 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)

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

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

Correct answer (1)

4

Example of calculation:

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

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

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

OR

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

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

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

g (= a) = 8.3 ms⁻² substituted (1)

Correct answer (1)

3

Example of calculation:

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

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

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

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

Correct answer (1)

2

Example of calculation:

$$H_0 = \frac{1}{t} = \frac{1}{12 \times 3.15 \times 10^{16} s} = 2.65 \times 10^{-18} s^{-1}$$

(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 c^2 (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 = $35 \text{ mm} \times 6 \text{ mm} / 4.5 \text{ mm}$ 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 9.11×10^{-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) 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} ($0.0156 \text{ kg m s}^{-1}$) before and 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 $v = r\omega = 55 \text{ m s}^{-1}$ [allow use of show that value] (1) 1
- (b) (i) Substitution into $p = \frac{1}{2} \rho A v^3$ (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)
 $F = 610 \text{ N}$ (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
- 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] 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 $4.0 \times 10^3 \text{ m s}^{-1}$] (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

[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:
 $1250 \times 28.0 + 3500 \times 25.5 = (1250 + 3500) v$
 $v = 26.16 \text{ m s}^{-1}$
 Recall of $ke = \frac{1}{2} mv^2$ or $ke = \frac{p^2}{2m}$ (1)
 Total ke before (1)
 Total ke after (1)
 Loss in ke (1)
 Recall of work = force \times distance (1)
 Correct answer for force to 2 SF (1)
 Example:
 Total ke before = $1\,138\,000 \text{ J} + 490\,000 \text{ J} = 1\,627\,938 \text{ J}$
 Total ke after = $1\,625\,059 \text{ J}$
 Loss of KE = 2879 J
 Braking force = $2879/5 = 576 \text{ N}$ Max 8

[8]

18. (a) Identify particle

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

$\alpha_2^4 / {}^4_2\text{alpha}$ / α_2^4 / α

1

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

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

momentum = $6.6 \times 10^{-27} \text{ kg} \times 1.41 \times 10^7 \text{ m s}^{-1}$
= $9.3 \times 10^{-20} \text{ (kg m s}^{-1}\text{)}$

Or

Momentum = $\frac{2 \times 6.58 \times 10^{-13} \text{ J}}{1.41 \times 10^7 \text{ m s}^{-1}} = 9.3 \times 10^{-20} \text{ (kg m s}^{-1}\text{)}$

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 $3.89 \times 10^{-25} \text{ kg} \times 2.4 \times 10^5 \text{ m s}^{-1} = 9.3 \times 10^{-20} \text{ (kg m s}^{-1}\text{)}$ (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)
 $0.034/031 \text{ m s}^{-2}$ (1) 2
 $(6400 \times 10^3 \text{ m})(7.27 \times 10^{-5} \text{ rad s}^{-1})^2$
 $= 0.034 \text{ m s}^{-2}$
- (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)
 $p = mv$
 $= 2 \times 0.024 \times 0.88 \text{ (N s)} = 0.042(24) \text{ N s OR kg m s}^{-1}$ 2
- (b) recall of $\text{KE} = 1/2mv^2$ OR $p^2/2m$ [eqn or sub] (1)
 answer (1)
 $\text{KE} = 1/2mv^2$
 $= 0.5 \times 2 \times 0.024 \times 0.88 \times 0.88 \text{ (J)} = 0.0185(856) \text{ (J)}$ 2

- (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) $0.5 \times 0.096 \times 0.442$ 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 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

[6]

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 $T = 2\pi r/v$ or $T = 2\pi/\omega$ and $\omega = v/r$ (1)

Correct answer [0.084 s] (1)

e.g.

$$2\pi (0.28 \text{ m}) / (21 \text{ m s}^{-1}) \\ = 0.084 \text{ s}$$

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

Unit of ω

$\text{s}^{-1}/\text{rad s}^{-1}$ (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 $h = \text{their } r - R_E$ (1)

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

Example of answer:

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

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

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

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

$$= 4.23 \times 10^7 \text{ m}$$

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

$$= 3.59 \times 10^7 \text{ m}$$

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]

$$T \cos \theta = mg$$

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

$$\Rightarrow \tan \theta = v^2/rg \text{ (1)}$$

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

$$= 30 \times 30/9.81 \times \tan 20 \text{ m}$$

$$= 252 \text{ m (1)}$$

4

[5]

25. (a) Expression for gravitational force:

$$F = GMm/r^2 \text{ (1)}$$

1

- (b) Expression for gravitational field strength:
 $g = \text{force on 1 kg, so } g = GM/r^2$, 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:
 $r^3 = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 6.0 \times 10^{24} \text{ kg} \times (24 \times 60 \times 60 \text{ s})^2 / 4\pi^2$
 $= 7.6 \times 10^{22} \text{ m}^3$
 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) 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) Momentum at impact
 $p = mv$ 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) Momentum at release
 Minus (1)
 8.4 kg m s⁻¹ (1) 2
- (c) (i) Average force(ecf momenta values)
 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)

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

$$F = (-) 89.5 \text{ N}$$
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) Direction of force on diagram
 Right to left (1)
 [Accept arrow drawn anywhere on the diagram. Label not required] 1
- (d) Difference and similarity
 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 $E_K = \frac{1}{2} \times 6.65 \times 10^{-27} \text{ kg} \times (9.65 \times 10^5 \text{ m s}^{-1})^2$
 $= 3.096 \times 10^{-15} \text{ J}$
- (b) (i) Loss of E_K of proton [ecf their value for EK of helium nucleus]
 $3 \times 10^{-15} \text{ J}$ or $3.1 \times 10^{-15} \text{ J}$ (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 $3.1 \times 10^{-15} \text{ J}$ [= $1.7 \times 10^{-15} \text{ J}$] (1)
 Answer [(1.40 – 1.50) $\times 10^6 \text{ m s}^{-1}$] (1)
 eg $E_K = \frac{1}{2} 1.67 \times 10^{-27} \text{ kg} \times (2.4 \times 10^6 \text{ m s}^{-1})^2 (= 4.8 \times 10^{-15} \text{ J})$
 E_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)
 Eg $1.67 \times 10^{-27} \text{ kg} \times 2.4 \times 10^6 \text{ m s}^{-1}$
 $= 6.65 \times 10^{-27} \text{ kg} \times (9.65 \times 10^5 \text{ m s}^{-1}) + 1.67 \times 10^{-27} \text{ kg} \times V$
 $V = -1.44 \times 10^6 \text{ m s}^{-1}$
- [For both these solutions allow the second marking point to candidates who incorrectly write: 3
 the mass of the proton as $1.6 \times 10^{-27} \text{ kg}$ 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 $D = 140 - 155 \text{ N}$ [147.6 N by calc is OK] (1) 3
- (b) Resolve vertically (1)
correct value (1)
eg $P \cos 40^\circ = 850 \text{ N}$
 $\Rightarrow P = 1100 \text{ N}$ 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 ice (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: $W \cdot \tan 40 = mv^2/r$ (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) 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] 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 $1.23 \times 10 \times 20 = 246$ 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 kg m s^{-1} . (1) 2

Ecf value for mass. Ignore signs in front of values.]

(iii) Magnitude of the force

Answer: [$F = 4920 \text{ N}$ 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 $\text{N}2$) (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. Speed of sphere

Momentum conserved [stated or implied] (1)

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

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

Example of calculation:

$$\begin{aligned}54 \times 2.57 (+ 0) &= 54 \times v + 29 \times 2.12 \text{ (g m s}^{-1}\text{)} \\ \Rightarrow 138.78 &= 54 \times v + 61.48 \\ \Rightarrow v &= 1.43(\text{m s}^{-1})\end{aligned}$$

Elastic or inelastic collision

Recall K.E: $\frac{1}{2}mv^2$ (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 \equiv energy lost implied]

Example of calculation:

$$\begin{aligned}&= \frac{1}{2} \times 54 \times 2.57^2 = 178 \text{ mJ} \\ \text{Final total K.E: } &\frac{1}{2} \times 29 \times 2.12^2 + \frac{1}{2} \times 54 \times 1.43^2 \text{ mJ} \\ &= 65 \text{ mJ} + 55 \text{ mJ} \\ &= 120 \text{ mJ} \\ &\Rightarrow \text{Inelastic}\end{aligned}$$

Average speed of the spheres

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

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

Example of calculation:

$$\begin{aligned}v &= 2\pi r / t = \pi \times 0.17 \times 2 \text{ m} / 0.37 \text{ s} \\ &= 2.9 \text{ m s}^{-1} \text{ or } 290 \text{ cm/s}\end{aligned}$$

Calculation of centripetal force

Recall $F = mv^2 / r$ OR $mr\omega^2$ OR $m v \omega$ (1)

Correct answer [1.43 N, ecf for their v] (1) 2

Example of calculation:

$$\begin{aligned}F &= mv^2 / r \\ &= 0.029 \times 2.9^2 / 0.17 \text{ N [watch out for 29 twice]} \\ &= 1.43 \text{ N [ecf]}\end{aligned}$$

Tension

Weight of sphere ($= mg = 0.029 \times 9.81 \text{ N} = 0.28 \text{ N}$) (1)

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

2

Example of calculation:

$$= 1.43 - 0.28 \text{ (N)}$$
$$\Rightarrow T = 1.15 \text{ N}$$

[12]

□ È32.

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 $\frac{1}{2} mv^2$ 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

[6]

33. (a) From what height?

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

$$mg \Delta h = \frac{1}{2} mv^2 \text{ (1)}$$

[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

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

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

$$= 0.8(2) \text{ m}$$

(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)

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

(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 $f \times V$ equation]

Use of energy divided by power (1)

Answer in range 2.6 s to 2.7 s (1)

[ecf their value for u]

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

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

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

$$t = 2.6(5) \text{ s}$$

[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)

$$(-)0.12 \text{ N} = (3) \times 80 \times (10^{-3}) \text{ kg} \times a \quad (a = (-)0.5 \text{ m s}^{-2})$$

$$0 = 1.33 \text{ m s}^{-1} - 0.5 \text{ m s}^{-2} \times t \quad \text{or} \quad (-)0.5 \text{ m s}^{-2} = \frac{(-)1.33 \text{ m s}^{-1}}{t}$$

$$t = 2.6(6) \text{ s}$$

OR

Select $Ft = \Delta p$ (1)

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

$$\text{Radius} = 70 - 80 \text{ m} \quad (74.48 \text{ m}) \quad (1)$$

2

(b) Resultant force

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

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 /changing 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

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

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

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

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 \Rightarrow) F (needed) increases (1)

EITHER only 470 N available or the force is the same \Rightarrow NO

OR friction increases as mass increases (\Rightarrow 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)

$7.3 \times 10^{-5} \text{ rad s}^{-1}$ OR 0.26 rad h^{-1} OR $4.2 \times 10^{-3} \text{ s}^{-1}$ OR 15° h^{-1} (1) 2

(ii) Resultant force on student

Use of $F = m\omega^2$ 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

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

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

$$\Rightarrow u = 12.8 \text{ (m s}^{-1}\text{) [value] (1) 2}$$

Magnitude of the momentum of car 2

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

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

$$= 18\,300 \text{ (18\,600) N s or kg m s}^{-1} \text{ (1) 2}$$

Calculation of easterly component of momentum

Component = momentum $\times \cos \theta$ (1)

Car 1: $23\,800 \text{ N s} \times \cos 45$

= $16\,800 \text{ N s}$ (1)

Car 2: $18\,300 (18\,600) \text{ N s} \times \cos 30 = 15\,800 (16\,100) \text{ N s}$ (1) 3

Whether car 1 was speeding before accident

(Sum of two easterly components) $\sim 33\,000 \text{ N s}$ [ecf] (1)

(\div mass of car 1) $\Rightarrow \sim 16.8 \text{ m s}^{-1}$ [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 $p = mv$ (1)

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

Speed of nucleus

Total mass attempted to be found (1)

Conservation of momentum used (1)

$v = 2.01 \times 10^6 \text{ m s}^{-1}$ [ecf from p above only] (1) 3

Whether collision was elastic

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

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

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

[8]

39. Resultant force

Direction of travel changing (1)

Velocity changing/accelerating (1)

Force is towards centre of circle (1) 3

Why no sharp bends

Relate sharpness of bend to r (1)

Relate values of v , r and F (1) 2

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

Bobsleigh

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

$N \sin \theta$ (1)

$= m v^2 / r$ or ma (1)

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

Calculation of angle

$77 - 78^\circ$ (1) 1

[10]

40. Discussion of type of collision

Inelastic (1)

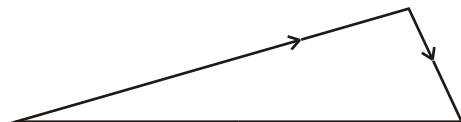
Energy \rightarrow heat at impact/plastic deformation (1) 2

Momentum vector diagram

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

Labelling (1) 2

Castalia
 $1.2 \times 10^{-12} \text{ kg} \times 25\,000 \text{ m s}^{-1}$
($= 3 \times 10^{16} \text{ N s}$)



Mass: $5.8 \times 10^6 \text{ kg} \times 35\,000 \text{ m s}^{-1}$
($= 2.0 \times 10^{11} \text{ N s}$)

Calculation of change in direction

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

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

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

Formula for net force in terms of momentum

$$F = \frac{d}{dt}(mv) \text{ OR words (1)} \quad 1$$

Calculation of number of rockets required

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

$$N = 220 \text{ [must be a whole number] (1)} \quad 2$$

[9]

41. Speed of rim of drum

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

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

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

Acceleration

$$\text{Use of } a = r\omega^2 \text{ OR } a = v^2/r \text{ (1)}$$

$$1.5 \times 10^3 \text{ ms}^{-2} \text{ (1)} \quad 2$$

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. Mass of head of mallet
 Selecting density x volume (1)
 Correct substitutions (1)
 Mass = 1.15 (kg) [3 significant figures, minimum] (1) 3
- Momentum change
 $p = mv$ used (1)
 $\Delta p = 1.15$ or 1.2 kg $(4.20 + 0.58)$ m s⁻¹ (1)
 $= 5.50 / 5.74$ kg m s⁻¹/N s (1) 3
- Average force
 Their above / 0.012 s (1)
 $F = 458/478$ N [e.c.f. Δp above] (1) 2
- Value for force
 Handle mass/weight/ head weight/force exerted by user (handle) neglected (1) 1
- Effectiveness of mallet with rubber head
 Δt goes up/ Δp goes up (1)
 \Rightarrow *less force, less effective/more force, more effective* [consequent] (1) 2
- [11]**
43. Homogeneity
 $p = \text{mass} \times \text{velocity}$ (1)
 p units N s or kg m s⁻¹ [This alone implies above mark] (1)
 E unit (J) N m or kg m² s⁻² (1)
 c unit m s⁻¹ (1) 4
- [4]**

44. Magnitude of F
 $F = mv^2 / r$ (1)
 Towards the centre (1) 2

Calculation

(i) 9.07×10^3 N (1)

(ii) $R = mg - mv^2 / r$ (1)

Substitutions (1)

5.37×10^3 N

[Calculation of mv^2 / r max 1] (1) 4

Explanation

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

Critical speed

Use of $(m)g = (m)v^2 / r$ (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

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

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

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

$$= 936 \text{ N (1)}$$

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

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

$$F = mrw^2 \quad (*)$$

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

$$= 936 \text{ N (1)}$$

4

Calculation of weight

$$W = mg = 60 \times 9.81$$

$$= 589 \text{ N (1)}$$

1

Calculation of magnitude of push

$$F_{\text{net}} = W + P$$

$$P = F - W = 936 - 589$$

$$= 347 \text{ N (1)}$$

1

Diagram

$$W \downarrow \text{ (1)}$$

$$P \uparrow \text{ (1)}$$

2

[10]

46. Deceleration of Earth

$F = m\Delta v / \Delta t = 7 \times 3 \times 10^4 \text{ N}$ [Equation or substitution] (1)
 $= 2.1 \times 10^5 \text{ N}$ (1)

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

4

OR

in 1 second: Δv for debris $= 3 \times 10^4 \text{ m s}^{-1}$

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

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

F on Earth $= F$ on debris

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

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

OR Conservation of momentum } (1)

or $m_1u_1 + m_2v_2 = m_3v_3$ etc }

$6 \times 10^{24} \times 3 \times 10^4 (+ 7 \times 0) = (6 \times 10^{24} + 7) \times v_3$ (1)

OR An answer ($3.5 \times 10^{-20} \text{ m s}^{-2}$) 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 \times 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 $v^2 \div r$ 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

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

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

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

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

= 0.35%

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

1

[6]

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 = $500\,000 \times 100 / 661\,500 = 76\%$ (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 $500 \times 0.0474 = \text{£}23.70$ 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)

4

[14]

51. Angular speed

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

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

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

3

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 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)

$F = 35 - 39 \text{ N}$ [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)

\Rightarrow force on ions / force \rightarrow acceleration (1)

2

Speed of xenon atom

$$eV = \frac{1}{2} mv^2/eV = E_k \text{ (1)}$$

$$\Rightarrow v = \sqrt{2eV/m} \text{ (1)}$$

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

$$= 4.3 \times 10^4 \text{ m s}^{-1} \text{ [No u.e.] (1)}$$

4

Thrust on space probe

$$\text{Force} = \text{rate of change of momentum (1)}$$

$$= 2.1 \times 10^{-6} \times 43\,000 \text{ N (1)}$$

$$= 0.090 \text{ N (1)}$$

3

[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)

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

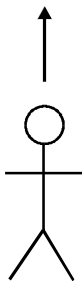
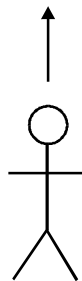


Diagram 2



(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
- $a = v^2/r / F = mv^2 / r / a = \omega^2 r / F = m\omega^2 r / F = m v \omega$
- $= \left(\frac{2\pi r}{t} \right)^2 / r = \frac{4\pi^2 r}{t^2} = \frac{4\pi^2 \times (10/2)}{10^2}$ [Any one] or calculate v or ω
- $= 2.0 \text{ m s}^{-2}$ [No u.e.]
- artificial field varies with $1/r$ radius (1) (1) (1) (1)

4

$\approx 1.6 \text{ N kg}^{-1}$ [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 \times velocity (1)

Use of mass \times speed (A) = mass \times speed (B) (1)

1.8 m s^{-1} [ignore -ve signs] (1)

3

[8]

55. Magnitude of charges

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

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

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

Value of F ($F = 2 \times 10^{20}$ N) (1)

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

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)

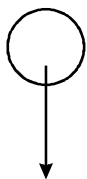
The tension provides this force [consequent] (1)

[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, $p = 1400 \text{ J} / 3 \times 10^8 \text{ m s}^{-1}$

$= 4.7 \times 10^{-6} \text{ N s (kg m s}^{-1}\text{)}$

[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)

2

Calculation of maximum increase in speed:

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

$$(= 0.006 \text{ m s}^{-2})$$

$$\Delta v = a \Delta t = 0.006 \text{ m s}^{-2} \times 604\,800 \text{ s (1)}$$

$$= 3500 \text{ m s}^{-1} \text{ (1)}$$

3

[9]

58. Calculation of minimum height x:

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

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

$$\text{At top: } \frac{1}{2} m v^2 = mgx \text{ [OR } mgh \text{ 1 mark] (2)}$$

$$\Rightarrow v^2 = 2gx \text{ (Note: derived from } v^2 = u^2 + 2as = 0)$$

$$\text{[For } v^2 = 2g(x + 1) \text{ (1)(speed at bottom)]}$$

$$\Rightarrow 2gx/r \geq g \text{ at top}$$

$$\Rightarrow x \geq r/2$$

$$\Rightarrow x \geq 0.25 \text{ m}$$

$$\text{[} \geq \text{ or } = \text{] (1)}$$

[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:
- 2nd and 3rd 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)
- $v_{\text{after}} = \frac{1}{2} v_{\text{before}}$ / calculate mv before and after/check e.g. $m_1 v_1 = (m_1 + m_2) v_2$ 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)
 $= 1500 \text{ N s}$ OR 1500 kg m s^{-1} (1) 2

Average resultant force:

Correct choice of $F \times t = \Delta p$ OR $F = ma$ (1)
 $F \times 0.07 \text{ (s)} = 1500 \text{ (N s)}$ $F = 50 \times 429/50 \times 30/0.07$ (1)
 $= 21 \text{ kN}$ $= 21 \text{ kN}$ (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 \times velocity [accept defined symbols] 1

Physical quantity:

(Net) force (1)

on lorry (1) 2

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

Magnitude:

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

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 ∝ 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) 4

[Standard symbols, undefined, OK; “=” throughout only loses mark 4. No marks for just manipulating units. If no Δv (e.g. mv/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 $\Delta p = \text{constant}$]

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)

= $4.4 \times 10^{-3} \text{ rad min}^{-1} / 0.26 \text{ rad h}^{-1} / 2\pi \text{ rad day}^{-1}$ 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:

$$\begin{aligned} \text{Force B} &= 539\text{N} - 1.9\text{N} \text{ (1)} \\ &= 537 \text{ N} \text{ (1)} \end{aligned} \quad 2$$

[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:

$$\begin{aligned} \text{Time} &= 2\pi \times 60 \text{ m} / 0.20 \text{ m s}^{-1} \text{ (1)} \\ &= 1900 \text{ s} / 1884 \text{ s} / 31.4 \text{ min} \text{ (1)} \end{aligned} \quad 2$$

Change in passenger's velocity:

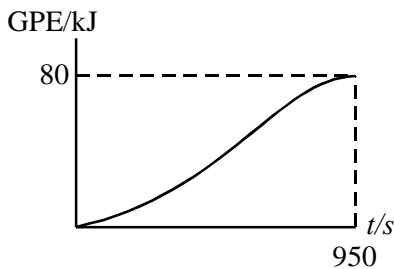
Direction changes OR up (N) → down (S) OR + → - (1)
OR 180° (1) 2

$$\begin{aligned} &0.40 \text{ m s}^{-1} \\ &[0.40 \text{ m s}^{-1} \text{ without direction} = 2/2] \end{aligned}$$

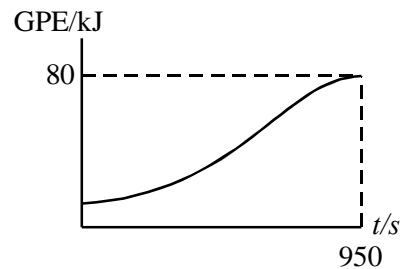
Calculation of mass:

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

Sketch graph:



OR



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 \times 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 $v_1 = \frac{1}{2} v_2$ (1) Max 4

[9]

66. Demonstration that water must be thrown backwards at about 13 m s⁻¹:

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

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

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

Calculation of power expended:

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

$$1.6 \times 10^7 \text{ W OR } 15 \text{ MW} \quad (1) \quad 2$$

Calculation of rate at which water gains kinetic energy:

$$\frac{1}{2} \times m/t \times v^2 = \frac{1}{2} \times 6 \times 10^4 \text{ kg/s} \times (13 \text{ m s}^{-1})^2 \quad (1)$$

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

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

Overall efficiency:

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

[Intermediate value not explicitly needed]

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

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

[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 only force acting on an object (1)

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

(3 marks)

[Total 6 marks]