# Fm1Ch2 XMQs and MS

(Total: 188 marks)

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 1. FM1_2019a    Q4 . 12 marks - FM1ch2 Work, energy and power
 2. FM1_2020     Q2 .  9 marks - FM1ch2 Work, energy and power
 3. FM1_2021     Q1 .  9 marks - FM1ch2 Work, energy and power
 4. FM1_2022     Q2 .  8 marks - FM1ch2 Work, energy and power
 5. FM1_2022     Q6 . 13 marks - FM1ch2 Work, energy and power
 6. FM1_2019b    Q4 . 12 marks - FM1ch2 Work, energy and power
 7. FM1_Sample   Q2 .  6 marks - FM1ch2 Work, energy and power
 8. FM1_Sample   Q5 .  9 marks - FM1ch2 Work, energy and power
 9. FM1_Specimen Q1 .  9 marks - FM1ch2 Work, energy and power
10. FM1(AS)_2018 Q1 .  8 marks - FM1ch2 Work, energy and power
11. FM1(AS)_2018 Q2 .  9 marks - FM1ch2 Work, energy and power
12. FM1(AS)_2018 Q3 .  9 marks - FM1ch2 Work, energy and power
13. FM1(AS)_2019 Q1 . 10 marks - FM1ch2 Work, energy and power
14. FM1(AS)_2019 Q3 .  7 marks - FM1ch2 Work, energy and power
15. FM1(AS)_2020 Q2 . 12 marks - FM1ch2 Work, energy and power
16. FM1(AS)_2020 Q4 . 11 marks - FM1ch2 Work, energy and power
17. FM1(AS)_2021 Q1 .  7 marks - FM1ch2 Work, energy and power
18. FM1(AS)_2021 Q3 . 11 marks - FM1ch2 Work, energy and power
19. FM1(AS)_2022 Q1 .  5 marks - FM1ch2 Work, energy and power
20. FM1(AS)_2022 Q3 . 12 marks - FM1ch2 Work, energy and power
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**4.** A car of mass 600 kg pulls a trailer of mass 150 kg along a straight horizontal road. The trailer is connected to the car by a light inextensible towbar, which is parallel to the direction of motion of the car. The resistance to the motion of the trailer is modelled as a constant force of magnitude 200 N. At the instant when the speed of the car is $v\,\mathrm{m\,s^{-1}}$, the resistance to the motion of the car is modelled as a force of magnitude $(200 + \lambda v)$ N, where $\lambda$ is a constant.

When the engine of the car is working at a constant rate of 15 kW, the car is moving at a constant speed of $25\,\mathrm{m\,s^{-1}}$

(a) Show that $\lambda = 8$

**(4)**

Later on, the car is pulling the trailer up a straight road inclined at an angle $\theta$ to the horizontal, where $\sin\theta = \dfrac{1}{15}$

The resistance to the motion of the trailer from non-gravitational forces is modelled as a constant force of magnitude 200 N at all times. At the instant when the speed of the car is $v\,\mathrm{m\,s^{-1}}$, the resistance to the motion of the car from non-gravitational forces is modelled as a force of magnitude $(200 + 8v)$ N.

The engine of the car is again working at a constant rate of 15 kW.

When $v = 10$, the towbar breaks. The trailer comes to instantaneous rest after moving a distance $d$ metres up the road from the point where the towbar broke.

(b) Find the acceleration of the car immediately after the towbar breaks.

**(4)**

(c) Use the work-energy principle to find the value of $d$.

**(4)**

| Question | Scheme | Marks | AOs | Notes |
|---|---|---|---|---|
| **4(a)** | Use of $P = Fv$ : $F = \frac{15000}{25} (= 600)$ | B1 | 3.3 | 600 or equivalent |
| | Equation of motion: | M1 | 3.4 | Use the model to form the equation of motion<br>If they start with two separate equations each one must be correct. |
| | $F - (200 + 200 + 25\lambda) = 0$ | A1 | 1.1b | Correct unsimplified equation |
| | $\lambda = 8$ * | A1* | 2.2a | Deduce **given answer** from correct working. |
| | | **(4)** | | |
| **4(b)** | Equation of motion: | M1 | 3.4 | Use the model to form the equation of motion for the car (with $v = 10$ used). All terms required. Dimensionally correct. Condone sign error and sin/cos confusion |
| | $\frac{15000}{10} - 280 - 600g\sin\theta = 600a$ | A1<br>A1 | 1.1b<br>1.1b | Unsimplified equation with at most one error.<br>Correct unsimplified equation |
| | $a = 1.38$ m s$^{-2}$ (1.4) | A1 | 1.1b | 2 or 3 sf only – follows use of 9.8 |
| | | **(4)** | | |
| **4(c)** | Work energy equation | M1 | 3.1b | Complete strategy to form the work-energy equation.<br>Condone sin/cos confusion and sign errors |
| | $\frac{1}{2} \times 150 \times 100 = 200d + 150gd\sin\theta$ | A1<br>A1 | 1.1b<br>1.1b | Unsimplified equation with at most one error<br>Correct unsimplified equation for d |
| | $d = 25.2$ (m) (25) | A1 | 1.1b | Max 3 sf – follows use of 9.8 |
| | | **(4)** | | |
| | | **(Total 12 marks)** | | |

**2.** A truck of mass 1200 kg is moving along a straight horizontal road.

At the instant when the speed of the truck is $v\,\text{m s}^{-1}$, the resistance to the motion of the truck is modelled as a force of magnitude $(900 + 9v)$ N.

The engine of the truck is working at a constant rate of 25 kW.

(a) Find the deceleration of the truck at the instant when $v = 25$

**(4)**

Later on, the truck is moving up a straight road that is inclined at an angle $\theta$ to the horizontal, where $\sin\theta = \dfrac{1}{20}$

At the instant when the speed of the truck is $v\,\text{m s}^{-1}$, the resistance to the motion of the truck from non-gravitational forces is modelled as a force of magnitude $(900 + 9v)$ N.

When the engine of the truck is working at a constant rate of 25 kW the truck is moving up the road at a constant speed of $V\,\text{m s}^{-1}$.

(b) Find the value of $V$.

**(5)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **2(a)** | Equation of motion: $F-(900+9\times 25)=1200a$ | M1 | 3.3 |
| | Use of $25000=F\times 25$ | M1 | 3.4 |
| | $\frac{25000}{25}-(900+225)=1200a$ | A1 | 1.1b |
| | $a=-\frac{5}{48}$ deceleration = $\frac{5}{48}$ $(=0.10416..)$ $(\text{m s}^{-2})$ | A1 | 1.1b |
| | | **(4)** | |
| **(b)** | Equation of motion: | M1 | 3.3 |
| | $\frac{25000}{V}-1200g\sin\theta-(900+9V)=0$ | A1<br>A1 | 1.1b<br>1.1b |
| | Form quadratic and solve for $V$: | M1 | 1.1b |
| | $(9V^2+1488V-25000=0)$ $V=15.4\,(15)$ | A1 | 1.1b |
| | | **(5)** | |
| | | | **(9 marks)** |

**Notes:**

| | |
|---|---|
| **(a)M1** | Dimensionally correct. Condone sign errors |
| **M1** | Correct use of $P=Fv$. Allow in (b) if not seen in (a). |
| **A1** | Correct unsimplified equation |
| **A1** | 0.10 or better. Final answer must be positive. |
| **(b)M1** | Need all terms. Dimensionally correct. Condone sign errors |
| **A1**<br>**A1** | Unsimplified equation with at most one error<br>Correct unsimplified equation |
| **M1** | Complete method to solve for $V$ |
| **A1** | Correct to 2 sf or 3 sf |
| | |
| | |

**1.** A van of mass 900 kg is moving along a straight horizontal road.

At the instant when the speed of the van is $v\,\text{m s}^{-1}$, the resistance to the motion of the van is modelled as a force of magnitude $(500 + 7v)$ N.

When the engine of the van is working at a constant rate of 18 kW, the van is moving along the road at a constant speed $V\,\text{m s}^{-1}$

(a) Find the value of $V$.

**(5)**

Later on, the van is moving up a straight road that is inclined to the horizontal at an angle $\theta$, where $\sin\theta = \frac{1}{21}$

At the instant when the speed of the van is $v\,\text{m s}^{-1}$, the resistance to the motion of the van from non-gravitational forces is modelled as a force of magnitude $(500 + 7v)$ N.

The engine of the van is again working at a constant rate of 18 kW.

(b) Find the acceleration of the van at the instant when $v = 15$

**(4)**

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| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **1(a)** | Equation of motion: $F = 500 + 7V$ | M1 | 3.3 |
| | Use of $18000 = F \times V$ | M1 | 3.4 |
| | $\Rightarrow \dfrac{18000}{V} = 500 + 7V$ | A1 | 1.1b |
| | $\Rightarrow 7V^2 + 500V - 18000 = 0$ | M1 | 1.1b |
| | $V = 26 \quad (26.309....)$ | A1 | 1.1b |
| | | **(5)** | |
| **(b)** | Equation of motion: | M1 | 3.3 |
| | $\dfrac{18000}{15} - (500 + 7 \times 15) - 900g \times \dfrac{1}{21} = 900a$ | A1<br>A1 | 1.1b<br>1.1b |
| | $a = 0.194\,(0.19)\,(\mathrm{m\,s^{-2}})$ | A1 | 1.1b |
| | | **(4)** | |
| | | | **(9 marks)** |

**Notes:**

| | |
|---|---|
| **(a) M1** | Dimensionally correct. Condone sign errors. Must be using $a = 0$ |
| **M1** | Correct use of $P = Fv$ |
| **A1** | Correct unsimplified equation. Allow with *F*. Allow with 18K |
| **M1** | Form and solve a 3 term quadratic |
| **A1** | 26 or better (26.309……) |
| **(b)M1** | Dimensionally correct. All terms required. Condone sign errors and sin/cos confusion. Omission of *g* is an accuracy error |
| **A1**<br>**A1** | Unsimplified equation with at most one error<br>Correct unsimplified equation. Allow if $\sin\theta$ not substituted. Allow with 18K |
| **A1** | 2 sf or 3 sf only not $\frac{7}{36}$ |
| | |
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| | |
| | |

**2.**

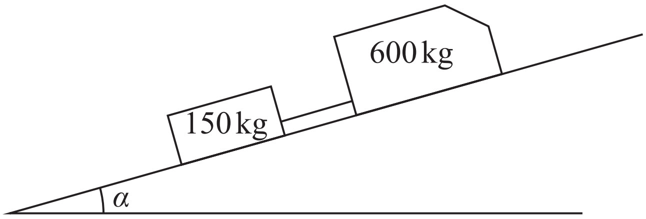



**Figure 1**

A van of mass 600 kg is moving up a straight road which is inclined at an angle $\alpha$ to the horizontal, where $\sin\alpha = \dfrac{1}{15}$. The van is towing a trailer of mass 150 kg. The van is attached to the trailer by a towbar which is parallel to the direction of motion of the van and the trailer, as shown in Figure 1.

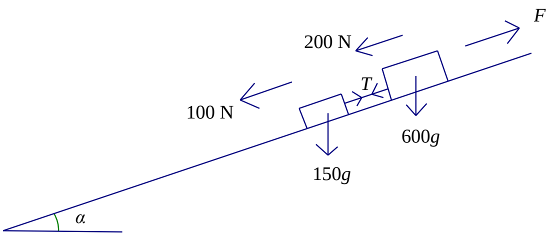
The resistance to the motion of the van from non-gravitational forces is modelled as a constant force of magnitude 200 N.
The resistance to the motion of the trailer from non-gravitational forces is modelled as a constant force of magnitude 100 N.

The towbar is modelled as a light rod.

The engine of the van is working at a constant rate of 12 kW.

Find the tension in the towbar at the instant when the speed of the van is $9\,\text{m}\,\text{s}^{-1}$

**(8)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **2.** |  | | |
| | Equation of motion for the system or for the van | M1 | 3.3 |
| | $F-(100+200)-(150+600)g\sin\alpha=(150+600)a$<br>or $F-200-T-600g\sin\alpha=600a$ | A1<br>A1 | 1.1b<br>1.1b |
| | Equation of motion for the trailer | M1 | 3.1b |
| | $T-100-150g\sin\alpha=150a$ | A1 | 1.1b |
| | Use of $F=\dfrac{12000}{9}$ | M1 | 3.4 |
| | Solve for $T$ | M1 | 1.1b |
| | $T=307\,(310)\,(\text{N})$ | A1 | 2.2a |
| | | **(Total 8 Marks)** | |

**Notes**

| | |
|---|---|
| M1 | Need all terms and no extras (the inclusion of + $T$ -$T$ is not an error). Dimensionally correct. Condone sign errors and sin/cos confusion<br>Must have non-zero acceleration and include the driving force |
| A1<br>A1 | Unsimplified equation in $F$ or their $F$ (and $T$ if relevant) with at most one error<br>Correct unsimplified equation in $F$ or their $F$ (and $T$ if relevant) |
| M1 | Need all terms. Dimensionally correct. Condone sign errors and sin/cos confusion<br>Or a second equation of motion involving the driving force. |
| A1 | Correct unsimplified equation (in $T$ and / or $F$ or their $F$ if relevant) |
| M1 | **Use** of $P=Fv$ seen or implied. |
| M1 | **Complete** method to find $T$ $\left(\text{FYI}: a=0.72(4)\right)$ |
| A1 | Tension correct to 3 sf or 2 sf<br>A fractional answer $\left(\dfrac{920}{3}\right)$ is not acceptable because this result follows the use of $g$ = 9.8 |
| | |

**6.**

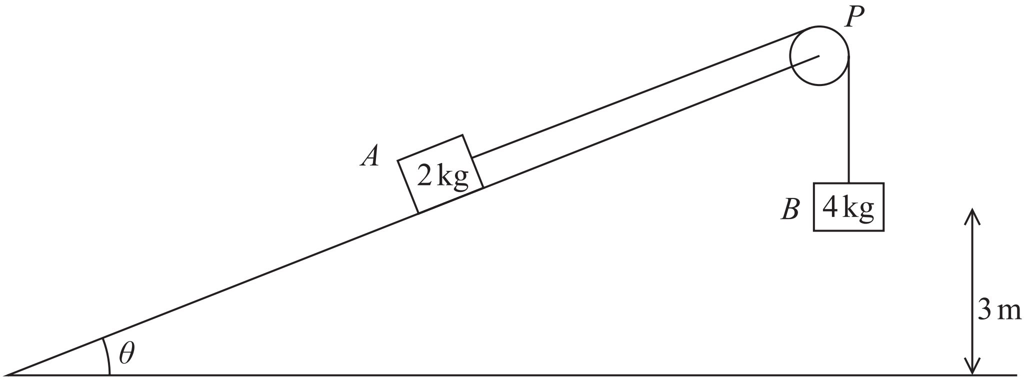



**Figure 4**

Two blocks, $A$ and $B$, of masses 2 kg and 4 kg respectively are attached to the ends of a light inextensible string.

Initially $A$ is held on a fixed rough plane. The plane is inclined to horizontal ground at an angle $\theta$, where $\tan\theta = \frac{3}{4}$

The string passes over a small smooth light pulley $P$ that is fixed at the top of the plane. The part of the string from $A$ to $P$ is parallel to a line of greatest slope of the plane.

Block $A$ is held on the plane with the distance $AP$ greater than 3 m.
Block $B$ hangs freely below $P$ at a distance of 3 m above the ground, as shown in Figure 4.

The coefficient of friction between $A$ and the plane is $\mu$

Block $A$ is released from rest with the string taut.

By modelling the blocks as particles,

(a) find the potential energy lost by the whole system as a result of $B$ falling 3 m.

**(3)**

Given that the speed of $B$ at the instant it hits the ground is $4.5\,\mathrm{m\,s^{-1}}$ and ignoring air resistance,

(b) use the work-energy principle to find the value of $\mu$

**(6)**

After $B$ hits the ground, $A$ continues to move up the plane but does not reach the pulley in the subsequent motion.
Block $A$ comes to instantaneous rest after moving a total distance of $(3 + d)$ m from its point of release.

Ignoring air resistance,

(c) use the work-energy principle to find the value of $d$

**(4)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **6(a)** | GPE lost by $B$ – GPE gained by $A$ | M1 | 3.4 |
| | $=4\times g\times 3-2\times g\sin\theta\times 3$ | A1 | 1.1b |
| | $=82\,(82.3)\,(\text{J})$ | A1 | 1.1b |
| | | **(3)** | |
| | | | |
| **6(b)** | Total KE gained $=\frac{1}{2}\times 6\times 4.5^2\ (=60.75)\,(\text{J})$ | B1 | 3.1b |
| | Max friction $\mu 2g\cos\theta\ (=\mu\times 2\times 9.8\times\cos\theta=15.68\mu)$ | B1 | 3.1b |
| | Work done against friction $=3\times F_{\max}\ (=47.04\mu)$ | B1ft | 3.4 |
| | Work-energy equation:<br>their GPE lost = their KE gained + their WD against friction | M1 | 3.4 |
| | $82.32=60.75+47.04\mu$ | A1 | 1.1b |
| | $\mu=0.459\,(0.46)$ | A1 | 1.1b |
| | | | |
| | | **(6)** | |
| **6(c)** | Work-energy equation for $A$: | M1 | 3.4 |
| | $\frac{1}{2}\times 2\times 4.5^2=2g\sin\theta\times d+2g\cos\theta\times\mu d$<br>$\left(=19.6\times\frac{3}{5}\times d+19.6\times\frac{4}{5}\times\mu d\right)$ | A1ft<br>A1ft | 1.1b<br>1.1b |
| | $d=1.07\,(1.1)$ | A1 | 1.1b |
| | | **(4)** | |
| | **(Total 13 marks)** | | |

**Notes**

| | |
|---|---|
| (a)M1 | Expression for change in GPE. Must be dimensionally correct and resolved terms where necessary.<br>Allow subtraction either way round |
| A1 | Correct unsimplified expression for the change in PE (before substitution for $\sin\theta$ )<br>Allow subtraction either way round |
| A1 | 2 sf or 3 sf. Accept 8.4g or $\frac{42g}{5}$ ISW<br>Must be positive but condone a sign change at the end without explanation |
| (b) B1 | Gain in KE for the system (not just for one block) |

| | |
|---|---|
| B1 | Correct unsimplified expression for $F_{max}$ seen or implied |
| B1ft | Correct expression for work done: follow their $F_{max}$ This is dependent on them having found an expression for $F_{max}$ |
| M1 | Complete method using work-energy to form an equation in $\mu$. Require all terms (needs to consider the KE and GPE of both blocks). Dimensionally correct. Condone sign errors. |
| A1 | Correct unsimplified equation in $\mu$ |
| A1 | 3 sf or 2 sf only |
| | NB: It is possible to find the value of $\mu$ by finding the tension in the string and forming a work-energy equation for particle *B*, but in this case the first<br>B1 is for KE of *B* and correct tension (25.7(N))<br>B1 for $F_{max}$<br>B1ft is for work done by the tension in the string and against friction<br>M1 for 3 x 25.7 = 20.25 + 35.28 + 3 x 15.68$\mu$ O.E. |
| (c)M1 | All terms required. Dimensionally correct. Condone sign errors and sin / cos confusion.<br>If the equation uses $d+3$ in place of *d* in the PE term it is correct if it also includes a term for the initial PE.<br>If the equation uses $d+3$ in place of *d* in the term for work done then it scores M0. |
| A1<br>A1 | Unsimplified equation in *d* and $\mu$ with at most one error<br>Correct unsimplified equation in *d* and $\mu$<br>The ft is on their $\mu$ if they have substituted a value. |
| A1 | 3 sf or 2 sf only |

**4.** A car of mass 600 kg pulls a trailer of mass 150 kg along a straight horizontal road. The trailer is connected to the car by a light inextensible towbar, which is parallel to the direction of motion of the car. The resistance to the motion of the trailer is modelled as a constant force of magnitude 200 N. At the instant when the speed of the car is $v\,\mathrm{m\,s^{-1}}$, the resistance to the motion of the car is modelled as a force of magnitude $(200 + \lambda v)$ N, where $\lambda$ is a constant.

When the engine of the car is working at a constant rate of 15 kW, the car is moving at a constant speed of $25\,\mathrm{m\,s^{-1}}$

(a) Show that $\lambda = 8$

**(4)**

Later on, the car is pulling the trailer up a straight road inclined at an angle $\theta$ to the horizontal, where $\sin\theta = \frac{1}{15}$

The resistance to the motion of the trailer from non-gravitational forces is modelled as a constant force of magnitude 200 N at all times. At the instant when the speed of the car is $v\,\mathrm{m\,s^{-1}}$, the resistance to the motion of the car from non-gravitational forces is modelled as a force of magnitude $(200 + 8v)$ N.

The engine of the car is again working at a constant rate of 15 kW.

When $v = 10$, the towbar breaks. The trailer comes to instantaneous rest after moving a distance $d$ metres up the road from the point where the towbar broke.

(b) Find the acceleration of the car immediately after the towbar breaks.

**(4)**

(c) Use the work-energy principle to find the value of $d$.

**(4)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **4(a)** | Using CLM | M1 | 3.1b |
| | $2mu = 2mv_A + 3mv_B$ | A1 | 1.1b |
| | Using NIL | M1 | 3.4 |
| | $eu = -v_A + v_B$ | A1 | 1.1b |
| | Overall strategy for setting up two equations and solving for $v_A$ or $v_B$ | M1 | 3.1b |
| | Speed of *A* is $\frac{u(3e-2)}{5}$ | A1 | 1.1b |
| | Speed of *B* is $\frac{2u(1+e)}{5}$ | A1 | 1.1b |
| | | **(7)** | |
| **(b)** | Direction of motion of *A* is reversed by the collision, since $\frac{u(3e-2)}{5}$ is positive when $e > \frac{2}{3}$ | B1 | 2.4 |
| | | **(1)** | |
| **(c)** | Speed of *A* = $\frac{u}{10}$ Speed of *B* = $\frac{11u}{15}$ | B1**ft** | 1.1b |
| | Calculation of KE loss with all terms; condone 'increase' | M1 | 2.1 |
| | $= \frac{1}{2}\times 2mu^2 - \left\{\frac{1}{2}\times 2m\left(\frac{u}{10}\right)^2 + \frac{1}{2}\times 3m\left(\frac{11u}{15}\right)^2\right\}$ | A1**ft** | 1.1b |
| | $= \frac{11mu^2}{60}$ | A1 | 1.1b |
| | | **(4)** | |
| | | **(12 marks)** | |

**Notes:**

**(a)**
**M1:** Correct no.of appropriate terms, condone sign errors
**A1:** Correct equation
**M1:** Need *e* on the correct side of the equation
**A1:** Correct equation
**M1:** Solving for either
**A1:** Correct speed of *A*
**A1:** Correct speed of *B*

**(b)**
**B1:** Correct direction with appropriate justification

**(c)**
**B1ft:** Follow through their answers for (a)
**M1:** All terms but condone a negative loss
**A1ft:** Follow their speeds
**A1:** cao

**2.** A parcel of mass 5 kg is projected with speed $8\,\text{m}\,\text{s}^{-1}$ up a line of greatest slope of a fixed rough inclined ramp.

The ramp is inclined at angle $\alpha$ to the horizontal, where $\sin\alpha = \frac{1}{7}$

The parcel is projected from the point $A$ on the ramp and comes to instantaneous rest at the point $B$ on the ramp, where $AB = 14\,\text{m}$.

The coefficient of friction between the parcel and the ramp is $\mu$.

In a model of the parcel's motion, the parcel is treated as a particle.

(a) Use the work-energy principle to find the value of $\mu$.

**(5)**

(b) Suggest one way in which the model could be refined to make it more realistic.

**(1)**

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| Question | Scheme | Marks | AOs |
|---|---|---|---|
| 2(a) | $R = 5g\cos\alpha \left( = 5g \times \frac{4\sqrt{3}}{7} = 48.497... \right)$ | M1 | 3.4 |
| | Force due to friction = $\mu \times 5g\cos\alpha$ | M1 | 3.4 |
| | Work-Energy equation | M1 | 3.4 |
| | $\frac{1}{2} \times 5 \times 64 = 5 \times 9.8 \times 14\sin\alpha + 14\mu R$ | A1 | 1.1b |
| | $\mu = 0.0913$ or $0.091$ | A1 | 1.1b |
| | | **(5)** | |
| **(b)** | Appropriate refinement | B1 | 3.5c |
| | | **(1)** | |
| | | **(6 marks)** | |

**Notes:**

**(a)**

**M1:** Condone sin/cos confusion

**M1:** Use of $\mu \times$ their R

**M1:** Must be using work-energy. Requires all terms
Condone sin/cos confusion, sign errors and their $R$

**A1:** Correct in $\theta$ and $\mu R$

**A1:** Accept 0.0913 **or** 0.091

**(b)**

**B1:** e.g.
- do not model the parcel as a particle and therefore take air resistance into account
- take into account the dimensions/uniformity of the parcel

**5.** A car of mass 600 kg is moving along a straight horizontal road.

At the instant when the speed of the car is $v\,\mathrm{m\,s^{-1}}$, the resistance to the motion of the car is modelled as a force of magnitude $(200 + 2v)$ N.

The engine of the car is working at a constant rate of 12 kW.

(a) Find the acceleration of the car at the instant when $v = 20$

**(4)**

Later on the car is moving up a straight road inclined at an angle $\theta$ to the horizontal,

where $\sin\theta = \dfrac{1}{14}$

At the instant when the speed of the car is $v\,\mathrm{m\,s^{-1}}$, the resistance to the motion of the car from non-gravitational forces is modelled as a force of magnitude $(200 + 2v)$ N.

The engine is again working at a constant rate of 12 kW.

At the instant when the car has speed $w\,\mathrm{m\,s^{-1}}$, the car is decelerating at $0.05\,\mathrm{m\,s^{-2}}$.

(b) Find the value of $w$.

**(5)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **5(a)** | Use of $P = Fv$ : $F = \dfrac{12000}{20}$ | B1 | 3.3 |
| | Equation of motion: $F - (200 + 2v) = 600a$ | M1 | 3.4 |
| | $600 - 240 = 600a$ | A1ft | 1.1b |
| | $360 = 600a$, $a = 0.6$ (m s$^{-2}$) | A1 | 1.1b |
| | | **(4)** | |
| **(b)** | Equation of motion: | M1 | 3.3 |
| | $\dfrac{12000}{w} - (200 + 2w) - 600g\sin\theta = -600 \times 0.05$ | A1<br>A1 | 1.1b<br>1.1b |
| | 3 term quadratic and solve: $2w^2 + 590w - 12000 = 0$ | M1 | 1.1b |
| | $w = \dfrac{-590 + \sqrt{590^2 + 96000}}{4} = 19.1$ (m s$^{-1}$) | A1 | 1.1b |
| | | **(5)** | |
| | | | **(9 marks)** |

**Notes:**

**(a)**

**B1:** 600 or equivalent

**M1:** Use the model to form the equation of motion
Must include all terms .Condone sign errors

**A1ft:** Correct for their *F*

**A1:** cao

**(b)**

**M1:** Use the model to form the equation of motion
All terms needed. Condone sign errors and sin/cos confusion

**A1:** All correct A1A1
One error A1A0

**M1:** Dependent on the preceding M1. Use the equation of motion to form a 3-term quadratic in *w* only

**A1:** Accept 19. Do not accept more than 3 s.f.

**Answer ALL questions. Write your answers in the spaces provided.**

Unless otherwise indicated, whenever a numerical value of $g$ is required, take $g = 9.8\,\text{m s}^{-2}$ and give your answer to either 2 significant figures or 3 significant figures.

**1.** A van of mass 750 kg is moving along a straight horizontal road.

At the instant when the speed of the van is $v\,\text{m s}^{-1}$, the resistance to the motion of the van is modelled as a force of magnitude $(200 + v^2)$ N.

When the engine of the van is working at a constant rate of 12 kW, and the van is moving at a constant speed,

(a) show that the van must be moving at $20\,\text{m s}^{-1}$, justifying your answer.

**(4)**

Later on, the van is moving up a straight road inclined at an angle $\theta$ to the horizontal, where $\sin\theta = \frac{1}{15}$

At the instant when the speed of the van is $v\,\text{m s}^{-1}$, the resistance to the motion of the van from non-gravitational forces is modelled as a force of magnitude $(200 + v^2)$ N.

The engine of the van is now working at a constant rate of 15 kW.

(b) Find the acceleration of the van at the instant when $v = 10$

**(5)**

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## Specimen Paper 9FM0/3C: Further Mechanics 1 Mark scheme

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **1(a)** | Driving force $= \dfrac{12000}{V}$ (N) | B1 | 3.1b |
| | No resultant force $\Rightarrow 200 + V^2 = \dfrac{12000}{V} \Rightarrow V^3 + 200V - 12000 = 0$ | M1 | 3.4 |
| | $(V-20)(V^2+20V+600)=0 \Rightarrow V=20$ is a solution* | A1* | 2.2a |
| | $b^2-4ac = 400-2400<0$ so no more real roots,<br>$V=20$ is the only solution. | A1 | 2.4 |
| | | **(4)** | |
| **(b)** | Equation of motion: | M1 | 3.4 |
| | $\dfrac{15000}{v} - 200 - v^2 - 750g\sin\theta = 750a$ | A1<br>A1 | 1.1b<br>1.1b |
| | $\Rightarrow 1200 - 50g = 750a$ | M1 | 1.1b |
| | $a = 0.95$ m s$^{-2}$ (0.947) | A1 | 1.1b |
| | | **(5)** | |
| | | | **(9 marks)** |

**Notes:**

| | | |
|---|---|---|
| 1a | B1 | Use $P = Fv$ to find the driving force |
| | M1 | Use the model to form an equation in $V$ |
| | A1* | Solve equation to obtain solution $V = 20$ (complex roots $-10 \pm 10\sqrt{5}\text{i}$ ) |
| | A1 | CSO. Justification that $V = 20$ is the only real solution e.g. by considering determinant of quadratic factor, completing the square or stating all 3 roots and confirming that only one root is real |
| SR | A candidate who verifies that $V = 20$ is a solution can score 2/4: | |
| | B1 | Use $P = Fv$ to find the driving force |
| | M1 | Complete method to show that there is no resultant force when that $V = 20$ |
| 1b | M1 | Use the model to form the equation of motion of the van. All terms required. Condone sign errors and sin/cos confusion |
| | A1 | Unsimplified equation with at most one error |
| | A1 | Correct unsimplified equation |
| | M1 | Substitute for $v$ and trig and solve for $a$ |
| | A1 | Accept 2s.f. or 3s.f. (9.8 used) |

Whenever a numerical value of $g$ is required, take $g = 9.8\,\text{m s}^{-2}$ and give your answer to either 2 significant figures or 3 significant figures.

**Answer ALL questions. Write your answers in the spaces provided.**

**1.** A small ball of mass 0.3 kg is released from rest from a point 3.6 m above horizontal ground. The ball falls freely under gravity, hits the ground and rebounds vertically upwards.

In the first impact with the ground, the ball receives an impulse of magnitude 4.2 N s. The ball is modelled as a particle.

(a) Find the speed of the ball immediately after it first hits the ground.

**(5)**

(b) Find the kinetic energy lost by the ball as a result of the impact with the ground.

**(3)**

| Qu | Scheme | Marks | AOs | Notes |
|---|---|---|---|---|
| **1(a)** | Speed just before impact: $v^2 = u^2 + 2as = 2\times 9.8\times 3.6 (= 70.56)$ | M1 | 3.4 | Use the model and *suvat* or energy to find speed before impact |
| | $v = 8.4$ (m s$^{-1}$) | A1 | 1.1b | Correct answer. Accept $\sqrt{70.56}$, $\sqrt{7.2g}$ |
| | Use of $I = mv - mu$ : $4.2 = 0.3(w-(-8.4))$ | M1 | 3.1b | A complete strategy to find *w*: Use the model and impulse-momentum equation using given impulse and their speed of impact. Must be using a difference in velocities. Be vigilant for sign fudges that make the original equation incorrect. |
| | Follow their 8.4 | A1ft | 1.1b | Correct unsimplified equation using their speed |
| | $w = 5.6$ (m s$^{-1}$) | A1 | 1.1b | Correct positive answer |
| | | **(5)** | | |
| **1(b)** | KE lost $= \frac{1}{2}m(v^2 - w^2)$ | M1 | 3.3 | Correct method to find the KE lost in the impact. Need to be using speeds immediately before and immediately after impact. |
| | $= \frac{0.3}{2}(8.4^2 - 5.6^2)$ Follow their 8.4 and 5.6 | A1ft | 1.1b | Correct expression for their speeds. Accept subtraction either way round |
| | $= 5.88$ (J) | A1 | 1.1b | Correct solution only. Accept 5.9 |
| | | **(3)** | | |
| | | | **(8 marks)** | |

**2.**

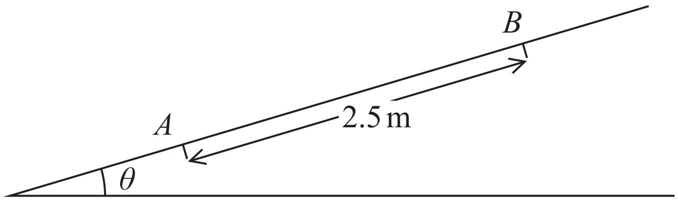


**Figure 1**

Figure 1 shows a ramp inclined at an angle $\theta$ to the horizontal, where $\sin\theta = \frac{2}{7}$

A parcel of mass 4 kg is projected, with speed $5\text{ m s}^{-1}$, from a point $A$ on the ramp. The parcel moves up a line of greatest slope of the ramp and first comes to instantaneous rest at the point $B$, where $AB = 2.5$ m. The parcel is modelled as a particle.

The total resistance to the motion of the parcel from non-gravitational forces is modelled as a constant force of magnitude $R$ newtons.

(a) Use the work-energy principle to show that $R = 8.8$

**(4)**

After coming to instantaneous rest at $B$, the parcel slides back down the ramp. The total resistance to the motion of the particle is modelled as a constant force of magnitude 8.8 N.

(b) Find the speed of the parcel at the instant it returns to $A$.

**(3)**

(c) Suggest two improvements that could be made to the model.

**(2)**





P 6 0 2 0 6 A 0 4 1 6

| Qu | Scheme | Marks | AOs | Notes |
|---|---|---|---|---|
| **2(a)** | Work-energy equation: KE lost = PE gained + Work Done | M1 | 2.1 | A complete method to obtain $R$. The question requires the use of work-energy. Need to consider all three terms with no duplication. Condone sign error and sin/cos confusion. |
| | $\frac{1}{2}\times 4\times 5^2 - 4\times g\times 2.5\times\sin\theta = 2.5R$ | A1 | 1.1b | Unsimplified equation with at most one error |
| | $\frac{1}{2}\times 4\times 5^2 - 4\times g\times 2.5\times\frac{2}{7} = 2.5R$ | A1 | 1.1b | Correct unsimplified |
| | $2.5R = 22 \Rightarrow R = 8.8$ * | A1* | 1.1b | Correct answer with sufficient working shown to justify **given answer** |
| | | **(4)** | | |
| **(b)** | Work-energy equation: KE after =initial KE – 2 (Work Done) | M1 | 3.3 | Work-energy equation considering $A \to A$ or $B \to A$. Requires all relevant terms with no duplication. Condone sign errors and sin/cos confusion |
| | $\frac{1}{2}\times 4\times v^2 = \frac{1}{2}\times 4\times 25 - 2\times 8.8\times 2.5$ | A1 | 1.1b | Correct unsimplied equation |
| | $\Rightarrow 2v^2 = 6,\ \ v = 1.7$ (m s$^{-1}$) | A1 | 1.1b | Accept 1.7 or 1.73 (answer depends on use of g). Not $\sqrt{3}$ |
| | | **(3)** | | |
| **(b) alt** | Work-energy equation: KE at $B$ = PE lost – Work Done | M1 | | |
| | $\frac{1}{2}\times 4\times v^2 = 4\times 9.8\times\frac{2}{7}\times 2.5 - 8.8\times 2.5$ | A1 | | |
| | $\Rightarrow 2v^2 = 6,\ \ v = 1.7$ (m s$^{-1}$) | A1 | | |
| | | **(3)** | | |

| | | | | |
|---|---|---|---|---|
| **(b) alt** | Equation of motion and *suvat*: $4g\sin\theta - 8.8 = 4a \quad (a = 0.6)$ | M1 | | Complete method to find *v* or $v^2$. |
| | $v^2 = 2 \times a \times 2.5$ | A1 | | Correct unsimplified expression for *v* or $v^2$. |
| | $v = 1.7$ (m $s^{-1}$) | A1 | | Accept 1.7 or 1.73 (answer depends on use of g) |
| | | **(3)** | | |
| **(c)** | A valid improvement | B1 | 3.5c | it has assumed a constant resistance - have variable resistance<br>-have air resistance proportional to speed …… |
| | A second valid, distinct, improvement | B1 | 3.5c | Do not model the parcel as a particle<br>- so can consider the possibility that the parcel rotates as it moves up/down the slope<br>- consider the dimensions of the parcel |
| | | | | The comments need to relate to the 2 modelling assumptions in the question. Air resistance and friction are already included in "non-gravitational forces". |
| | | **(2)** | | |
| | | | **(9 marks)** | |

**3.** A van of mass 750 kg is moving along a straight horizontal road. At the instant when the van is moving at $v\,\mathrm{m\,s^{-1}}$, the resistance to the motion of the van is modelled as a force of magnitude $\lambda v$ N, where $\lambda$ is a constant.

The engine of the van is working at a constant rate of 18 kW.
At the instant when $v = 15$, the acceleration of the van is $0.6\,\mathrm{m\,s^{-2}}$

(a) Show that $\lambda = 50$

**(4)**

The van now moves up a straight road inclined at an angle to the horizontal, where

$\sin\alpha = \dfrac{1}{15}$

At the instant when the van is moving at $v\,\mathrm{m\,s^{-1}}$, the resistance to the motion of the van from non-gravitational forces is modelled as a force of magnitude $50v$ N.
When the engine of the van is working at a constant rate of 12 kW, the van is moving at a constant speed $V\,\mathrm{m\,s^{-1}}$

(b) Find the value of $V$.

**(5)**

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| Qu | Scheme | Marks | AOs | Notes |
|---|---|---|---|---|
| 3(a) | Use of $P = Fv$ | B1 | 1.1a | Use of $P = Fv$ seen or implied. Allow in (b) if not seen in (a) |
| | Equation of motion: $F - \lambda v = 750 \times 0.6$ | M1 | 2.1 | Requires all three terms. Must be dimensionally correct.<br>Need not have substituted for *F*. Condone sign errors.<br>Allow if equation not seen but all steps in working correct.<br>The method needs to show that $\lambda = 50$ is the only solution. |
| | $\frac{18000}{15} - \lambda \times 15 = 750 \times 0.6$ | A1 | 1.1b | Correct unsimplified equation |
| | $1200 - 15\lambda = 450 \Rightarrow \lambda = 50$ * | A1* | 1.1b | Obtain given answer correctly |
| | | **(4)** | | |
| 3(b) | Overall strategy | M1 | 3.1b | Complete strategy e.g. use the model to form quadratic in $V$ and solve for $V$ |
| | Equation of motion | M1 | 3.4 | Use the model to form equation of motion. All terms required.<br>Condone sign errors and sin/cos confusion.<br>Need not have substituted for *F*. |
| | $\frac{12000}{V} - 50V - 750g\sin\alpha = 0$ | A1 | 1.1b | Substituted equation with at most one error (unsimplified). Allow in *F* or *V*. |
| | $\frac{12000}{V} - 50V - 490 = 0 \Rightarrow 5V^2 + 49V - 1200 = 0$ | A1 | 1.1b | Correct quadratic equation. e.g. $5V^2 + 49V - 1200 = 0$ or equivalent<br>Allow in *F* or *V*. |
| | $\Rightarrow V\left(= \frac{-49 + \sqrt{49^2 + 20 \times 1200}}{10}\right) = 11.3$ only | A1 | 1.1b | Accept 11 or 11.3 (follows use of 9.8)<br>Negative root should be rejected if seen |
| | | **(5)** | | |
| | | | **(9 marks)** | |

**1.** A lorry of mass 16 000 kg moves along a straight horizontal road.

The lorry moves at a constant speed of 25 $\mathrm{m\,s^{-1}}$

In an initial model for the motion of the lorry, the resistance to the motion of the lorry is modelled as having constant magnitude 16 000 N.

(a) Show that the engine of the lorry is working at a rate of 400 kW.

**(4)**

The model for the motion of the lorry along the same road is now refined so that when the speed of the lorry along the same road is $V$ $\mathrm{m\,s^{-1}}$, the resistance to the motion of the lorry is modelled as having magnitude $640V$ newtons.

Assuming that the engine of the lorry is working at the same rate of 400 kW

(b) use the refined model to find the speed of the lorry when it is accelerating at 2.1 $\mathrm{m\,s^{-2}}$

**(6)**

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| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **1(a)** | Equation of motion parallel to the road with $a$ = 0 and using the model | M1 | 3.3 |
| | $F - 16000 = 0$ | A1 | 1.1b |
| | $P = 16\,000 \times 25$ | M1 | 3.4 |
| | $= 400\,000 = 400$ kW * | A1* | 1.1b |
| | | **(4)** | |
| **(b)** | Use of $\dfrac{400\,000}{V}$ | M1 | 3.3 |
| | Equation of motion parallel to the road and using the refined model | M1 | 3.4 |
| | $\dfrac{400\,000}{V} - 640V = 16000 \times 2.1$ | A1 | 1.1b |
| | $2V^2 + 105V - 1250 = 0 \quad \left(640V^2 + 33600V - 400000 = 0\right)$ | A1 | 1.1b |
| | Solve for $V$ | M1 | 1.1b |
| | $V = 10$ (i.e. speed is 10 $\text{m s}^{-1}$) | A1 | 1.1b |
| | | **(6)** | |
| | | | **(10 marks)** |

**Notes**

| | | |
|---|---|---|
| **(a)** | M1 | Correct no. of terms with $a$ = 0, condone sign errors<br>Given answer, so step must be seen, but allow if in verbal form or on a diagram. |
| | A1 | Correct equation |
| | M1 | Use of $P = Fv$<br>Independent mark - could be the first mark seen |
| | A1* | Obtain **given answer** from correct working |
| **(b)** | M1 | Use of $P = Fv$ |
| | M1 | Correct no. of terms, condone sign errors.<br>Dimensionally correct |
| | A1 | Correct unsimplified equation |
| | A1 | Correct 3 term quadratic |
| | M1 | For solving a 3 term quadratic – this mark can be implied by a correct value of $V$ but otherwise can only be earned for evidence of an explicit method being used. |
| | A1 | $V$ = 10 only |

3. A particle, $P$, of mass $m$ kg is projected with speed 5 $\text{m s}^{-1}$ down a line of greatest slope of a rough plane. The plane is inclined to the horizontal at an angle $\alpha$, where $\sin\alpha = \frac{3}{5}$

The total resistance to the motion of $P$ is a force of magnitude $\frac{1}{5}mg$

Use the work-energy principle to find the speed of $P$ at the instant when it has moved a distance 8 m down the plane from the point of projection.

**(7)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **3** | Work done $= \frac{1}{5}mg \times 8 \quad (15.68m)$ | B1 | 3.4 |
| | PE Loss = $8mg\sin\alpha \quad (47.04m)$ | B1 | 1.1b |
| | | | |
| | KE Gain = Difference of two KE terms | M1 | 3.4 |
| | $= \frac{1}{2}mv^2 - \frac{1}{2}m5^2$ | A1 | 1.1b |
| | Work done against friction = PE Loss – KE Gain | M1 | 2.1 |
| | $\frac{1}{5}mg \times 8 = 8mg\sin\alpha - \left(\frac{1}{2}mv^2 - \frac{1}{2}m5^2\right)$ | A1 | 1.1b |
| | $v$ = 9.4 or 9.37 (m $s^{-1}$) | A1 | 1.1b |
| | | **(7)** | |
| | | | **(7 marks)** |

## Notes

The question instructs candidates to use the work-energy principle, so *suvat* methods will not score the second M1.

| | |
|---|---|
| B1 | Work done against friction seen or implied |
| B1 | PE loss seen or implied |
| | NB: B1B1 for $\left(\frac{3}{5}mg - \frac{1}{5}mg\right)\times 8 \quad \left(=\frac{16}{5}mg\right)$ |
| M1 | Difference in two KE terms seen or implied (allow KE loss) |
| A1 | Correct unsimplified expression. Allow $\pm$ |
| M1 | Work-energy equation with all terms. Must be dimensionally correct but condone sign errors |
| A1 | Correct unsimplified equation |
| A1 | 2 sf or 3 sf (after use of $g$ = 9.8) |

**2.** A car of mass 1000 kg moves along a straight horizontal road.

In all circumstances, when the speed of the car is $v\,\text{m s}^{-1}$, the resistance to the motion of the car is modelled as a force of magnitude $cv^2$ N, where $c$ is a constant.

The maximum power that can be developed by the engine of the car is 50 kW.

At the instant when the speed of the car is $72\,\text{km h}^{-1}$ and the engine is working at its maximum power, the acceleration of the car is $2.25\,\text{m s}^{-2}$

(a) Convert $72\,\text{km h}^{-1}$ into $\text{m s}^{-1}$

**(1)**

(b) Find the acceleration of the car at the instant when the speed of the car is $144\,\text{km h}^{-1}$ and the engine is working at its maximum power.

**(7)**

The maximum speed of the car when the engine is working at its maximum power is $V\,\text{km h}^{-1}$.

(c) Find, to the nearest whole number, the value of $V$.

**(4)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **2a** | $72 \text{ km h}^{-1} = 20 \text{ m s}^{-1}$ | B1 | 1.1b |
| | | **(1)** | |
| **2b** | Use of $F = \dfrac{P}{v}$ and using the model | M1 | 3.4 |
| | Equation of motion and using the model to form equation in $c$ | M1 | 3.1b |
| | $\dfrac{50000}{20} - c \times 20^2 = 1000 \times 2.25 \qquad \left(c = \dfrac{5}{8}\right)$ | A1ft | 1.1b |
| | Equation of motion and using the model | M1 | 3.1b |
| | $\dfrac{50000}{40} - c \times 40^2 = 1000a$ | A1ft | 1.1b |
| | Solve for $a$ | M1 | 1.1b |
| | $0.25 \text{ (m s}^{-2}\text{)}$ | A1 | 1.1b |
| | | **(7)** | |
| **2c** | Equation of motion horizontally and using the model | M1 | 3.1b |
| | $\dfrac{50000}{W} - \dfrac{5}{8}W^2 = 0$ (max speed is $W$ m s$^{-1}$) | A1ft | 1.1b |
| | Solve for $W$ and convert to km h$^{-1}$ $\quad (W = 43.088...)$ | M1 | 1.1b |
| | $V = 155$ (nearest whole number) | A1 | 1.1b |
| | | **(4)** | |
| | | | **(12 marks)** |

**Notes**

| | | |
|---|---|---|
| **2a** | B1 | 20 m s$^{-1}$ seen |
| **2b** | M1 | Follow through the 72 or their $v$. Allow for 144 or their 144 |
| | M1 | Correct no. of terms required |
| | A1ft | Correct unsimplified equation ft on their 20 |
| | M1 | Correct no. of terms required |
| | | Allow the second and third M marks if they have an equation in $F$ rather than $P$. |
| | A1ft | Correct equation ft on their 40 and their $c$ |
| | M1 | Complete method to solve for $a$ |
| | A1 | Cao $\left(\text{Accept } \dfrac{1}{4}\right)$ |
| **2c** | M1 | Equation with correct no. of terms, correct structure and in terms of $W$ only. |

| | | |
|---|---|---|
| | A1ft | Correct equation, ft on their $c$ from part (b). |
| | M1 | Complete method to solve for $V$ (including clear attempt to convert units) |
| | A1 | Cao (The Q asks for a whole number) |

**4.** A small ball, of mass $m$, is thrown vertically upwards with speed $\sqrt{8gH}$ from a point $O$ on a smooth horizontal floor. The ball moves towards a smooth horizontal ceiling that is a vertical distance $H$ above $O$. The coefficient of restitution between the ball and the ceiling is $\frac{1}{2}$

In a model of the motion of the ball, it is assumed that the ball, as it moves up or down, is subject to air resistance of constant magnitude $\frac{1}{2}mg$.

Using this model,

(a) use the work-energy principle to find, in terms of $g$ and $H$, the speed of the ball immediately before it strikes the ceiling,

**(5)**

(b) find, in terms of $g$ and $H$, the speed of the ball immediately before it strikes the floor at $O$ for the first time.

**(5)**

In a simplified model of the motion of the ball, it is assumed that the ball, as it moves up or down, is subject to no air resistance.

Using this simplified model,

(c) explain, without any detailed calculation, why the speed of the ball, immediately before it strikes the floor at $O$ for the first time, would still be less than $\sqrt{8gH}$

**(1)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| 4a | $\frac{1}{2}mgH$ | B1 | 1.1b |
| | $\frac{1}{2}m(8gH - v^2)$ | B1 | 1.1b |
| | Apply the work-energy principle | M1 | 3.3 |
| | $\frac{1}{2}mgH = \frac{1}{2}m(8gH - v^2) - mgH$ | A1 | 1.1b |
| | $v = \sqrt{5gH}$ | A1 | 1.1b |
| | | **(5)** | |
| 4b | Use NLR to find rebound speed: $\frac{1}{2}\sqrt{5gH}$ | M1 | 3.4 |
| | Apply the work-energy principle or *suvat* with $a = \frac{1}{2}g$ | M1 | 3.3 |
| | $\frac{1}{2}mgH = mgH - \frac{1}{2}m(v_1^2 - \frac{1}{4}\times 5gH)$ or $(v_1)^2 = \frac{5gH}{4} + 2\times\frac{g}{2}\times H$ | A1ft<br>A1 | 1.1b<br>1.1b |
| | $v_1 = \frac{3}{2}\sqrt{gH}$ | A1 | 2.2a |
| | | **(5)** | |
| 4c | Since $e < 1$, ball loses energy in its collision with the ceiling. | B1 | 2.4 |
| | | **(1)** | |
| | | | **(11 marks)** |

**Notes**

| | | |
|---|---|---|
| **4a** | B1 | Work done against resistance (allow -ve) Can be implied by use of $\frac{3}{2}mgH$ (work done against resistance + work done against weight) |
| | B1 | KE loss (allow -ve) |
| | M1 | Correct no. of terms, dimensionally correct. Condone sign errors. |
| | A1 | Correct unsimplified equation |
| | A1 | Correct answer (any equivalent but must be in terms of *g* and *H*)<br>Accept $2.2\sqrt{gH}$ or better |
| **4b** | M1 | Use of NLR |
| | M1 | Correct no. of terms, dimensionally correct |
| | A1ft | Correct equation with at most one error ft on their answer to (a) |
| | | M1A1ft is available to a candidate who has not scored the first M1 |

| | | |
|---|---|---|
| | A1 | Correct equation (no ft) |
| | A1 | Correct answer (any equivalent but must be in terms of $g$ and $H$) |
| **4c** | B1 | Clear explanation |
| | | Need to identify that the loss of KE occurs in the impact with the ceiling. Do not insist on seeing $e < 1$ or equivalent.<br>If they include incorrect additional statements then B0 |

**1.**

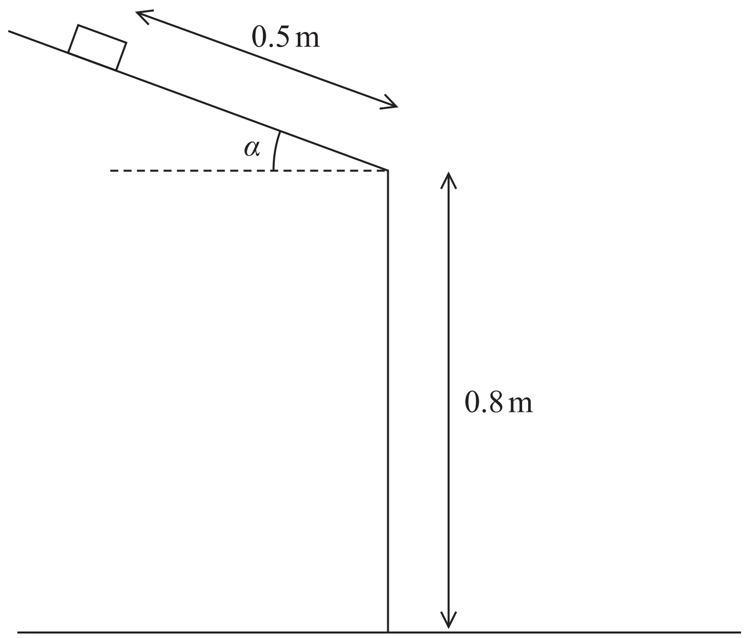


**Figure 1**

A small book of mass $m$ is held on a rough straight desk lid which is inclined at an angle $\alpha$ to the horizontal, where $\tan\alpha = \frac{3}{4}$. The book is released from rest at a distance of 0.5 m from the edge of the desk lid, as shown in Figure 1. The book slides down the desk lid and then hits the floor that is 0.8 m below the edge of the desk lid. The coefficient of friction between the book and the desk lid is 0.4

The book is modelled as a particle which, after leaving the desk lid, is assumed to move freely under gravity.

(a) Find, in terms of $m$ and $g$, the magnitude of the normal reaction on the book as it slides down the desk lid.

**(2)**

(b) Use the work-energy principle to find the speed of the book as it hits the floor.

**(5)**

M(A) Taking moments about A
N2L Newton's Second Law (Equation of Motion)
NEL Newton's Experimental Law (Newton's Law of Impact)
HL Hooke's Law
SHM Simple harmonic motion
PCLM Principle of conservation of linear momentum
RHS, LHS Right hand side, left hand side



| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **1(a)** | Resolve perpendicular to the plane | M1 | 3.4 |
| | $R = \frac{4}{5}mg$ | A1 | 1.1b |
| | | **(2)** | |
| **(b)** | Work done against friction = $0.4R \times 0.5$ (= $0.16mg$) | M1 | 3.4 |
| | PE Loss = $mg \times 0.5\sin\alpha + 0.8mg$ (= $1.1mg$) | M1 | 1.1b |
| | Using work-energy principle | M1 | 3.4 |
| | $1.1mg = 0.16mg + \frac{1}{2}mv^2$ | A1 | 1.1b |
| | $v$ = 4.3 or 4.29 ($\text{m s}^{-1}$) | A1 | 1.1b |
| | | **(5)** | |
| | | | **(7 marks)** |

**Notes:**

| | | |
|---|---|---|
| **1a** | M1 | Allow sin/cos confusion |
| | A1 | cao |
| **1b** | M1 | Correct form for work done against friction. ($1.568m$) |
| | M1 | Correct no. of terms, dimensionally correct, condone sin/cos confusion ($10.78m$) |
| | M1 | Correct number of terms (using their WD and PE for the **whole journey** to the floor) |
| | A1 | Correct unsimplified equation |
| | A1 | Either of the two possible answers (as $g$ = 9.8 has been used) |

**3.** The total mass of a cyclist and his bicycle is 100 kg.

In all circumstances, the magnitude of the resistance to the motion of the cyclist from non-gravitational forces is modelled as being $kv^2$ N, where $v\,\text{m s}^{-1}$ is the speed of the cyclist.

The cyclist can freewheel, without pedalling, down a slope that is inclined to the horizontal at an angle $\alpha$, where $\sin\alpha = \frac{1}{35}$, at a constant speed of $V\,\text{m s}^{-1}$

When he is pedalling up a slope that is inclined to the horizontal at an angle $\beta$, where $\sin\beta = \frac{1}{70}$, and he is moving at the same constant speed $V\,\text{m s}^{-1}$, he is working at a constant rate of $P$ watts.

(a) Find $P$ in terms of $V$.

**(7)**

If he pedals and works at a rate of $35V$ watts on a horizontal road, he moves at a constant speed of $U\,\text{m s}^{-1}$

(b) Find $U$ in terms of $V$.

**(4)**

| | | |
|---|---|---|
| | A1 | Correct derivative |
| | | If working from $\frac{1}{2}mu^2\left(1-e^4\right)$ allow M1A0 for a correct argument leading to $e=0$ |
| | M1 | Clear attempt to equate to zero |
| | A1 | cao |
| **2c** | B1 | Any clear equivalent statement |
| | B1 | Any clear equivalent statement. Allow speed tends to 0. |

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| **3(a)** | Freewheeling down: Equation of motion down the plane and using the model | M1 | 3.1b |
| | $100g\sin\alpha - kV^2 = 0$ $\left(kV^2 = \frac{100g}{35}\right)$ | A1 | 1.1b |
| | Cycling up: Equation of motion up the plane and using the model | M1 | 3.1b |
| | $F - 100g\sin\beta - kV^2 = 0$ | A1 | 1.1b |
| | Use of $F = \frac{P}{V}$ $\left(\frac{P}{V} = \frac{100g}{70} + \frac{100g}{35}\right)$ | M1 | 3.3 |
| | Solve the problem by solving for $P$ in terms of $V$ and substituting for $\sin\alpha$ and $\sin\beta$ | M1 | 1.1b |
| | $\left(P = \frac{300gV}{70}\right)$ $P = 42V$ | A1 | 1.1b |
| | | **(7)** | |
| **(b)** | Equation of motion horizontally and using the model | M1 | 3.4 |
| | $\frac{35V}{U} - kU^2 = 0$ | A1 | 1.1b |
| | Solve for $U$ in terms of $V$ $\left(\frac{35V}{U} - \frac{100g}{35V^2}U^2 = 0\right)$ | M1 | 3.1b |
| | $U = 1.1V$ or $U = 1.08V$ | A1 | 1.1b |
| | | **(4)** | |
| | | | **(11 marks)** |
| **Notes:** | | | |

| | | |
|---|---|---|
| **3a** | M1 | Dimensionally correct. Correct no. of terms, condone sin/cos confusion |
| | A1 | Correct equation |
| | M1 | Dimensionally correct. Correct no. of terms, condone sin/cos confusion |
| | A1 | Correct equation |
| | B1 | Any equivalent form |
| | M1 | Use correct strategy to set up and solve the equations to solve the problem |
| | A1 | cao |
| **3b** | M1 | Correct no. of terms. Allow $F - kU^2 = 0$ but not $F - kV^2 = 0$ |
| | A1 | Correct equation |
| | M1 | Use correct strategy to set up and solve the equations to solve the problem |
| | A1 | Accept 2 sf or 3 sf. $U = \sqrt[3]{\frac{5}{4}}V$ scores 3/4 (depends on the use of $g$) |

**1.** A car of mass 1200 kg moves up a straight road that is inclined to the horizontal at an angle $\alpha$, where $\sin\alpha = \dfrac{1}{15}$

The total resistance to the motion of the car from non-gravitational forces is modelled as a constant force of magnitude $R$ newtons.

At the instant when the engine of the car is working at a rate of 32 kW and the speed of the car is $20\,\text{m}\,\text{s}^{-1}$, the acceleration of the car is $0.5\,\text{m}\,\text{s}^{-2}$

Find the value of $R$

**(5)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| 1. | $F = \dfrac{32000}{20}$ | M1 | 3.3 |
| | Equation of motion | M1 | 3.1b |
| | $F - 1200g\sin\alpha - R = 1200 \times 0.5$ | A1 | 1.1b |
| | Substitute for $g$, trig and $F$ and solve for $R$ | DM1 | 1.1b |
| | $R = 216$ or $220$ (N) | A1 | 1.1b |
| | | **(5)** | |
| | | | **(5 marks)** |

**Notes:**

| | | |
|---|---|---|
| **1** | M1 | Use of $P = Fv$. Allow $\dfrac{32}{20}$.<br>Allow $32000 = 20F$ or $32 = 20F$, followed by an error when dividing<br>M0 for $32000 = 20(F - R)$ or similar |
| | M1 | Correct no. of terms, condone sign errors and sin/cos confusion<br>M0 if they use power in equation of motion |
| | A1 | Correct equation |
| | DM1 | Dependent on second M1 (allow if $g$ missing) |
| | A1 | Cao ($R = 215.2$ if they use $g = 9.81$) |

**3.** A plane is inclined to the horizontal at an angle $\alpha$, where $\tan\alpha = \frac{3}{4}$

A particle $P$ is held at rest at a point $A$ on the plane.

The particle $P$ is then projected with speed $25\,\text{m s}^{-1}$ from $A$, up a line of greatest slope of the plane.

In an initial model, the plane is modelled as being smooth and air resistance is modelled as being negligible.

Using this model and the principle of conservation of mechanical energy,

(a) find the speed of $P$ at the instant when it has travelled a distance $\frac{25}{6}$ m up the plane from $A$.

**(4)**

In a refined model, the plane is now modelled as being rough, with the coefficient of friction between $P$ and the plane being $\frac{3}{5}$

Air resistance is still modelled as being negligible.

Using this refined model and the work-energy principle,

(b) find the speed of $P$ at the instant when it has travelled a distance $\frac{25}{6}$ m up the plane from $A$.

**(8)**

| Question | Scheme | Marks | AOs |
|---|---|---|---|
| 3(a) | $mg \times \frac{25}{6} \sin\alpha$ | B1 | 1.1b |
| | Use of the principle of conservation of mechanical energy | M1 | 3.4 |
| | $\frac{1}{2}m \times 25^2 - \frac{1}{2}mv^2 = mg \times \frac{25}{6}\sin\alpha$ | A1 | 1.1b |
| | $v = 24\ (\text{m s}^{-1})$ (23.99895831… = 24 to 2SF if $g = 9.81$) | A1 | 1.1b |
| | | **(4)** | |
| 3(b) | Resolve perpendicular to the plane | M1 | 3.1a |
| | $R = mg\cos\alpha$ | A1 | 1.1b |
| | $F = \frac{3}{5}R$ | B1 | 3.4 |
| | WD against friction = $F \times \frac{25}{6}$ | B1 | 3.4 |
| | Use of work-energy principle | M1 | 3.1a |
| | $\frac{1}{2}m \times 25^2 - \frac{1}{2}mv^2 = mg \times \frac{25}{6}\sin\alpha + \frac{3}{5} \times mg\cos\alpha \times \frac{25}{6}$ | A1<br>A1 | 1.1b<br>1.1b |
| | $v = 23.2$ or $23\ (\text{m s}^{-1})$<br>(23.16700… = 23.2 or 23 to 3SF or 2SF if $g = 9.81$) | A1 | 1.1b |
| | | **(8)** | |
| | | | **(12 marks)** |

**Notes:**

| | | |
|---|---|---|
| | | **N.B.** If consistent use of a specific value of *m*, allow all the marks but deduct the final A mark in each part but allow full marks if *m*'s have been cancelled or don't appear. |
| **3a** | B1 | Seen anywhere |
| | M1 | Correct no. of terms, dimensionally correct, condone sign errors and sin/cos confusion<br>M0 for non-energy methods.<br>Allow max M1A0A0 if 25/6 not resolved or not resolved correctly in PE term |
| | A1 | Correct equation in *m*, *g*, *v* and $\alpha$ |
| | A1 | cao |
| **3b** | M1 | Correct no. of terms, dimensionally correct, condone sign errors and sin/cos confusion |
| | A1 | Correct equation |
| | B1 | Seen anywhere |
| | B1 | Seen anywhere |
| | M1 | Correct no. of terms, dimensionally correct, condone sign errors and sin/cos confusion<br>M0 for non work-energy methods<br>Allow max M1A1A0A0 if 25/6 not resolved or not resolved correctly in PE term |

| | | |
|---|---|---|
| | A1 | Equation in *m*, *g*, *v* and $\alpha$ with at most one error<br>**N.B**. If KE terms reversed, only penalise ONCE. |
| | A1 | Correct equation in *m*, *g*, *v* and $\alpha$ |
| | A1 | cao |