2021 ASSESSMENT MATERIALS

A-level PHYSICS

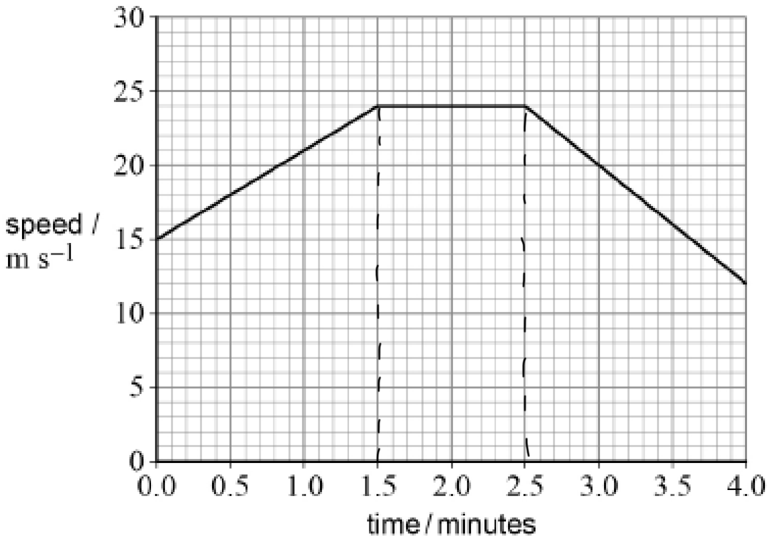
7408 – Mechanics and materials / Further Mechanics

Total number of marks: 48

0 4 A pair of cameras is used on a motorway to help determine the average speed of vehicles travelling between the two cameras.

Figure 5 shows the speed–time graph for a car moving between the two cameras.

Figure 5



0 4 . 1 The speed limit for the motorway between the two cameras is $22\ \text{m s}^{-1}$.

Determine whether the average speed of the car exceeded this speed limit.

[3 marks]

$\frac{1}{2}(15 + 24)(90) + (60 \times 24) + \frac{1}{2}(24 + 12)(90)$

$= 4815\ \text{m}$

4 mins = 240 secs

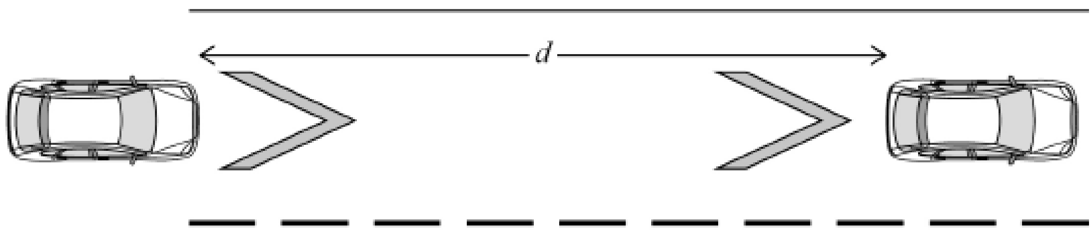
$\therefore$ avg. speed $= \frac{4815}{240} = 20.1\ \text{ms}^{-1}$

$20.1 < 22$ $\therefore$ Did not exceed speed limit

0 4 . 2 Markings called chevrons are used on motorways.

The chevron separation is designed to give a driver time to respond to any change in speed of the car in front. The driver is advised to keep a minimum distance d behind the car in front, as shown in **Figure 6**.

Figure 6



not to scale

Government research suggests that the typical time for a driver to respond is between 1.6 s and 2.0 s.

Suggest a value for d where the speed limit is 31 m s^{-1}.

[2 marks]

$v = \frac{d}{t}$ take $t = 1.8$ s

$31 = \frac{d}{1.8}$

$d = 55.8$

$d =$ 56 m

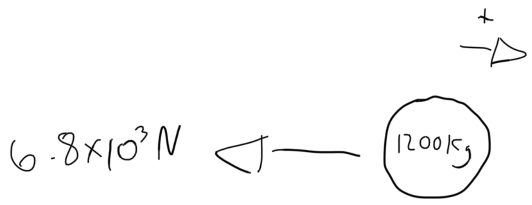
0 4 . 3 The chevron separation is based on the response time, not on the time taken for a car to stop.

The brakes of a car are applied when its speed is $31\ \mathrm{m\ s^{-1}}$ and the car comes to rest. The total mass of the car is $1200\ \mathrm{kg}$.

The average braking force acting on the car is $6.8\ \mathrm{kN}$.

Calculate the time taken for the braking force to stop the car **and** the distance travelled by the car in this time.

[4 marks]



$F = ma$

$\frac{F}{m} = a \quad \frac{-6.8\times10^3}{1200} = a$

$a = -5.67\ ms^{-2}$

$s =$
$u = 31$
$v = 0$
$a = -5.67$
$t =$

$v = u + at$

$\frac{v-u}{a} = t \quad \frac{0-31}{-5.67} = t = 5.47s$

$v^2 = u^2 + 2as$

$\frac{v^2 - u^2}{2a} = s \quad \frac{0-(31)^2}{2\times-5.67} = s$

$s = 84.8\ m$

time = 5.5 s

distance = 85 m

0 4 . 4 Suggest why the chevron separation on motorways does not take into account the distance travelled as a car comes to rest after the brakes are applied.

[1 mark]

Because the car in front is also still moving forwards and slowing down.

0 4 . 5 At bends on motorways the road is sloped so that a car is less likely to slide out of its lane when travelling at a high speed.

Figure 7 shows a car of mass 1200 kg travelling around a curve of radius 200 m. The motorway is sloped at an angle of 5.0°.

Figure 8 shows the weight W and reaction force N acting on the car. The advisory speed for the bend is chosen so that the friction force down the slope is zero.

Figure 7

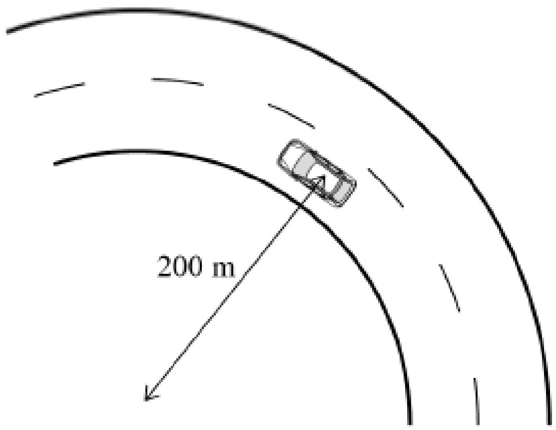
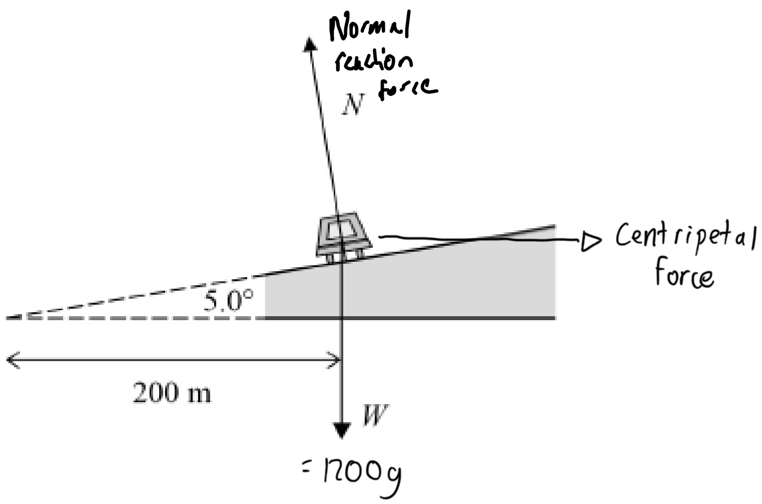


Figure 8



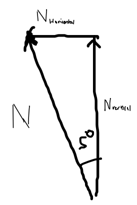
Suggest an appropriate advisory speed for this section of the motorway.

[4 marks]

Horizontal force balance → $F = N_{Horizontal}$

$N_{Horizontal} = N_{vertical} \tan(5) = 1200g \tan 5 = F$

$= 1029.92$



$$F = \frac{mv^2}{r}$$

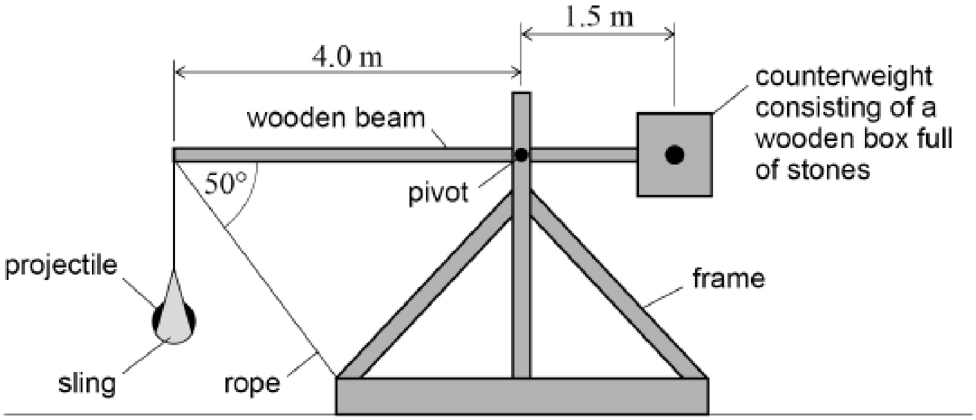
$$\sqrt{\frac{Fr}{m}} = v$$

$$v = \sqrt{\frac{1029.92 \times 200}{1200}} = 13.1 \text{ ms}^{-1}$$

advisory speed = 13 m s^{-1}

0 4 **Figure 5** shows a simplified catapult used to hurl projectiles a long way.

Figure 5



The counterweight is a wooden box full of stones attached to one end of the beam.
The projectile, usually a large rock, is in a sling hanging vertically from the other end of the beam. The weight of the sling is negligible.
The beam is held horizontal by a rope attached to the frame.

0 4 . 1 The catapult is designed so that the weight of the beam and the weight of the **empty** wooden box have no effect on the tension in the rope.

Suggest how the pivot position achieves this.

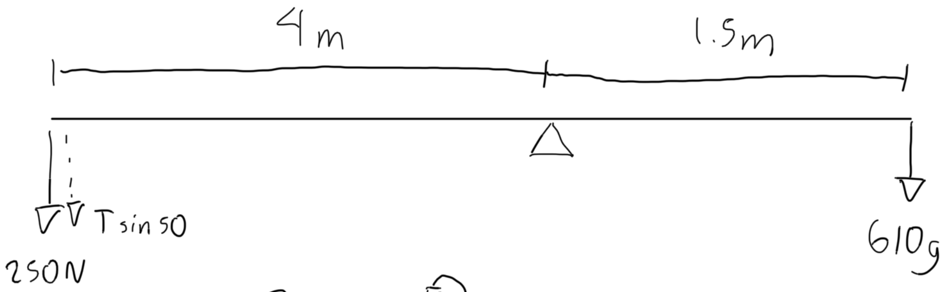
[2 marks]

The box and beam to the right of the pivot is heavier than the beam to the left of the pivot. Therefore, the pivot is positioned closer to the right so that clockwise and anticlockwise moments cancel.

0 4 . 2 The stones in the counterweight have a total mass of $610\ \text{kg}$ and the projectile weighs $250\ \text{N}$.

Calculate the tension in the rope.

[5 marks]



$M \circlearrowright = M \circlearrowleft$

$610g \times 1.5 = 4T\sin 50 + 4(250)$

$8976.15 = 1000 + 4T\sin 50$

$7976.15 = 4T\sin 50$

$T = 2603.03\ \text{N}$

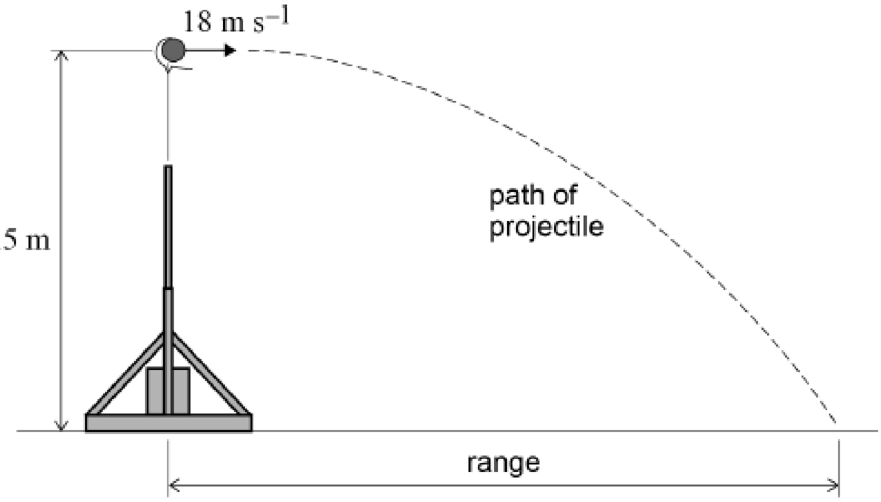
$T = 2600\ \text{N}$

tension = 2600 N

0 4 . 3 When the rope is cut, the counterweight rotates clockwise. When the beam is vertical it is prevented from rotating further. The projectile is then released horizontally with a velocity of $18\ m\ s^{-1}$, as shown in **Figure 6**.

The projectile is released at a height of $7.5\ m$ above ground level.

Figure 6



The range of the catapult is the horizontal distance between the point where the projectile is released to the point where it lands.

Calculate the range.
Ignore air resistance.

[2 marks]

Horiz.

$s =$
$u = 18$
$v =$
$a = 0$
$t = 1.237$

$s = ut + \frac{1}{2}at^2$
$s = 18(1.237) + 0$
$s = 22.3m \approx 22m$

Vert.

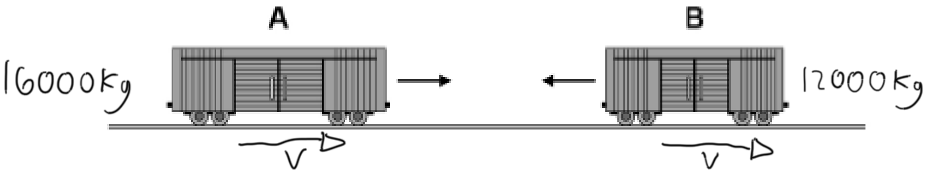
$s = 7.5$
$u = 0$
$v =$
$a = 9.81$
$t =$

$s = ut + \frac{1}{2}at^2$
$7.5 = 0 + 4.905t^2$
$t = 1.237$

range = 22 m

0 6 **Figure 10** shows two railway trucks **A** and **B** travelling towards each other on the same railway line which is straight and horizontal.

2.8 ms⁻¹ **Figure 10** −3.1 ms⁻¹



The trucks are involved in an inelastic collision. They join when they collide and then move together.

The trucks move a distance of 15 m before coming to rest.

Truck **A** has a total mass of 16 000 kg and truck **B** has a total mass of 12 000 kg

Just before the collision, truck **A** was moving at a speed of 2.8 m s^{-1} and truck **B** was moving at a speed of 3.1 m s^{-1}

0 6 . 1 State the quantity that is **not** conserved in an inelastic collision.

[1 mark]

Kinetic energy

0 6 . 2 Show that the speed of the joined trucks immediately after the collision is about 0.3 m s^{-1}

[3 marks]

$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$

16000(2.8) + 12000(-3.1) = 16000v + 12000v

7600 = 28000v

v = 0.27 ms⁻¹ ≈ 0.3 ms⁻¹

0 6 . 3 Calculate the impulse that acts on each truck during the collision.
Give an appropriate unit for your answer.

[2 marks]

B

I = m(v − u)

I = 12000(0.27 − −3.1)

I = 40440

impulse = 40 440 unit Ns

0 6 . 4 Explain, without doing a calculation, how the motion of the trucks immediately after the collision would be different for a collision that is perfectly elastic.

[2 marks]

The trucks would have a higher joint final velocity as no kinetic energy would be lost.

0 5 Safety barriers are used on UK motorways to prevent vehicles crossing from one carriageway to the other carriageway. The barriers also absorb some of the kinetic energy of a vehicle and deflect vehicles along the barrier.

The standard test of a safety barrier uses a vehicle that contains dummies. The total mass of the vehicle and its contents is 1.5×10^3 kg and its initial speed is $110\ \text{km h}^{-1}$.

0 5 . 1 Show that the initial kinetic energy of the test vehicle is 700 kJ.

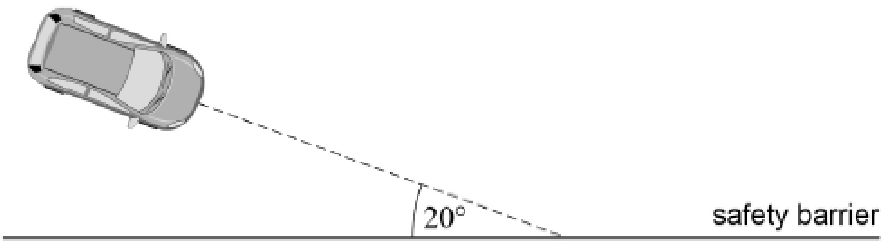
[2 marks]

$110\ \text{kmh}^{-1} = 30.556\ \text{ms}^{-1} = v$ $\quad E_K = \frac{1}{2}mv^2$ $\quad E_K = \frac{1}{2}(1.5\times10^3)(30.556)^2$

$E_K = 700231.48 \approx 700\ \text{kJ}$

0 5 . 2 The test vehicle hits a steel safety barrier at an angle of 20°, as shown in **Figure 7**.

Figure 7



Calculate the component of the momentum of the test vehicle in a direction along the line of the safety barrier.
Give an appropriate unit for your answer.

[3 marks]

$V_{Horiz.} = 30.556\cos 20 = 28.71\ \text{ms}^{-1}$

$p = mV_{Horiz.}$

$p = 1.5\times10^3 \times 28.71$

$p = 43069.87\ \text{Ns} \approx 43000$

momentum = 43000 unit Ns

0 5 . 3 Immediately after the collision, the test vehicle moves along the safety barrier with no change in its momentum in this direction.

Show that the kinetic energy lost in the collision is about 80 kJ.

[3 marks]

$E_{K\,before} = \frac{1}{2}mv^2 = \frac{1}{2}\times1.5\times10^3\times30.556^2 = 700251.852\ \text{J}$

$E_{K\,after} = \frac{1}{2}mv^2 = \frac{1}{2}\times1.5\times10^3\times28.71^2 = 618198.075$

$E_{K\,before} - E_{K\,after} = 82053.777 \approx 80\ \text{kJ}$

E_K = Work done = Fd

$618198.075 = 60\times10^3 d$

$d = 10.3\text{ m}$

0 5 . 4 The steel safety barrier deforms during the collision. For the barrier to pass the test, the test vehicle should not move more than 1.5 m towards the other carriageway.

The barrier can apply an average force of 60 kN at right angles to the carriageway.

Deduce whether the safety barrier will pass the test.

[3 marks]

Barrier will not pass the test

2 1 Small water drops leave a tap with zero velocity at intervals of 0.20 s. They then fall freely 0.80 m to reach a horizontal surface.

How far has a drop fallen when the previous drop hits the surface?

[1 mark]

- **A** 0.16 m ☐
- **B** 0.20 m ☑
- **C** 0.40 m ☐
- **D** 0.60 m ☐

$s =$
$u = 0$
$v =$
$a = 9.81$
$t = 0.2$

$s = ut + \frac{1}{2}at^2$

$s = 4.905(0.2)^2$

$s = 0.1962$

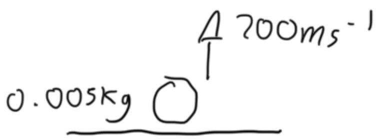
2 2 A pellet with velocity 200 m s^{-1} and mass 5.0 g is fired vertically upwards into a stationary block of mass 95.0 g. The pellet remains in the block. The impact causes the block to move vertically upwards.

What is the maximum vertical displacement of the block?

[1 mark]

- **A** 5.1 m ☐
- **B** 10 m ☐
- **C** 51 m ☐
- **D** 100 m ☑

0.095



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

$= \frac{1}{2}(0.005)(200)^2$

$= 100\text{ J}$

$GPE = (0.005+0.095)\times 9.81h$

$100\text{ J} = 0.981h$

$h = 101.9 \approx 100\text{ m}$

2 3 An electric motor lifts a load of weight W through a vertical height h in time t.
The potential difference across the motor is V and the current in it is I.

What is the efficiency of the motor?

[1 mark]

A $\frac{Wh}{VIt}$ ☑

B $\frac{VI}{Wht}$ ☐

C $\frac{Wht}{VI}$ ☐

D $\frac{VIt}{Wh}$ ☐

efficiency = $\frac{\text{Work done}}{\text{Power in} \times \text{time}}$

$= \frac{Wh}{IVt}$

0 6 Mechanical power

[1 mark]

$W = J/s = \frac{Nm}{s} = kg\,m\,s^{-2} \times m \times s^{-1}$ (watt)

$= kg\,m^2\,s^{-3}$

A is a vector quantity. ✗ ☐

B is measured in J. ✗ ☐

C has base units of $\text{kg m}^2\text{ s}^{-3}$. ☑

D can be calculated from force × distance moved. ✗ ☐

2 8 An object of mass m moves in a circle of radius r. It completes n revolutions every second.

What is the kinetic energy of the object?

[1 mark]

A $\frac{mn^2r^2}{8\pi^2}$ ☐

B $\frac{mn^2r^2}{4\pi^2}$ ☐

C $2m\pi^2n^2r^2$ ☑

D $4m\pi^2n^2r^2$ ☐

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

$v = r\omega = r \times \frac{2\pi}{t}$

$= nr \times 2\pi$

$= 2\pi nr$

$v^2 = 4\pi^2n^2r^2$

$E_K = \frac{1}{2} \times m \times 4\pi^2n^2r^2$

$= 2m\pi^2n^2r^2$

1 9 A load of 50 N is suspended from a wire that has an area of cross-section of 1 mm^2.

The stress in the wire, in Pa, is between

[1 mark]

A 10^0 and 10^3 ☐

B 10^3 and 10^6 ☐

C 10^6 and 10^9 ☑

D 10^9 and 10^{12} ☐

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{50}{1\times10^{-6}} = 5\times10^{7}$$

$$1\,mm^2 = 1\times10^{-6}\,m^2$$