Christ Church Grammar School

Year 12 2021

ATAR PHYSICS
UNIT 3: MOTION AND FORCES
TEST 1 2021

SOLUTIONS

Teacher: CJO JRM PCW
(Please circle)

Time allowed for this paper
Working time for paper: 50 minutes.

Instructions to candidates:

- You must include **all** working to be awarded full marks for a question. Answers should be expressed to 3 significant figures unless otherwise indicated.
- Marks may be deducted if diagrams are not drawn neatly with a ruler and to scale (if specified).
- Marks will be deducted for incorrect or absent units.
- **No** graphics calculators are permitted – scientific calculators only.

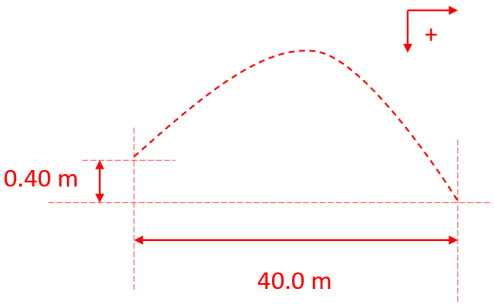
Mark:	/ 52
=	%

Question 1 **(6 marks)**

A boy and his younger brother are standing 40.0 m away from each other on level ground. The boy holds his paintball gun 1.40 m above the ground, and aims it at an angle to hit his brother's chest, 1.00 m above the ground. When he pulls the trigger, the paintball takes 0.640 s to reach his brother.

(a) Calculate the horizontal component of the paintball's velocity.

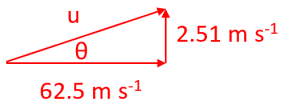
(2 marks)



Description	Marks
$v = \frac{s}{t}$	0.5
$v = \frac{40.0}{0.640}$	0.5
= 62.5 m s^{-1}	1
Total	2

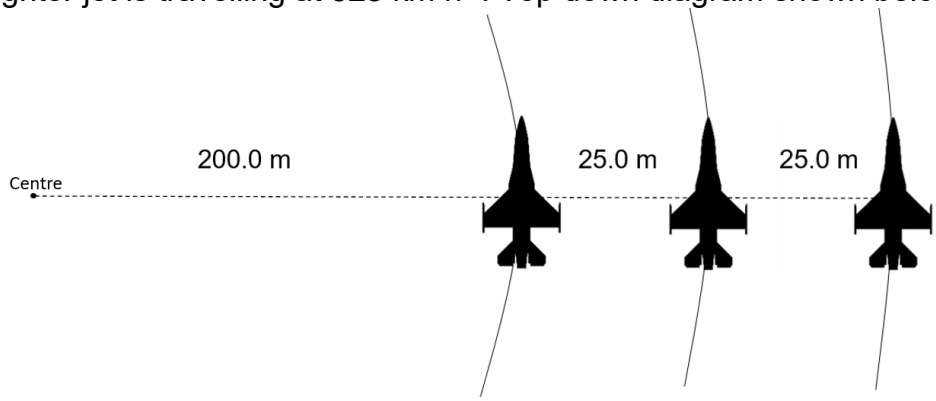
(b) Calculate the angle of the gun that would strike his brother directly on the chest.
(If you could not solve part (a) assume a horizontal velocity of 50.0 m s^{-1})

(4 marks)

Description	Marks
VERTICAL $s = ut + \frac{1}{2}at^2$ $u = \frac{s - \frac{1}{2}at^2}{t}$	1
$u = \frac{0.4 - \frac{1}{2}(9.8)(0.640)^2}{0.640}$	1
= -2.51 m s^{-1}	1
 $\tan\theta = \frac{2.51}{62.5}$ $\theta = 2.30\,°\ above\ horizontal$ (-0.5 if above is not specified) $(2.87\,°\ alternative\ answer)$	1
Total	4

Question 2 **(6 marks)**

Three fighter jets are performing an aeronautics display by flying in formation; completing a horizontal circular path so that they stay in line with each other. The fighter jets are 25.0 m apart and the inside fighter jet is travelling at 528 km h^{-1}. Top down diagram shown below (not to scale).



(a) Calculate the magnitude of the velocity of the middle pilot.

(3 marks)

Description	Marks
$T = \frac{2\pi r}{v}$ *Where T is a constant for all* $\frac{r_1}{v_1} = \frac{r_2}{v_2}$	1
$v_2 = \frac{r_2 v_1}{r_1}$ $v_2 = \frac{225(528)}{200}$	1
$v = 165\ m\ s^{-1} = 594\ km\ h^{-1}$	1
Total	3
note: If student calculates 156 m s^{-1}, they have equated a_c = constant = max 1 mark.	

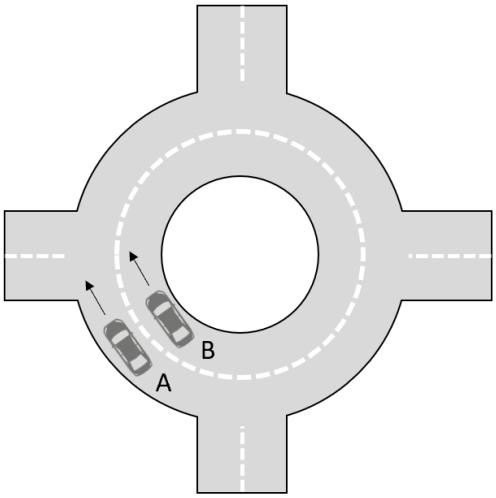
(b) Calculate the ratio of the lateral acceleration experienced by the inside pilot compared to the outside pilot.

(3 marks)

Description	Marks
$a = \frac{v^2}{r}$ *and* $v_O = \frac{r_O v_i}{r_i}$	1
$a_O = \frac{v_i^2\, r_O^2}{r_O\, r_i^2} = \frac{v_i^2 r_O}{r_i^2}$ $a_i = \frac{v_i^2}{r_i}$ Ratio = $\frac{v_i^2 r_O}{r_i^2} : \frac{v_i^2}{r_i}$	1
$\frac{r_O}{r_i} : 1$ $\frac{250}{200} : 1$ $1.25 : 1$	1
Total	3

Question 3 **(10 marks)**

In constructing roundabouts, the maximum safe horizontal force (supplied by friction) allowed by the Department of Mains Roads is 0.750 times the weight of the car travelling around it. Consider a proposed dual lane roundabout below.



(a) Calculate the minimum radius of curvature for the dual lane roundabout if the speed limit is 40.0 km h^{-1}.

(4 marks)

Description	Marks
$F_{c\,MAX} = 0.750\,mg$	1
$F_{c\,MAX} = \frac{mv^2}{r_{min}}$ $0.750\,mg = \frac{mv^2}{r_{min}}$	1
$r = \frac{v^2}{0.750\,g}$	1
$r = \frac{(40/3.6)^2}{0.750\,(9.8)}$ = 16.8 m	1
Total	4

(b) Comment on the speeds that the cars could safely travel at in the outer lane compared to the inner lane.

(3 marks)

Description	Marks
$F_c = \frac{mv^2}{r}$, therefore for a fixed Fc and mass, $\frac{v^2}{r}$ is a fixed ratio	1
If the radius of turn increases, v^2 increases proportionally	1
The outer lane has a larger radius and therefore car A can travel faster than car B safely	1
Total	3

(c) A 1250 kg super car can create 35,100 N of lateral force due to friction. Calculate the maximum speed (expressed in km h^{-1}) it could theoretically travel around the inner lane. (If you could not complete part (a), use r = 18.0 m)

(3 marks)

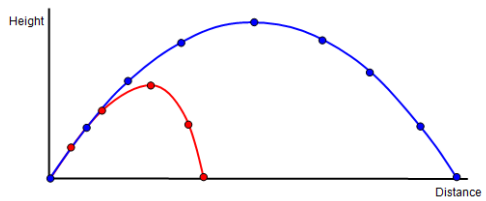
Description	Marks
$F_c = \frac{mv^2}{r}$ $v = \sqrt{\frac{rF_c}{m}}$	1
$v = \sqrt{\frac{16.8(35,100)}{1250}}$ $v = 21.7\ m\ s^{-1}$ (Alternative answer: 22.5 m s^{-1})	1
$v = 21.7\ (3.6)$ $v = 78.1\ km\ h^{-1}$ (Alternative answer: 81.0 km h^{-1})	1
Total	3

Question 4 **(4 marks)**

An idealised projectile that is launched and lands at the same level will spend the same amount of time travelling up and down, and its trajectory will form a perfectly parabolic shape. Describe and briefly explain the differences in trajectory of a real projectile, subject to the effects of air resistance.

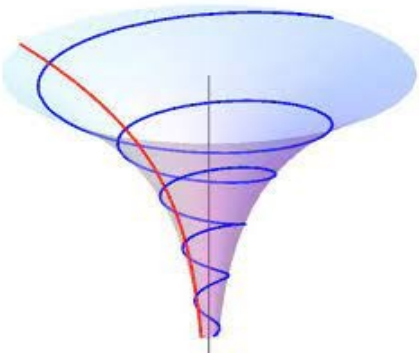
You must address:

- Time of flight up and down
- Horizontal range
- Shape of the trajectory

Description	Marks
Air resistance is a retarding force that always acts in the opposite direction of motion, hence slowing the object down. As a result:	1
• Time of flight up is shorter, time of flight down is longer	1
• Horizontal range is decreased	1
• Asymmetrical curve, steeper on the decline, lower peak (reasonable description of red curve) 	1
Total	4

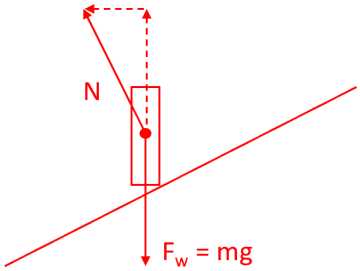
Question 5 **(8 marks)**

Charities often use a spiral wishing well to ask for coin donations. When a person drops a coin into the slot, the coin will roll around the well in a spiral fashion, gradually reducing its radius until it falls into the central hole. Its trajectory is similar to that shown in the diagram.



(a) Draw a side view free body diagram of the coin at any point during its spiralling motion, assuming the well is frictionless.

(2 marks)



Description	Marks
Correct two forces shown, in correct directions	1
Vectors have arrow heads, are labelled and are shown coming from a central point on shape	1
Total	2

(b) With reference to an equation of circular motion and the free body diagram above, explain why the radius of curvature of the coin decreases over time. (You may ignore the vertical component of its trajectory for the purposes of explanation)

(2 marks)

Description	Marks
To maintain a fixed radius, a component of the Normal force must provide a centripetal force equal to $F_C = \frac{mv^2}{r}$ (horizontal component shown on FBD)	1
The normal force must be providing more force than $\frac{mv^2}{r}$, hence accelerating the coin inwards and reducing the radius.	1
Total	2

(c) Explain your answer to part (b) with reference to Newton's 1st and 2nd Law.

(4 marks)

Description	Marks
According to Newton's 2nd law, an object will accelerate in the direction of an unbalanced force acting upon it (F=ma)	1
The horizontal component of the normal force is an unbalanced force which causes the coin to accelerate towards the centre of the well	1
Newton's first law states that an object with mass will continue moving in its current state of motion unless an unbalanced force acts upon it. The coin has mass therefore inertia.	
As a result, the coin will continue moving tangentially to the force, as it already had a substantial initial velocity. This tangential motion combined with the accelerating force inwards causes a spiraling path of reducing radius.	1
Total	4

Question 6 **(6 marks)**

The Gravitron, pictured below, is a popular fairground ride in which passengers are spun around horizontally in a cylinder shaped ride and feel as though they are "pushed" into the vertical walls of the spinning "room".

The ride spins at 30.0 rpm and the coefficient of friction of people on the walls is μ = 0.240, where frictional force $F_f = \mu N$.

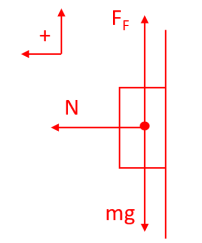
(a) Calculate the tangential speed at the walls in terms of 'r' (in m s^{-1})

(2 marks)

Description	Marks
$speed = \frac{distance}{time}$ $v = \frac{30\ (2\pi r)}{60}$	1
$v = \pi r$ $v = 3.14r\ m\ s^{-1}$ (Accept symbol or decimal answer but must have units)	1
Total	2

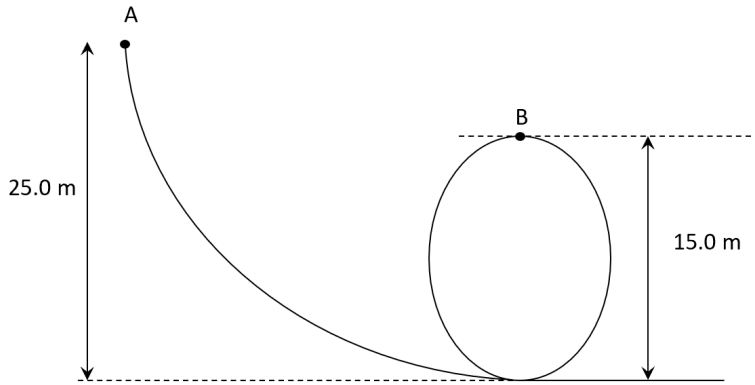
(b) Calculate the minimum radius of the spinning 'room' to ensure there is no downwards slippage of the passengers during the ride, allowing them to "defy gravity".

(4 marks)

Description	Marks
$\sum F_y = 0$ $F_F = mg$ $\mu N = mg$ $N = \frac{mg}{\mu}$ Equation 1 	1
$F_c = \frac{mv^2}{r} = \frac{m(\pi r)^2}{r}$ $N = m\pi^2 r$	1
Subbing in Equation 1 $\frac{mg}{\mu} = m\pi^2 r$ $r = \frac{g}{\mu\pi^2}$	1
$r = \frac{9.80}{0.240\ \pi^2}$ $r = 4.14\ m$	1
Total	4

Question 7 **(6 marks)**

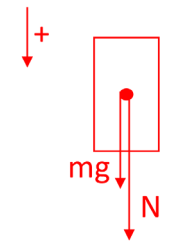
A passenger of mass 90.0 kg is sitting in a rollercoaster cart which is released from rest from a ramp at Point A at a height of 25.0 m above ground level. The cart then completes a vertical loop. Assume the rollercoaster is subject to the forces of gravity only and friction is negligible.



(a) Calculate the speed of the cart at the top of the loop, point B, 15.0 m above the ground.
(3 marks)

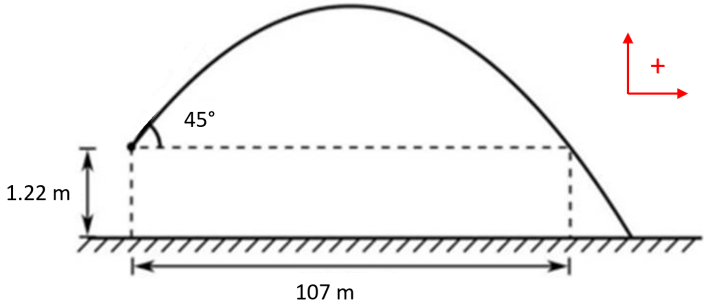
Description	Marks
$E_A = E_B$ $mgh_A = mgh_B + \frac{1}{2}mv^2$	1
$v = \sqrt{2g\Delta h}$ $v = \sqrt{2(9.80)(10)}$	1
$v = 14.0\ m\ s^{-1}$	1
Total	3

(b) Calculate the apparent mass of the passenger at Point B. (If you could not answer part (a) use v = 13.5 m s^{-1})
(3 marks)

Description	Marks
$\sum F = mg + N$ $\frac{mv^2}{r} = mg + N$ $N = \frac{mv^2}{r} - mg$ 	1
$N = 90.0(\frac{14.0^2}{(15.0/2)} - 9.80)$ $N = 1470\ N$	1
$Apparent\ Mass = \frac{N}{g}$ m = 1470/9.80 = 150 kg = 1.50 x 10^2 kg (Alternative answer: 133 kg)	1
Total	3

Question 8 **(6 marks)**

A batsman hits a ball at a height of 1.22 m above the ground so that the ball leaves the bat an angle of 45.0° with the horizontal. A 7.31 m high wall is situated at a distance of 97.5 m from the position of the batsman. If there were no wall, then the ball would be 107 m away when it is again at a height of 1.22 m. Prove through calculation whether the ball will clear the wall.



Description	Marks
Analyses Horizontal Component $v = \frac{s}{t}$ $t = \frac{107}{u\,sin(45)}$ - Equation A ALTERNATIVE METHODS ACCEPTABLE	1
Analyses Vertical Component $s = ut + \frac{1}{2}at^2$ $0 = u\sin(45) + \frac{1}{2}(-9.80)t$ $t = \frac{u\sin(45)}{4.90}$ - Equation B	1
Solves for initial speed t is the same, hence Equation A = Equation B $\frac{107}{u\,sin(45)} = \frac{u\sin(45)}{4.90}$ $u^2 = \frac{107(4.90)}{sin^2(45)}$ $u = 32.3\ m\ s^{-1}$ $u\sin(45) = 22.8\ m\ s^{-1}$	2
Analyses Horizontal Component When s = 97.5 m $t = \frac{s}{v}$ $t = \frac{97.5}{22.8} = 4.28\ s$	1
Analyses Vertical Component $s = ut + \frac{1}{2}at^2$ $s = (22.8)(4.28) + \frac{1}{2}(-9.80)(4.28)^2 = 7.82\ m$ Height = 1.22 + 7.82 = 9.02 m. 9.02 > 7.31 m therefore yes, ball will clear the wall.	1
Total	6

END OF TEST