QUESTION FIVE: THE PENDULUM (8 marks)

ASSESSOR'S USE ONLY

A pendulum bob (mass M) is released from the horizontal position shown in the diagram ($\theta = 0°$) and swings down to the vertical position ($\theta = 90°$).

(a) Explain why the motion of this pendulum will not be a simple harmonic motion.

(b) Show that the tension in the cord (which was originally zero) has increased to $3Mg$, as the bob passes through the lowest point.

ASSESSOR'S USE ONLY

(c) The pendulum cord is replaced with a thinner string, and is again released from rest when $\theta = 0°$.

If the string breaks when the tension is twice the weight of the bob, at what angle does it break?

(d) The bob of a pendulum is given a positive charge and oscillates with a small amplitude above a large, earthed, metal plate.

Explain how the period differs from the case where the metal plate is absent.

(8)

QUESTION SIX: COLLISIONS (8 marks)

ASSESSOR'S USE ONLY

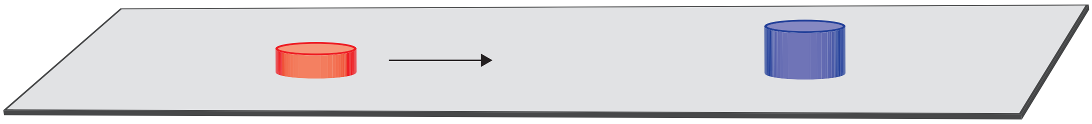
A red puck of mass 2.0×10^{-3} kg is set moving along a long, frictionless track towards a blue puck of mass 4.0×10^{-3} kg. The red puck has a velocity of 21 m s^{-1}, while the blue puck is at rest, but free to move. Both pucks carry a positive charge of 1.5×10^{-6} C. The pucks meet along the line of their centre of mass in an elastic interaction.

The charges cause an electrostatic force between the two pucks.

When they are separated by a distance r, the repulsive force is given by $F = \dfrac{kQ_1Q_2}{r^2}$.

The electric potential energy is given by $E_p = \dfrac{kQ_1Q_2}{r}$.

Q_1 and Q_2 are the two charges and k is a constant ($= 9.0 \times 10^9$ N m^2 C^{-1}).



- 2.0×10^{-3} kg
- 21 m s^{-1}
- +1.5 μC

- 4.0×10^{-3} kg
- +1.5 μC

(a) Describe (without calculations) the motion of each puck as it interacts with the other.

(b) At the instant of closest approach, both pucks have the same velocity.

Explain why this is so, and show that the velocity is 7.0 m s^{-1}.

(c) If the pucks are initially 10 m apart, show that the electrostatic potential energy at this separation is negligible compared with the kinetic energy of the moving puck.

(d) By considering the kinetic and electrostatic energies, calculate the distance of closest approach.

(e) Calculate the final velocities of the pucks (when they are a long distance apart).

ASSESSOR'S USE ONLY

(8)

<table>
<tr><th>Question</th><th>Evidence</th><th>1-4 marks</th><th>5-6 marks</th><th>7-8 marks</th></tr>
<tr><td>FIVE
(a)</td><td>At large angles (> 10º) there is no longer a linear relationship between the displacement and the restoring force.</td>
<td rowspan="4">Thorough understanding of these applications of physics.

OR

Partially correct mathematical solution to the given problems.

AND / OR

Partial understanding of these applications of physics.</td>
<td rowspan="4">(Partially) correct mathematical solution to the given problems.

AND / OR

Reasonably thorough understanding of these applications of physics.</td>
<td rowspan="4">Correct mathematical solution to the given problems.

AND

Thorough understanding of these applications of physics.</td></tr>
<tr><td>(b)</td><td>$F_{NET} = F_{TENSION} - F_{GRAVITY}$
At the bottom, Tension = $Mg + \dfrac{Mv^2}{r}$
Height energy lost = Mgr = KE gained = $\dfrac{Mv^2}{2}$
Therefore $2gr = v^2$
Tension = $Mg + \dfrac{2Mgr}{r} = 3Mg$</td></tr>
<tr><td>(c)</td><td>$T = mg\sin\theta + \dfrac{mv^2}{r}$
Height lost is $r \sin \theta$
Energy lost $= mgr\sin\theta = \dfrac{1}{2}mv^2$
So centripetal force $\left(\dfrac{mv^2}{r}\right) = 2mg\sin\theta$

Gives $T = 2\,m\,g = 2mg \sin \theta$ {the centripetal component} + $mg \sin \theta$ {the weight component}

Cancel and get $\sin \theta = 2/3$

$\theta = 41.8°$</td></tr>
<tr><td>(d)</td><td>The positive bob will induce a negative charge on the metal plate. This will increase the downward force acting on the bob. The net effect of this is that the restoring force is increased. This leads to a reduction in the period.</td></tr>
</table>

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
SIX (a)	As the 2 g red puck approaches, electrostatic repulsion will cause it to slow down and the 4 g blue puck to start moving. The 4 g will accelerate in the original direction and the 2 g will stop and recoil in the opposite direction.	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND/OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)	At closest approach, the relative velocity of the pucks must be zero. So both will have the same velocity with respect to the track. Conservation of momentum $m_{2g}v_{2g} = (m_{2g} + m_{4g})v_c$ $v_c = 42 / 6 = 7\ \text{m s}^{-1}$			
(c)	At 10 m, the electrostatic potential energy is $\dfrac{kQQ}{r} = 9\times10^{9}\times\dfrac{(1.5\times10^{-6})^2}{10} = 2.02\times10^{-3}\ \text{J}$ Kinetic energy is $\dfrac{1}{2}\times2\times10^{-3}\times21^2 = 441\times10^{-3}\ \text{J}$			
(d)	Total energy is conserved. Original KE = KE_{2g} at closest + KE_{4g} at closest + electric potential energy $\dfrac{1}{2}\times2\times10^{-3}\times21^2 = \left(\dfrac{1}{2}\times2\times10^{-3}\times7^2\right)$ $+\left(\dfrac{1}{2}\times4\times10^{-3}\times7^2\right)+\dfrac{1.5\times10^{-6}\times1.5\times10^{-6}\times9\times10^{9}}{d}$ $(441-49-98)\times10^{-3} = 0.294 = \dfrac{0.02025}{d}$ $d = 0.069\,\text{m}$			
(e)	The collision is elastic $2\times21 = 2v_R + 4v_B$ (conservation of momentum) $\tfrac{1}{2}\times2\times21^2 = \tfrac{1}{2}\times2\times{v_R}^2 + \tfrac{1}{2}\times4\times{v_B}^2$ (conservation of kinetic energy) (and taking the original electric PE as zero) From 1st equation: $2v_R = 2\times21 - 4v_B \Rightarrow 4{v_R}^2 = (2\times21-4v_B)^2$ Using 2nd: $2\times21^2 = \dfrac{(2\times21-4v_B)^2}{2} + 8{v_B}^2$ $2\times2\times21^2 = (2\times21)^2 - 336v_B + 16{v_B}^2 + 8{v_B}^2$ $336v_B = 24{v_B}^2$ $v_{Blue} = 14\,\text{m s}^{-1}$ $v_{Red} = -7\,\text{m s}^{-1}$			