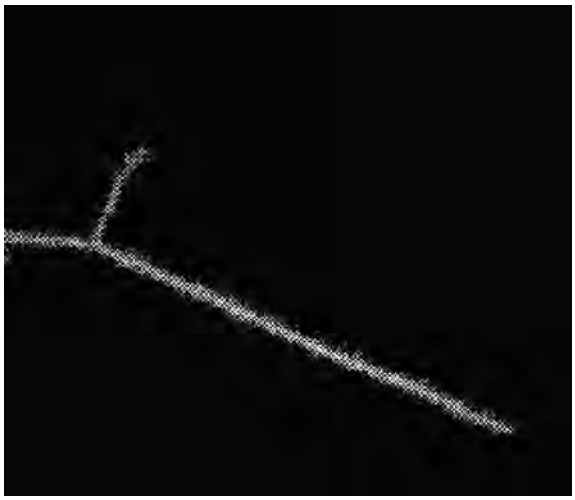
1 A low-energy particle collides elastically with a stationary particle of the same mass. The particle enters from the left of the photograph.



(a) State what is meant by collides *elastically*.

(1)

(b) Sketch a labelled vector diagram to show how the momentum of the initial moving particle relates to the momenta of the two particles after the collision.

(2)

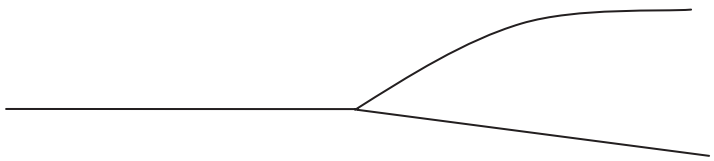
(c) Use your answers to (a) and (b) to confirm that the angle between the subsequent paths of both particles must be 90°.

(2)

(d) (i) Explain the process by which a proton is given energy in a particle accelerator.

(3)

The diagram shows a collision between a high-energy proton (track from the left) and a stationary proton in a particle accelerator experiment.



(ii) Explain why the angle between the two paths is not 90°.

(2)

(e) Deduce the direction of the magnetic field in this particle accelerator experiment. Circle the correct direction from those given below.

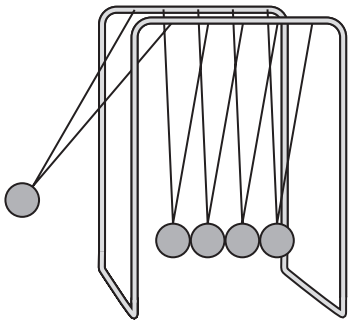
(1)

left to right across the paper out of the plane of the paper into the plane of the paper

(Total for Question = 11 marks)

2 A student is using a 'Newton's Cradle'. This consists of a set of identical solid metal balls hanging by threads from a frame so that they are in contact with each other.

She initially pulls one ball to the side as shown.



She releases the ball, it collides with the nearest stationary ball and stops. The ball furthest to the right immediately moves away. The middle three balls remain stationary.

*(a) Explain what measurements the student would take and describe how she would use them to investigate whether momentum had been conserved in this event.

(4)

(b) The student makes the following observations:

- the ball on the right returns and collides with a similar result; this repeats itself a number of times
- after a while, the middle balls are also moving
- shortly afterwards, the balls all come to rest.

Discuss these observations in terms of energy.

(3)

(Total for Question 7 marks)

***3** In 2012 Neil Armstrong, the first man to step on the moon during the Apollo 11 lunar mission, died at the age of 82.

During this mission, a planned explosion caused the separation of the module in which Armstrong was travelling and the final-stage rocket. This explosion resulted in an increase in the speed of the module.

Discuss how the conservation of momentum and the conservation of energy apply to this situation.

(5)

(Total for Question = 5 marks)

4 In order to make an object move around a circular path at a constant speed a resultant force must act on it.

(a) Explain why a resultant force is required and state the direction of this force.

(2)

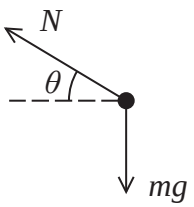
(b) When vehicles move around a bend on a level road, the resultant force is provided by friction between the tyres and the road. For a given vehicle and road surface there is a maximum value for this sideways frictional force.

Explain why roads designed for high-speed travel, such as motorways, do not have any sharp bends.

(2)

(c) Some cycling tracks are banked. When cornering, a cyclist moves up the track until the sideways frictional force is zero.

The free-body force diagram for a cyclist and bicycle is shown. The normal contact force exerted by the track is N and the weight of cyclist and bicycle is mg.



(i) By considering the vertical and horizontal motion, show that

$$\tan \theta = gr/v^2$$

where r is the radius of the cyclist's path and v is the cyclist's speed.

(3)

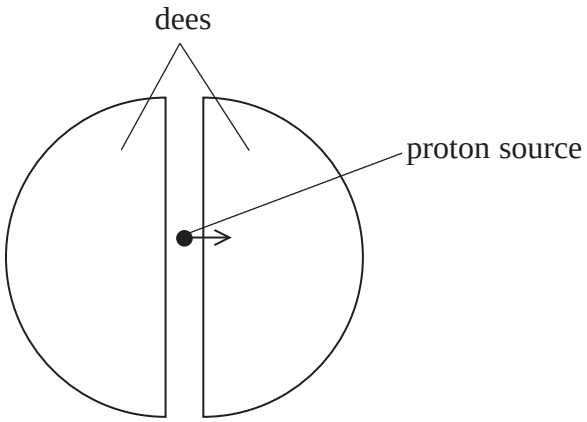
(ii) Calculate the value of θ for a cyclist travelling at 11.0 m s^{-1} around a bend of radius 18.7 m.

(2)

$\theta =$

(Total for Question = 9 marks)

5 (a) A cyclotron is a particle accelerator which can be used to accelerate protons. The cyclotron consists of two semicircular electrodes called 'dees'. An alternating potential difference is applied across the gap between the dees. A uniform magnetic field is applied at right angles to the plane of the dees.



(i) Complete the diagram to show the path of the protons.

(1)

(ii) State the direction of the magnetic field needed in order to produce the path you have sketched.

(1)

(iii) Explain how the kinetic energy of the protons is increased as they follow the path you have shown.

(3)

(iv) Show that the magnetic flux density B of the applied magnetic field is given by

$$B = \frac{2\pi f m}{e}$$

where f is the frequency of the alternating potential difference, m is the mass of the proton and e is the charge on the proton.

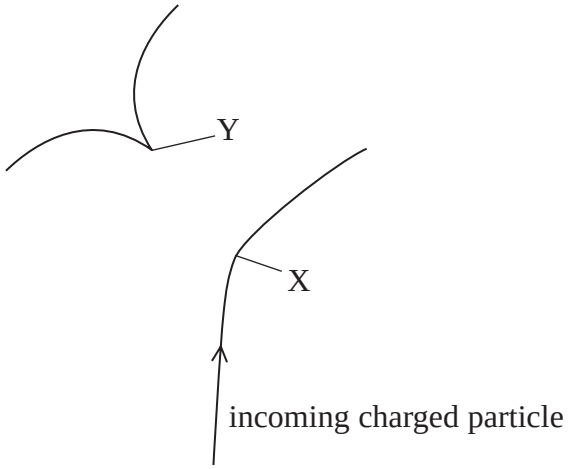
(3)

(v) In a particular cyclotron B is 1.2 mT.
Calculate the frequency f of the alternating potential difference.

(2)

f =

(b) The diagram shows the tracks produced in a bubble chamber.



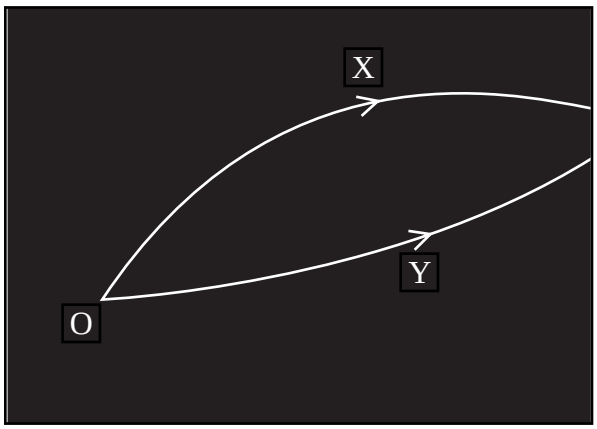
At X an incoming charged particle interacts with a stationary proton.

Describe and explain what can be deduced about the interaction at X and subsequent events. You may add to the diagram to help your answer.

(5)

(Total for Question = 15 marks)

6 A particle detector shows tracks produced by two particles X and Y that were created by the decay of a lambda particle at O.



(i) Which of the following is a valid conclusion from these facts?

☒ **A** X is a negatively charged particle.

☒ **B** Y is a positively charged particle.

☒ **C** The lambda particle is neutral.

☒ **D** The magnetic field is acting into the plane of the paper.

(ii) Which of the following is a correct statement about momentum at the decay?

☒ **A** The vector sum of the momenta of X and Y must equal that of the lambda particle.

☒ **B** The momentum of X is equal to that of Y.

☒ **C** The total momentum of this system is zero.

☒ **D** The vector sum of the momenta of X and Y must equal zero.

(iii) Which of the following is a correct statement about energy at the decay?

☒ **A** The energy of X must be greater than that of Y.

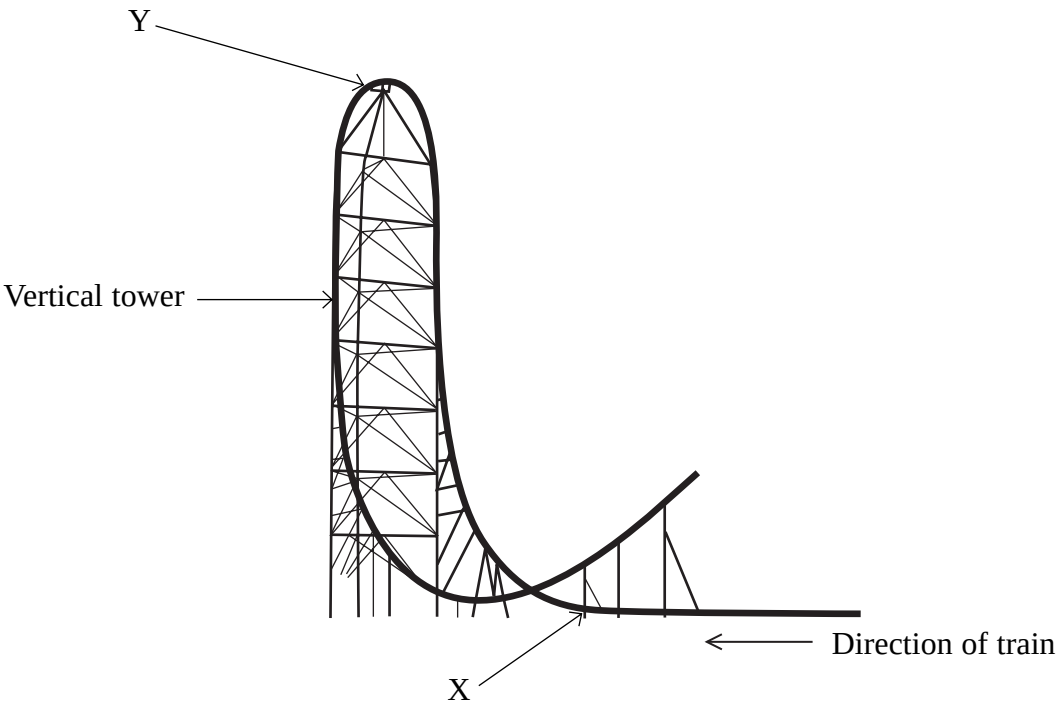
☒ **B** The combined energy of X and Y must be more than the energy of the lambda particle.

☒ **C** The mass of the lambda particle must equal the combined energy of X and Y.

☒ **D** The mass energy of the lambda particle must equal the total energy of X and Y.

(Total for Question = 3 marks)

7 Kingda Ka was the highest roller coaster in the world in 2007. A train is initially propelled along a horizontal track by a hydraulic system. It reaches a speed of 57 m s^{-1} from rest in 3.5 s. It then climbs a vertical tower before falling back towards the ground.



(a) Calculate the average force used to accelerate a fully loaded train along the horizontal track.

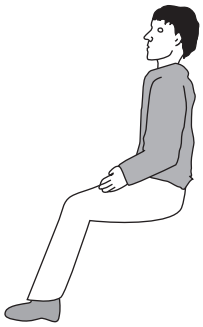
Total mass of fully loaded train = 12 000 kg

(2)

Force =

(b) Point X is just before the train leaves the horizontal track and moves into the first bend. Complete the free-body diagram below to show the two forces acting on a rider in the train at this point.

(3)



(c) The mass of the rider is m and g is the acceleration of free fall. Just after point X, the reaction force of the train on the rider is $4mg$ and can be assumed to be vertical. This is referred to as a g-force of $4g$.
Show that the radius of curvature of the track at this point is about 100 m.

(3)

(d) Show that the speed of the train as it reaches the top of the vertical tower is about 20 m s^{-1}. Assume that resistance forces are negligible.

The height of the vertical tower is 139 m.

(2)

(e) Riders will feel momentarily weightless if the vertical reaction force becomes zero. The track is designed so that this happens at point Y.

Calculate the radius of the track at point Y.

(2)

.....

.....

.....

.....

Radius =

(Total for Question = 12 marks)

***8** Particle accelerators accelerate particles to very high speeds before collisions occur. New particles are created during the collisions.

Two particles of the same type can undergo two kinds of collision.

Fixed target: a high speed particle hits a stationary particle.

Colliding beams: two particles travelling at high speeds, in opposite directions, collide head-on.

By considering the conservation of energy and momentum, explain which type of collision is able to create a new particle with the largest mass.

(6)

(Total for Question = 6 marks)