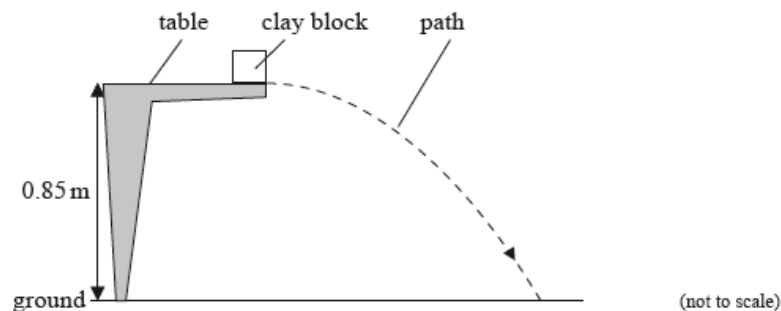


Mechanics motion HL 3 [36 marks]

This question is in **two** parts. **Part 1** is about collisions. **Part 2** is about the gravitational field of Mars.

Part 1 Collisions

The experiment is repeated with the clay block placed at the edge of the table so that it is fired away from the table. The initial speed of the clay block is 4.3 m s^{-1} horizontally. The table surface is 0.85 m above the ground.



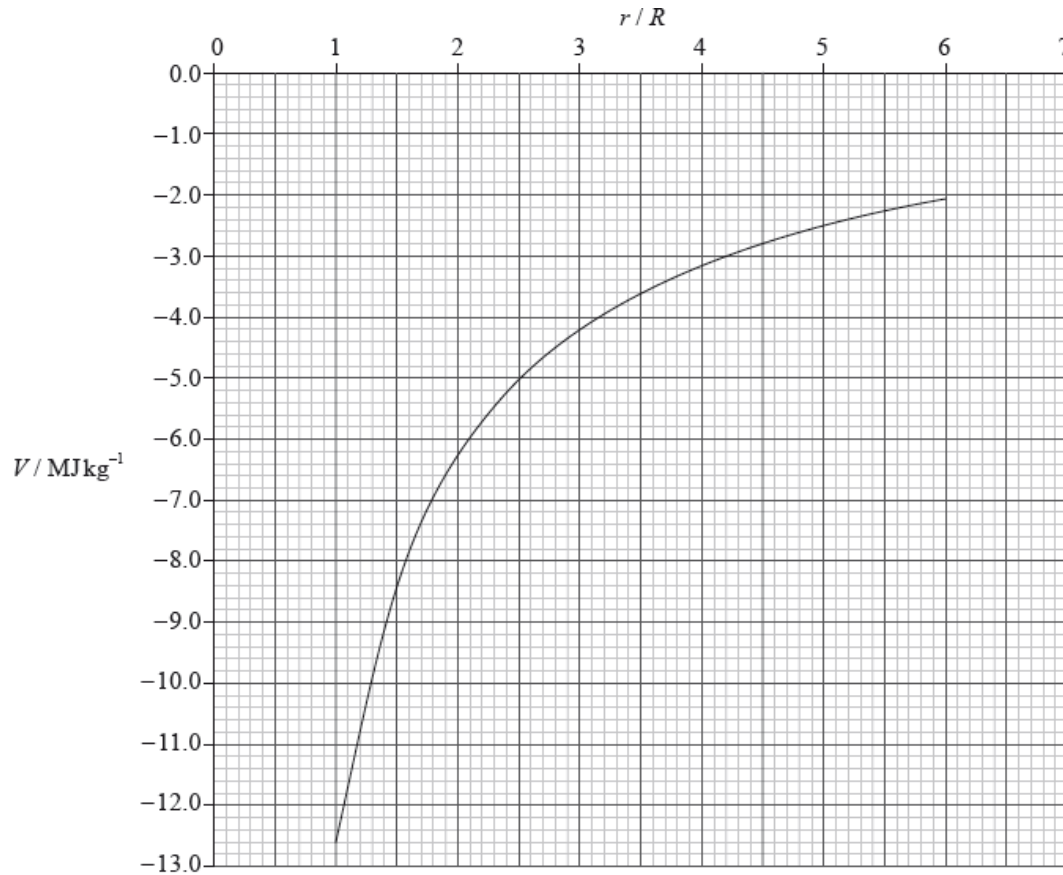
- 1a. (i) Ignoring air resistance, calculate the horizontal distance travelled by [7 marks]
the clay block before it strikes the ground.
- (ii) The diagram in (c) shows the path of the clay block neglecting air resistance.
On the diagram, draw the approximate shape of the path that the clay block will
take assuming that air resistance acts on the clay block.

Part 2 Gravitational field of Mars

- 1b. Define *gravitational potential energy* of a mass at a point.

[1
mark]

The graph shows the variation with distance r from the centre of Mars of the gravitational potential V . R is the radius of Mars which is 3.3 Mm. (Values of V for $r < R$ are not shown.)

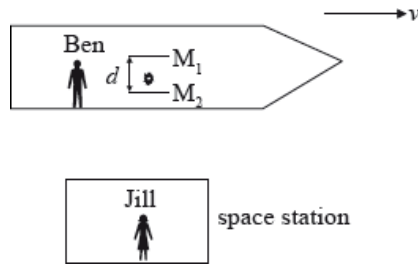


A rocket of mass $1.2 \times 10^4 \text{ kg}$ lifts off from the surface of Mars. Use the graph to

- 1c. (i) calculate the change in gravitational potential energy of the rocket at a distance $4R$ from the centre of Mars. [5 marks]
- (ii) show that the magnitude of the gravitational field strength at a distance $4R$ from the centre of Mars is 0.23 N kg^{-1} .

This question is about a Galilean transformation and time dilation.

Ben is in a spaceship that is travelling in a straight-line with constant speed v as measured by Jill who is in a space station.

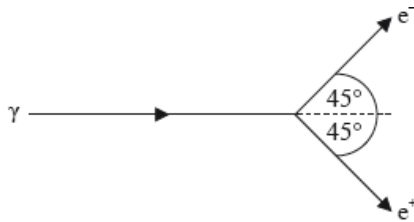


Ben switches on a light pulse that bounces vertically (as observed by Ben) between two horizontal mirrors M_1 and M_2 separated by a distance d . At the instant that the mirrors are opposite Jill, the pulse is just leaving the mirror M_2 . The speed of light in air is c .

2. The questions (e) and (f) introduce the concepts of time dilation and length contraction. Discuss how muon decay in the atmosphere provides experimental evidence for these concepts. [5 marks]

This question is about pair production and relativistic mechanics.

A γ -photon of energy 2.46 MeV is travelling close to the nucleus of a gold atom. It converts into an electron (e^-) – positron (e^+) pair. Each particle travels at 45° to the original direction of the photon.



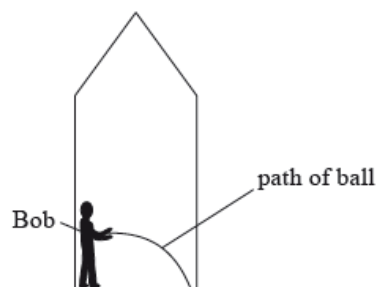
Immediately after the conversion, the kinetic energies of the electron and positron are equal. The magnitude of the recoil momentum of the gold nucleus is $0.880 \text{ MeV } c^{-1}$ and is in the direction of the photon.

- 3a. Calculate, immediately after the decay, the magnitude of the momentum of the electron. [4 marks]

- 3b. Calculate the value V of the potential difference through which an electron at rest must be accelerated in order to have the same magnitude of momentum as that in (a). [2 marks]

This question is about general relativity.

Bob is standing on the floor of a spaceship and he throws a ball in a direction parallel to the floor.



Between leaving Bob's hand and landing on the floor, the ball follows the path shown.

4a. State and explain whether, from the path followed by the ball, Bob can deduce that the spaceship is at rest on the surface of a planet. *[3 marks]*

4b. Outline how the concept of spacetime can be used to explain the *[4 marks]*

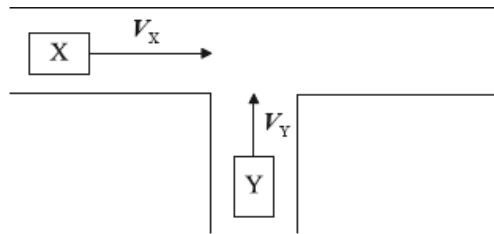
- (i) trajectory of the ball if the spaceship is at rest on the surface of a planet.
- (ii) nature of a black hole.

4c. Calculate the radius that Earth would have to have in order for it to behave as a black hole. The mass of Earth is 6.0×10^{24} kg. *[1 mark]*

5. Which of the following quantities can be determined from a speed-time graph of a particle travelling in a straight line? *[1 mark]*

- A. Only the magnitude of the acceleration at a given instant
- B. Both the velocity and the acceleration at a given instant
- C. Only the distance travelled in a given time
- D. Both the distance travelled in a given time and the magnitude of the acceleration at a given instant

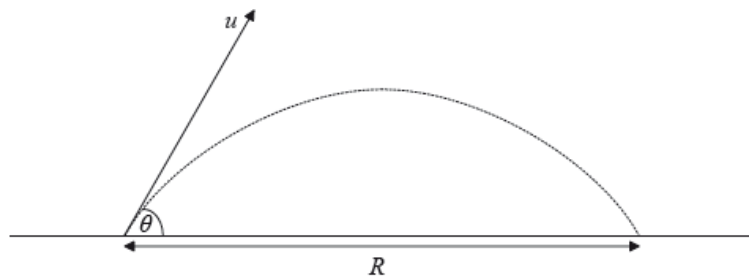
6. Two cars, X and Y, are travelling towards a junction. The velocity of car X is $\mathbf{V}_X$ and car Y is $\mathbf{V}_Y$. [1 mark]



Which of the following vectors represent the velocity of Y relative to X?

- A.  B. 
- C.  D. 

7. A football is kicked with an initial velocity u at an angle θ to the horizontal and reaches the ground t seconds later. [1 mark]



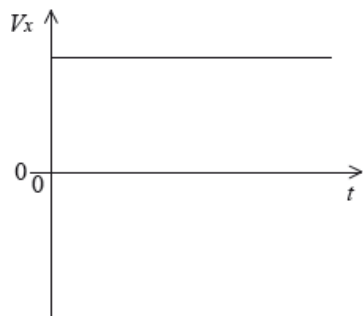
Ignoring air resistance what is the range R of the football?

- A. ut
B. $ut \cos \theta$
C. $ut \sin \theta$
D. $ut \tan \theta$

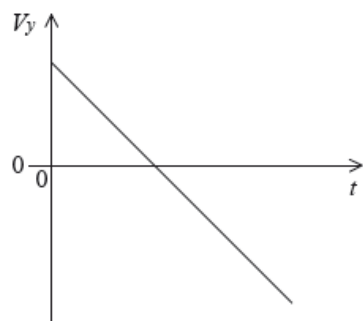
8. An object moves in the x - y plane. The graphs below show how the component of its velocity V_x in the x -direction and the component of its velocity V_y in the y -direction, vary with time t .

[1
mark]

x -direction component



y -direction component



The particle is moving

- A. in a parabola.
- B. with simple harmonic motion.
- C. with constant velocity in a straight line.
- D. in a circle.