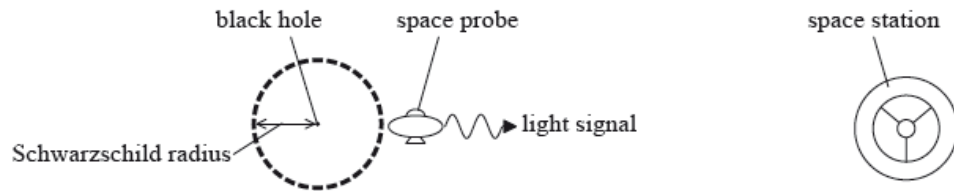


Mechanics motion HL 2 [258 marks]

This question is about black holes.

A space probe is stationary in the gravitational field of a black hole.



The mass of the black hole is 4.5×10^{31} kg. The space probe is emitting a pulse of blue light at a time interval of 1.0 seconds as measured on the space probe. The light is received by an observer on a distant space station that is stationary with respect to the space probe.

- 1a. Explain why the light reaching the space station will be red-shifted. [3 marks]

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins or other markings on the paper.

- 1b. The time between the pulses as measured by the observer on the distant [3 marks]
space station is found to be 1.5 s. Calculate the distance of the space
probe from the black hole.

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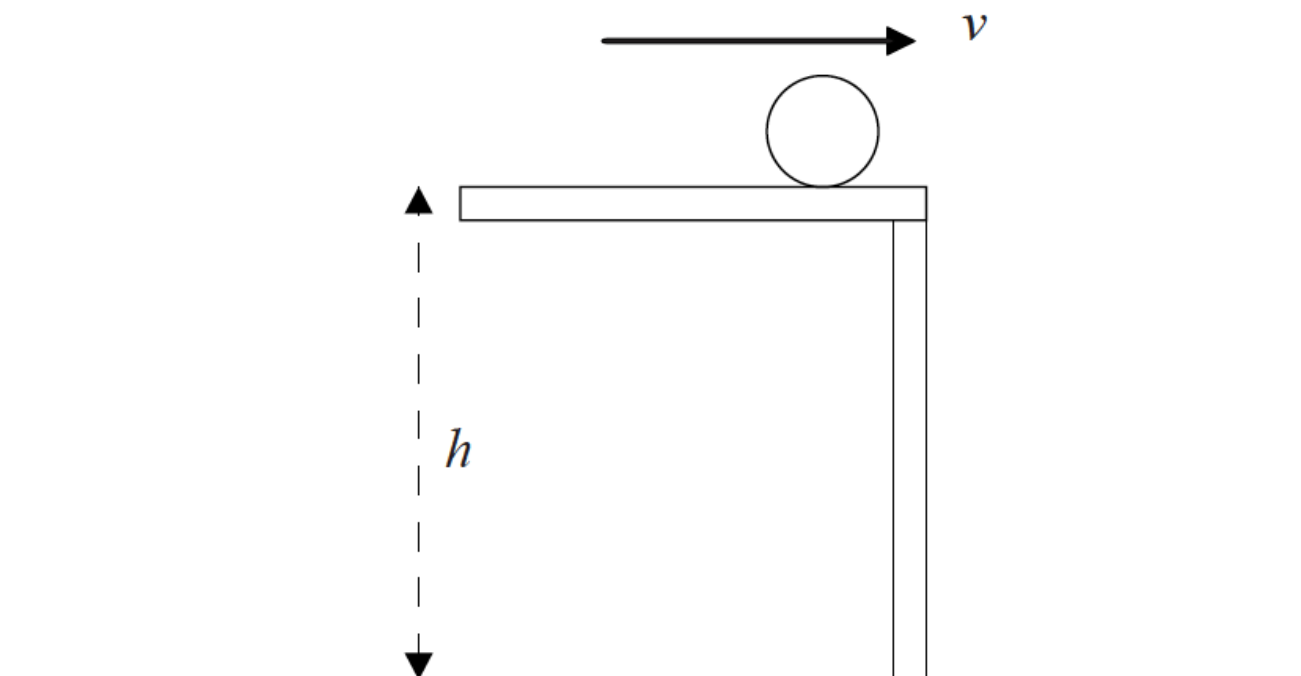
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2. A ball of mass m is projected horizontally with speed v from a height h [1
above the floor. Air resistance is negligible. mark]



The horizontal distance travelled by the ball to the point where it lands on the floor depends on

- A. m and h only.
- B. m and v only.
- C. h and v only.
- D. m , h and v .

3. A projectile is fired from level ground with speed v at an angle θ to the ground. Ignoring air resistance, which of the following is a correct expression for the maximum height reached by the projectile? [1 mark]

A. $\frac{v^2 \sin^2 \theta}{2g}$

B. $\frac{v^2 \cos^2 \theta}{2g}$

C. $\frac{v \sin \theta}{g}$

D. $\frac{v \cos \theta}{g}$

4. This question is about relativistic dynamics. [4 marks]

A proton is accelerated from rest through a potential difference of 2.5 GV. Determine the momentum of the proton after acceleration.

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This question is about general relativity.

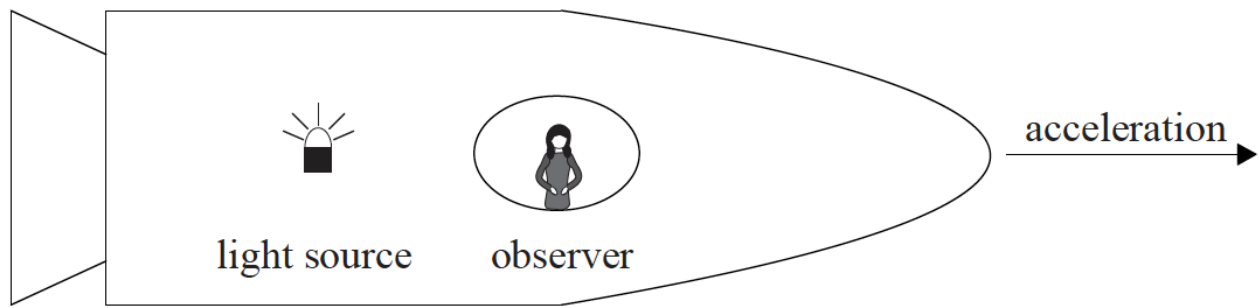
- 5a. State the principle of equivalence. [1 mark]

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- 5b. An observer in a spaceship moving at constant speed measures the frequency f_0 of light emitted by a source. The spaceship now accelerates to the right. [5 marks]



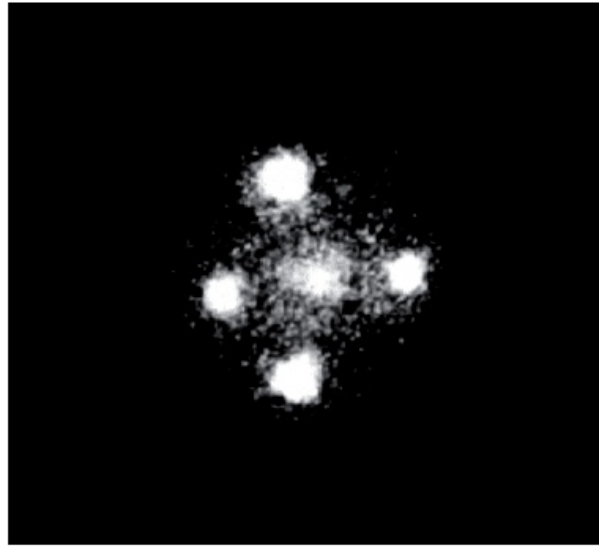
The observed frequency changes to f .

- (i) Outline why, during the acceleration, f is less than f_0 .
(ii) Explain how the result outlined in (b)(i) leads to the deduction that time dilates near a planet.

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins or other markings on the paper.

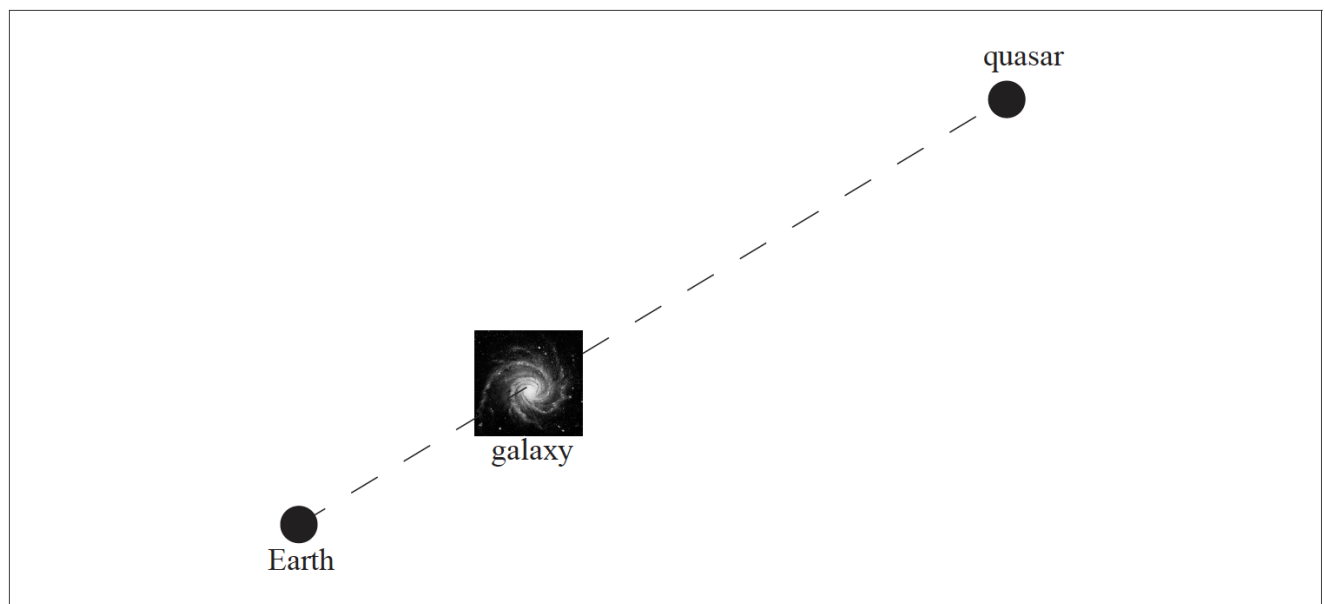
6. This question is about evidence that supports general relativity. [3 marks]

The astronomical photograph taken from Earth shows four separate images of a single distant quasar that appear to surround a galaxy. The galaxy is closer to Earth than the quasar.



[Source: www.hubblesite.org/newscenter/archive/releases/1990/20/image/a/]

Outline how one image of the quasar is formed. You may draw on the diagram below that shows the arrangement of the Earth, the galaxy and the quasar to support your answer.



[Source: adapted from www.sciencephoto.com/media/332699/enlarge]

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A rho meson (ρ) decays at rest in a laboratory into a pion(π^+) and an anti-pion (π^-) according to

$$m_\rho = 770 \text{ MeV c}^{-2}$$

7b. The pion (π^+) emits a muon in the same direction as the velocity of the pion. The speed of the muon is $0.271c$ relative to the pion. Calculate the speed of the muon relative to the laboratory. *[2 marks]*

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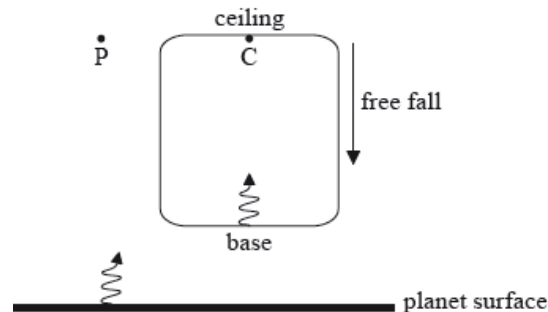
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This question is about general relativity.

The diagram shows monochromatic light of frequency f_0 being emitted from the base of a box towards an observer C at the ceiling of the box. The box is in free fall above the surface of the planet. Light of the same frequency is also emitted from the surface of the planet towards an observer P at rest above the surface of the planet.



The frequency of the light as measured by C is f_C and the frequency of the light as measured by P is f_P .

State and explain whether the frequencies f_C and f_P are less than, equal to or greater than f_0 .

- 8a. (i) f_C
(ii) f_P

[5 marks]

- 8b. Newton explained the motion of a planet around the Sun in terms of a force of gravitation between the Sun and the planet. Describe how Einstein's theory of general relativity explains the motion of the planet around the Sun. *[2 marks]*

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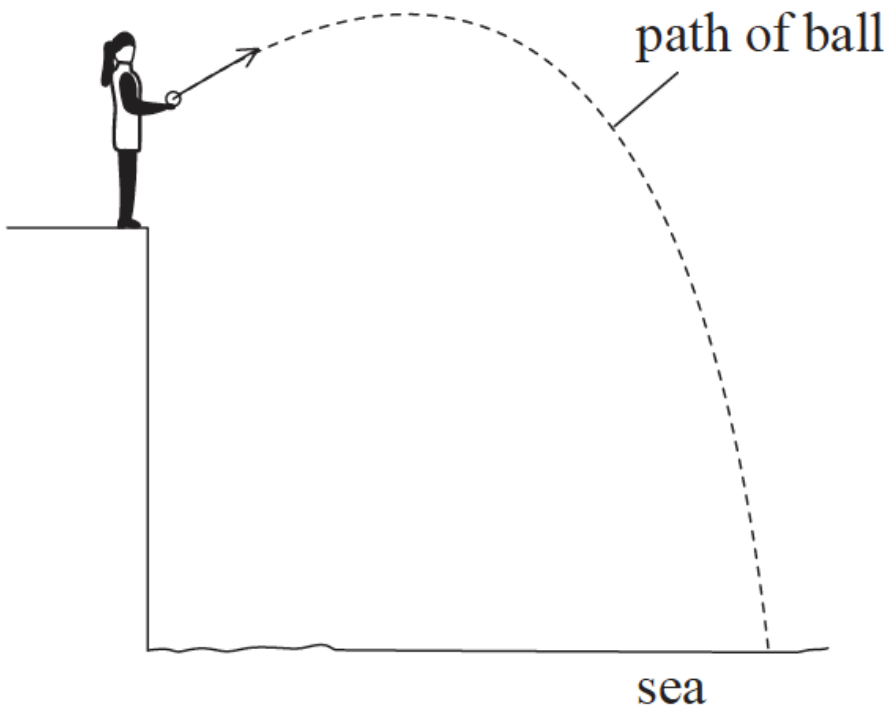
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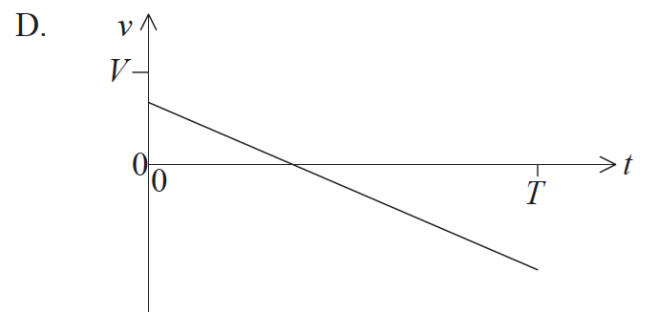
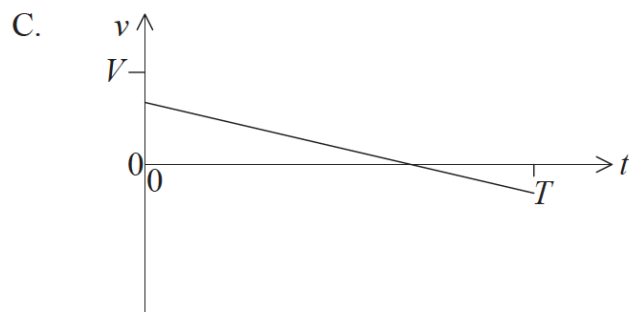
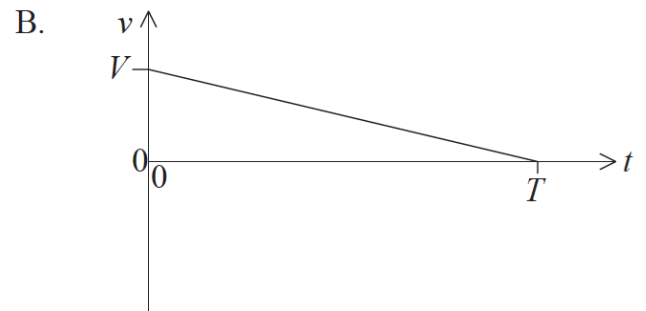
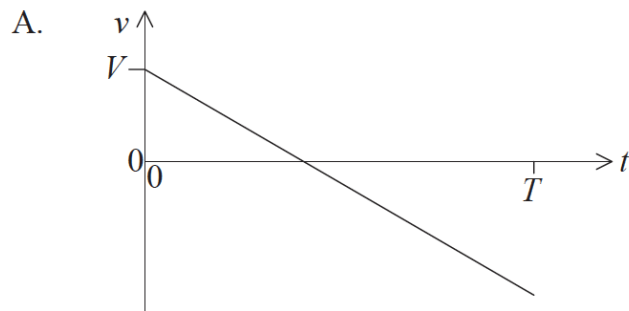
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9. A ball is thrown from the top of a cliff. The initial magnitude of the velocity [1
of the ball at time $t=0$ is V . The ball hits the sea at time $t=T$. Air resistance mark]
is negligible.



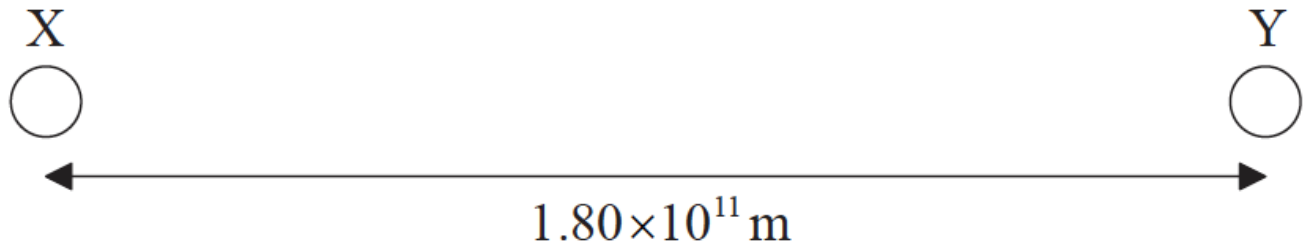
Which graph shows how the **vertical** component of the velocity v of the ball varies with t as it falls to the sea?



This question is about time dilation and relativistic mass.

- 10a. Two space stations X and Y are at rest relative to each other. The separation of X and Y as measured in their frame of reference is $1.80 \times 10^{11} \text{ m}$.

[1
mark]



State what is meant by a frame of reference.

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. A radio signal is sent to both space stations in (a) from a point midway between them. On receipt of the signal a clock in X and a clock in Y are each set to read zero. A spaceship S travels between X and Y at a speed of $0.750c$ as measured by X and Y. In the frame of reference of S, station X passes S at the instant that X's clock is set to zero. A clock in S is also set to zero at this instant. [9 marks]

(i) Calculate the time interval, as measured by the clock in X, that it takes S to travel from X to Y.

(ii) Calculate the time interval, as measured by the clock in S , that it takes S to travel from X to Y .

(iii) Explain whether the clock in X **or** the clock in S measures the proper time.

(iv) Explain why, according to S , the setting of the clock in X and the setting of the clock in Y does not occur simultaneously.

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins or other markings on the paper.

- 10c. Muons are produced in the upper atmosphere of Earth and travel towards [3 marks]
the surface of Earth where they are detected. Explain how, with reference
to the situation described in (b), the production and detection of muons provide
evidence for time dilation.

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This question is about relativistic energy and momentum.

- 11a. A proton is accelerated from rest through a potential difference V . After [3 marks]
acceleration the mass of the proton is equal to four times its rest mass.
Determine the value of V .

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11b. For the proton in (a) calculate, after acceleration, its

[3 marks]

(i) speed.

(ii) momentum.

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12a. Describe what is meant by spacetime.

[2 marks]

12b. Outline how the concept of spacetime accounts for the

[5 marks]

(i) orbiting of Earth about the Sun.

(ii) nature of a black hole.

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13. Two identical balls are dropped from a tall building, one a few seconds after the other. Air resistance is **not** negligible. As the balls fall, the distance between the balls will

[1 mark]

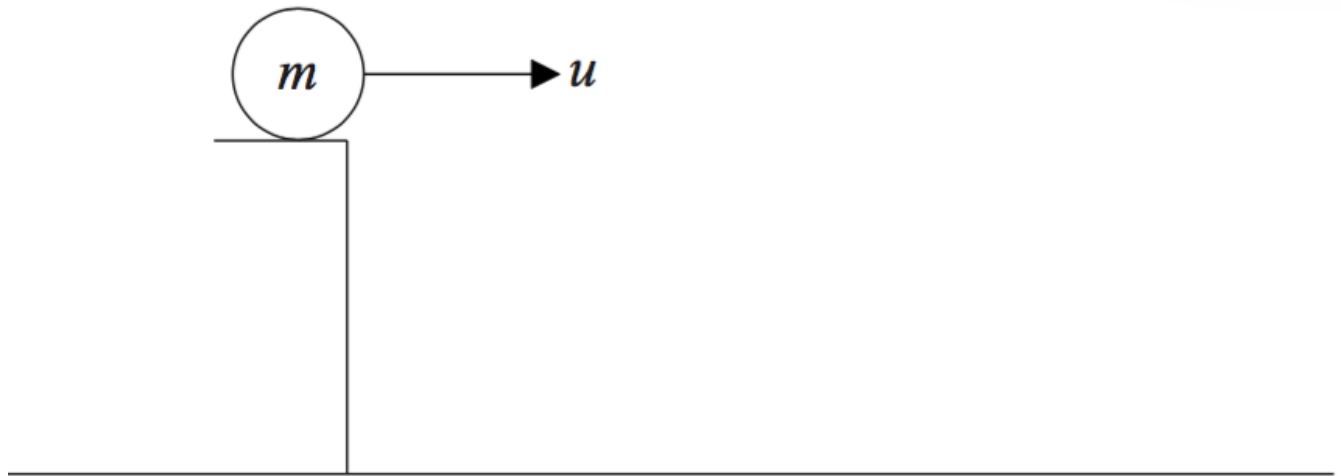
A. decrease.

B. increase.

C. increase then remain constant.

D. remain constant.

14. A ball of mass m is thrown horizontally from a cliff with initial velocity u . Air resistance is negligible. [1 mark]



A change in which of the following will affect the horizontal distance travelled?

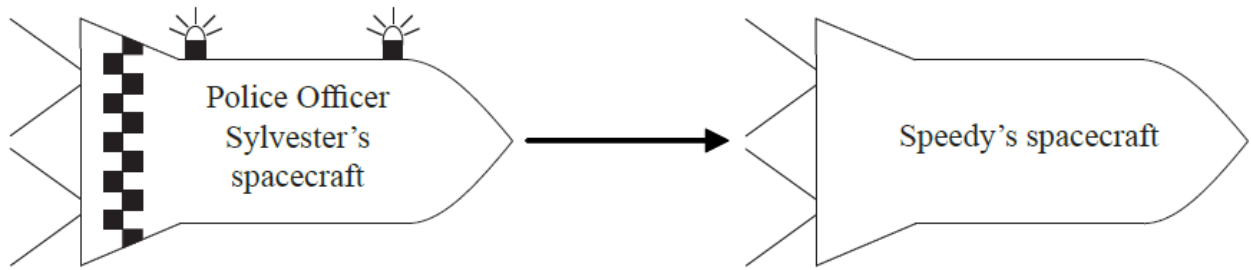
- A. m only
 - B. u only
 - C. both m and u
 - D. neither m nor u
-
15. Which of the following is always true for an object moving in a straight line at constant speed? [1 mark]
- A. No forces act on the object.
 - B. No resultant force acts on the object.
 - C. The momentum of the object is zero.
 - D. No work is being done on the object.

16. An object is thrown horizontally from the edge of a high crater on the Moon. [1 mark]
The Moon has no atmosphere. Which of the following describes the changes, if any, to the horizontal and vertical components of the velocity of the object?

	Horizontal velocity	Vertical velocity
A.	stays constant	increases at a constant rate
B.	decreases	increases at a constant rate
C.	stays constant	increases at a non-constant rate
D.	decreases	increases at a non-constant rate

This question is about relativistic kinematics.

Speedy is in a spacecraft being chased by Police Officer Sylvester. In Officer Sylvester's frame of reference, Speedy is moving directly towards Officer Sylvester at $0.25c$.



17. Officer Sylvester switches on the blue flashing lamps on his police spacecraft. [4 marks]

- (i) Calculate, assuming that a Galilean transformation applies to this situation, the value of the speed of the light that Speedy would measure using the flashing lamps.
- (ii) Speedy measures the speed of the light emitted by the flashing lamps. Deduce, using the relativistic addition of velocities, that Speedy will obtain a value for the speed of light equal to c .

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This question is about relativistic dynamics.

18. A proton is accelerated from rest by a potential difference V and reaches a *[3 marks]* speed of $2.5 \times 10^8 \text{ m s}^{-1}$. Calculate V .

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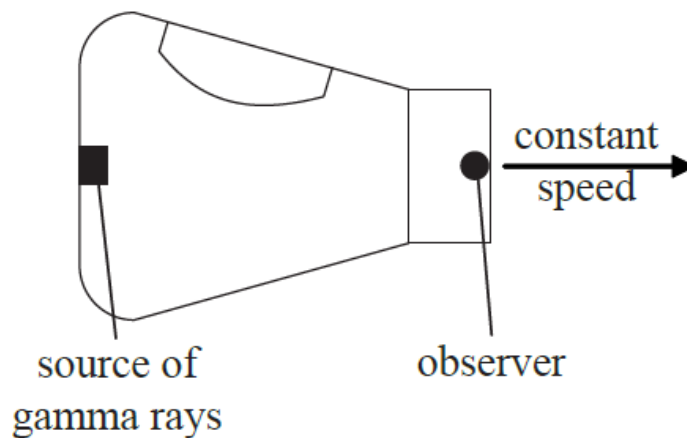
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This question is about gravitational red-shift.

An observer is in a space capsule moving at a constant speed in the absence of gravitational fields.



A monochromatic source of gamma rays is fixed to the rear wall of the capsule. An observer at the other end of the capsule measures the frequency of the gamma rays.

The capsule now starts to decelerate.

- 19a. Deduce the change in the frequency of the gamma rays, as measured by [3 marks] the observer, when the deceleration begins.

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- 19b. Outline, with reference to the principle of equivalence, how the situation [2 marks] in (a) relates to the concept of gravitational red-shift.

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This question is about spacetime.

20. Explain, with reference to the warping of spacetime, the gravitational attraction between Earth and the Sun. *[3 marks]*

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This question is about black holes.

21. Sirius B has a mass of 2.0×10^{30} kg. *[2 marks]*

Calculate the minimum density required for Sirius B to become a black hole in the future.

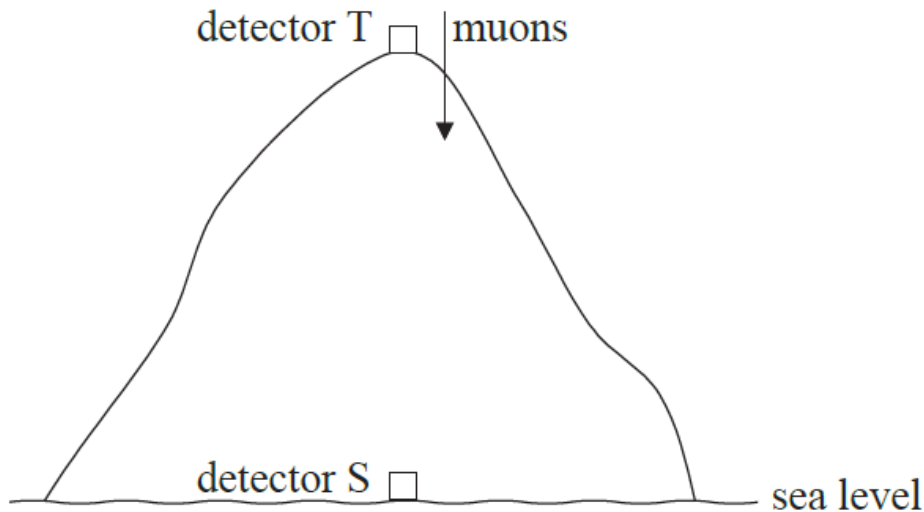
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This question is about muon decay experiments.

Muons created high in the atmosphere move vertically down towards the surface of Earth. A muon detector T is placed on top of a mountain and another, detector S, is placed at sea level.



Detector T detects 570 muons per hour. In the rest frame of the muons their half-life is $1.5 \mu\text{s}$. According to an observer, at rest on the mountain, the muons take $6.0 \mu\text{s}$ to travel from detector T to detector S.

22a. Show that, if the muons move at non-relativistic speed, the number of muons detected at sea level would be approximately 36 per hour. [2 marks]

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22b. The muons in (a) move toward the surface of Earth with a relativistic speed of $0.968c$. [4 marks]

(i) Determine the half-life of the muons according to the observer at rest on the mountain.

(ii) The number of muons observed at detector S is 285 per hour. Explain, using your answers to (a) and (b)(i), how this observation provides evidence for time dilation.

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This question is about relativistic mechanics.

A proton, after acceleration from rest through a potential difference V , has momentum 1600MeVc^{-1} .

23. Calculate the value of V . [3 marks]

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24. Calculate the speed of the proton after acceleration.

[2 marks]

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This question is about general relativity.

25a. State the equivalence principle.

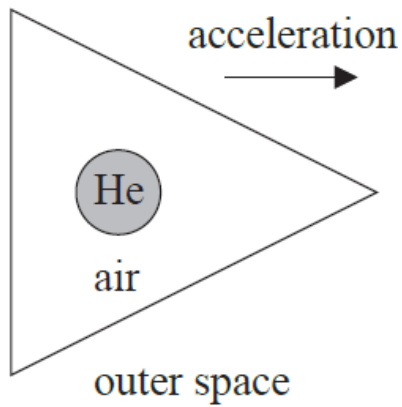
[2 marks]

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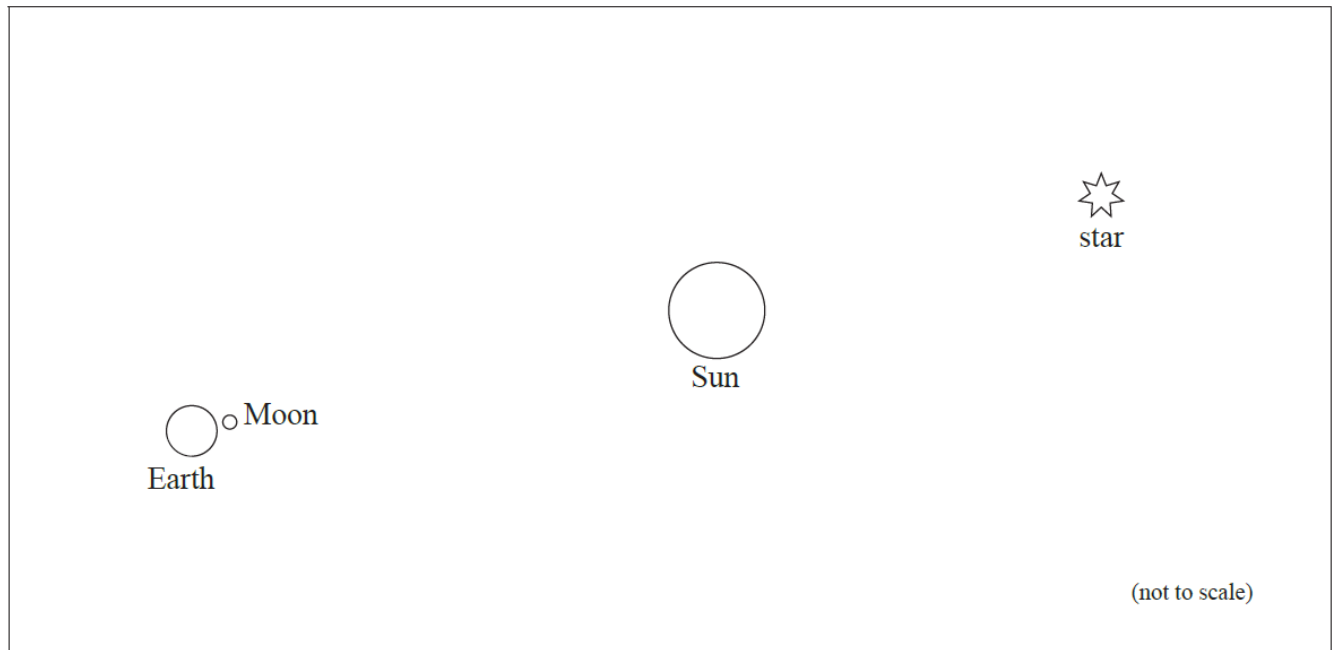
25b. A helium filled balloon is floating in air inside a spacecraft in outer space. [3 marks]
The spacecraft begins to accelerate to the right.



Explain, with reference to the equivalence principle, the motion, if any, of the helium balloon relative to the spacecraft.

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25c. In an experiment, to verify the bending of light as it passes close to the Sun, the position of a star was measured during a total solar eclipse. [5 marks]



- (i) Explain why the measurement of the star's position was made during a total solar eclipse.
- (ii) On the diagram above, draw lines to determine the apparent position of the star as seen from Earth.
- (iii) State what other measurement must be made in order to determine the angle by which rays from the star are bent by the Sun.
- (iv) The angle of bending of a light ray from the star that just grazes the Sun's surface is θ . State and explain the effect, if any, on θ if the Sun were to be replaced by another star of equal radius but larger mass.

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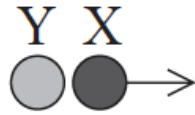
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26. Balls X and Y are at the same height. X is projected horizontally at the same time that Y is dropped. Y is the same size as X but has half its mass. [1 mark]



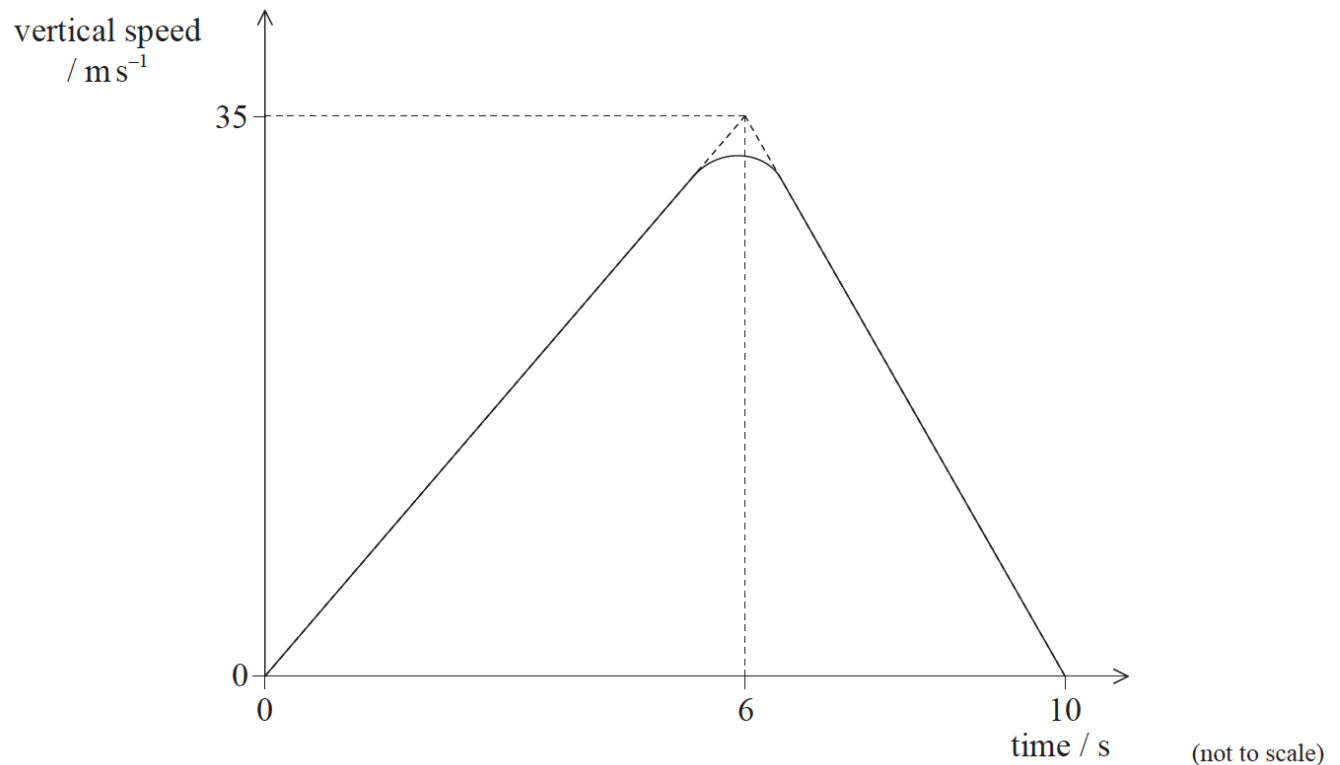
————— ground

Ignoring air resistance, which statement is **true**?

- A. Y will hit the ground before X.
- B. Y will hit the ground after X.
- C. Y will hit the ground at the same time as X.
- D. The outcome can only be determined if the initial speed of X is known.

Part 2 Rocket motion

A test model of a two-stage rocket is fired vertically upwards from the surface of Earth. The sketch graph shows how the vertical speed of the rocket varies with time from take-off until the first stage of the rocket reaches its maximum height.



is about 170 m.

to the surface of the Earth. Ignore air resistance.

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There is no text or other markings on the paper.

27b. A full-scale version of the rocket reaches a height of 260km when the first [3 marks]
stage falls away. Using the data below, calculate the speed at which the
second stage of the rocket will orbit the Earth at a height of 260km.

Mass of Earth = 6.0×10^{24} kg

Radius of Earth = 6.4×10^6 m

This question is about rest mass and relativistic energy.

28a. (i) Define the *rest mass* of a particle.

[2 marks]

(ii) The rest mass of a particle is said to be an invariant quantity. State, with reference to special relativity, what is meant by the term invariant.

28b. In a thought experiment, two particles X and Y, each of rest mass 380 MeVc^{-2} , are approaching each other head on. [5 marks]



The speed of X and of Y is $0.60c$ relative to a laboratory.

- Calculate the momentum of X in the frame of reference in which Y is at rest.
- As a result of the collision a single particle Z is formed. Determine the rest mass of Z. The gamma factor for a speed of $0.60c$ is 1.25.

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This question about general relativity.

29a. State the principle of equivalence.

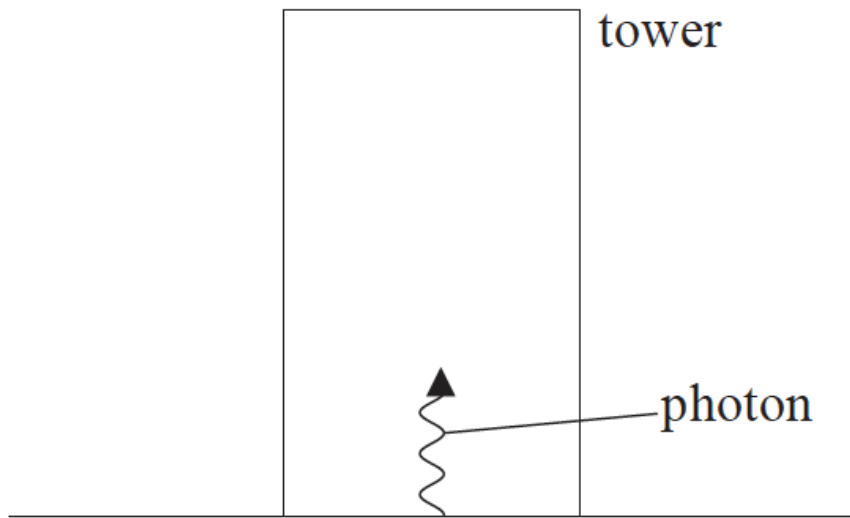
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29b. A gamma-ray photon is emitted from the base of a tower towards the top of the tower. [5 marks]

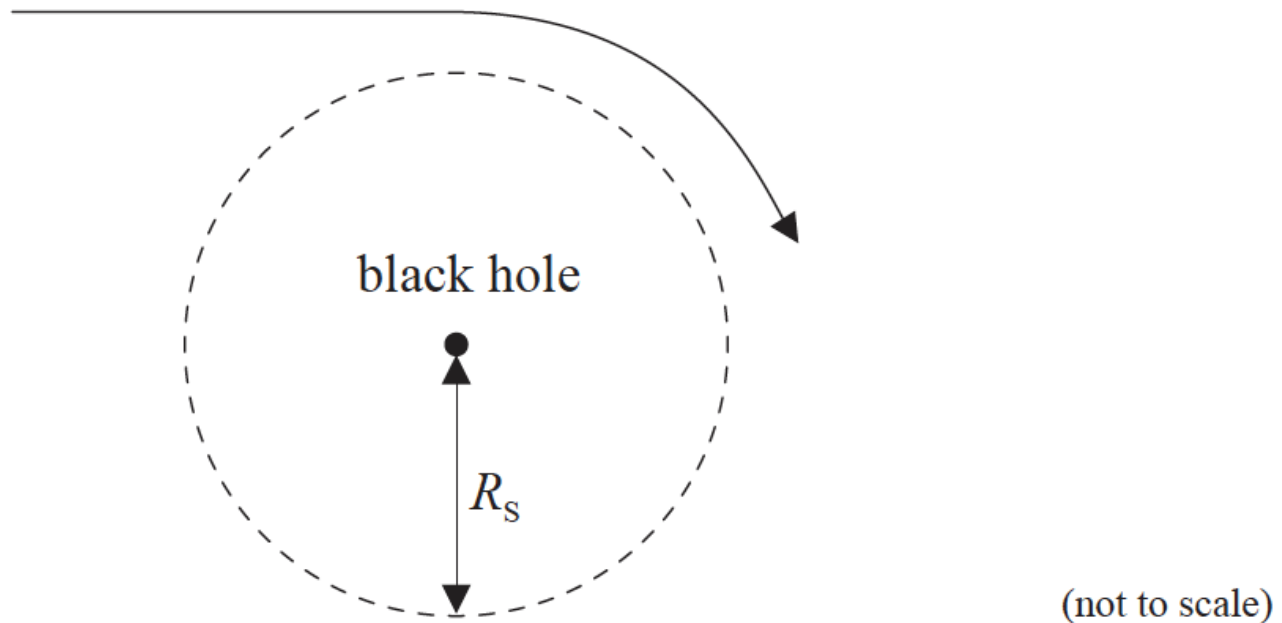


- (i) Explain, using the principle of equivalence, why the frequency of the photon as measured at the top of the tower is less than that measured at the base of the tower.
- (ii) The frequency of the photon at the base is 3.5×10^{18} Hz and the tower is 23 m high. Determine the shift Δf in the frequency of the photon at the top of the tower.
- (iii) Suggest, using your answer to (b)(ii), why the photon frequency must be measured very precisely for this experiment to be successful.

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There is no handwriting or other markings on the paper.

This question is about black holes.

The diagram shows the path of a light ray in the space around a black hole.



The radius of the dotted circle is the Schwarzschild radius of the black hole.

30a. Define the *Schwarzschild radius* of a black hole.

[1
mark]

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30b. Explain, using the concept of spacetime, why the path of the light ray is straight at distances far from the black hole and curved when near the black hole.

[3 marks]

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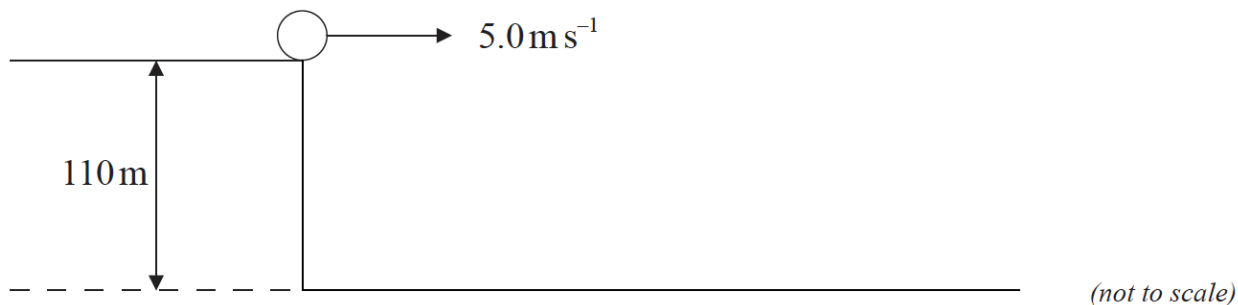
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31. A gun fires a bullet of mass m at a horizontal velocity of v . Air resistance on the bullet is negligible. A change in which of the following will affect the time for the bullet to hit the ground? [1 mark]

- A. m only
- B. v only
- C. m and v
- D. neither m nor v

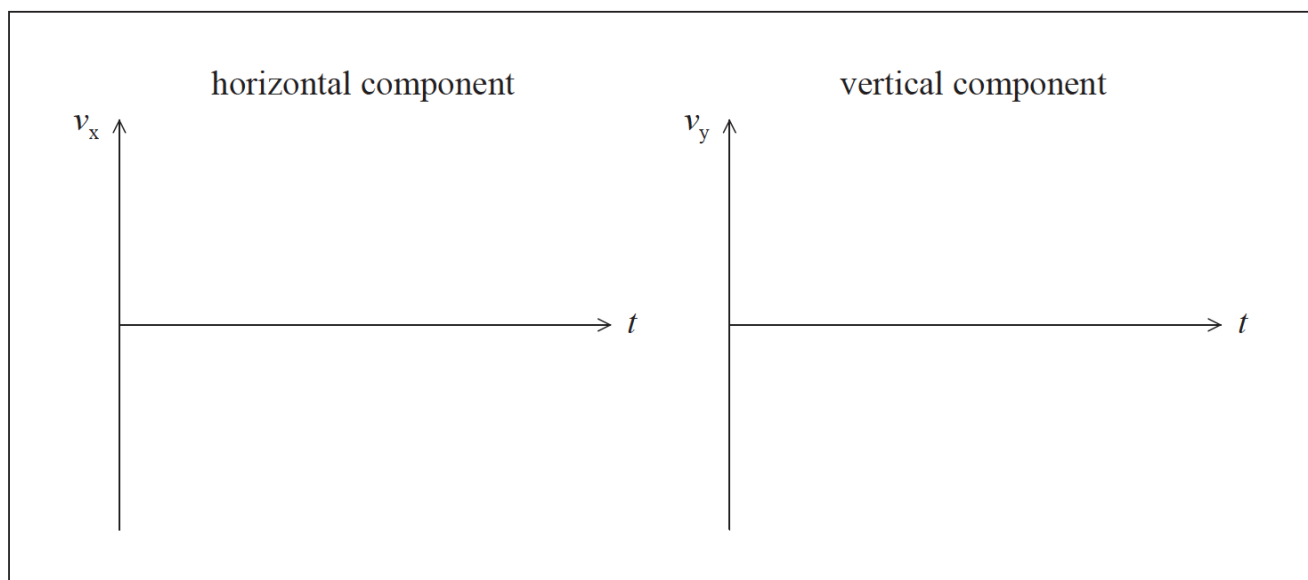
Part 2 Projectile motion

A ball is projected horizontally at 5.0ms^{-1} from a vertical cliff of height 110m . Assume that air resistance is negligible and use $g=10\text{ms}^{-2}$.



32a. (i) State the magnitude of the horizontal component of acceleration of the ball after it leaves the cliff. *[3 marks]*

(ii) On the axes below, sketch graphs to show how the horizontal and vertical components of the velocity of the ball, v_x and v_y , change with time t until just before the ball hits the ground. It is not necessary to calculate any values.



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32b. (i) Calculate the time taken for the ball to reach the ground. [4 marks]

(ii) Calculate the horizontal distance travelled by the ball until just before it reaches the ground.

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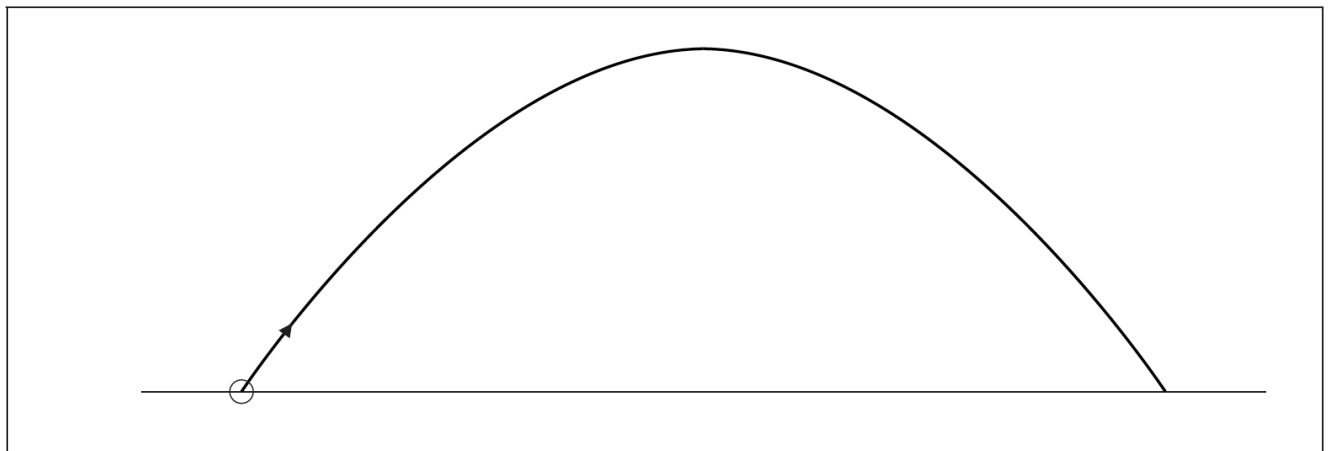
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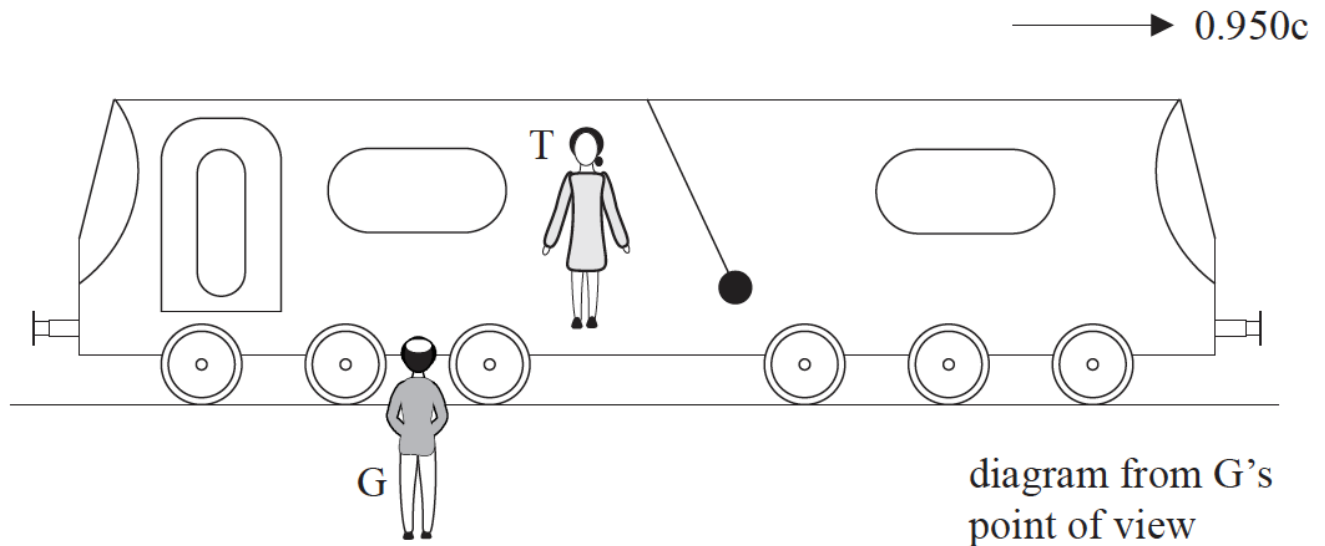
32c. Another projectile is launched at an angle to the ground. In the absence of air resistance it follows the parabolic path shown below. [3 marks]



On the diagram above, sketch the path that the projectile would follow if air resistance were not negligible.

This question is about relativistic kinematics.

In a thought experiment, a train is moving at a speed of $0.950c$ relative to the ground. A pendulum attached to the ceiling of the train is set into oscillation.



An observer T on the train and an observer G on the ground measure the period of oscillation of the pendulum.

33. Observer G sees a second train moving towards the first train (*i.e.* towards the left) at a speed of $0.950c$ with respect to the ground. Calculate the relative speed of the trains. [2 marks]

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This question is about relativistic mechanics.

- 34a. In an experiment at CERN in 1964, a neutral pion moving at a speed of $0.99975c$ with respect to the laboratory decayed into two photons. The speed of each photon was measured with respect to the laboratory. [2 marks]

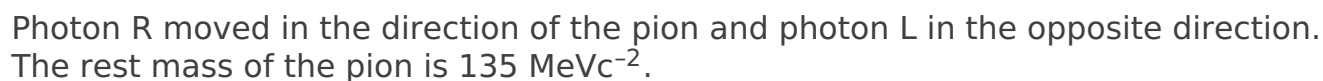
Describe how the result of this experiment provided support for special relativity.

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[6 marks]



- determine the total energy of the pion in MeV.
- determine the momentum of the pion, in $\text{MeV}c^{-1}$.
- state and explain which photon, R or L, has the greater energy.

This question is about the equivalence principle and black holes.

35a. State the principle of equivalence.

[1
mark]

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35b. The gravitational field strength near the surface of a neutron star is $1.2 \times 10^{13} \text{ N kg}^{-1}$. A light ray is emitted from a stationary probe at a height of 250 m above the surface. The frequency of the light measured in the probe is $4.8 \times 10^{14} \text{ Hz}$. [4 marks]

- (i) Determine the frequency of the light received at the surface of the star according to an observer at the surface.
- (ii) Describe how gravitational red-shift leads to the concept of gravitational time dilation.

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35c. General relativity predicts the existence of black holes.

[3 marks]

- (i) State what is meant by a black hole.
- (ii) Suggest **two** ways in which a black hole may be detected.

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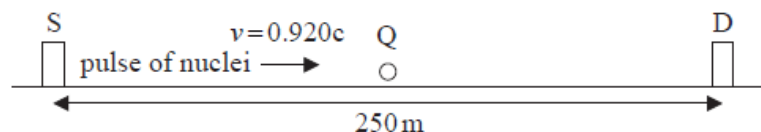
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This question is about relativistic kinematics.

A short pulse containing many nuclei of a radioactive isotope is emitted from a source S in a laboratory. The nuclei have speed $v = 0.920c$ as measured with respect to the laboratory.



The pulse arrives at a detector D. The detector is 250 m away as measured by an observer in the laboratory.

36a. Calculate the time it takes the pulse to travel from S to D, according to [3 marks]

- (i) an observer in the laboratory.
- (ii) an observer Q moving along with the pulse.

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36b. Calculate the distance between the source S and the detector D according to observer Q. [1 mark]

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36c. A particular nucleus in the pulse decays by emitting an electron in the same direction as that of the nucleus. The speed of the electron measured in the laboratory is $0.985c$. [2 marks]

Calculate the speed of the electron as measured by observer Q.

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36d. The laboratory observer and observer Q agree that by the time the pulse arrives at D, half of the nuclei in the pulse have decayed. [2 marks]

Outline, without further calculation, how this is evidence in support of time dilation.

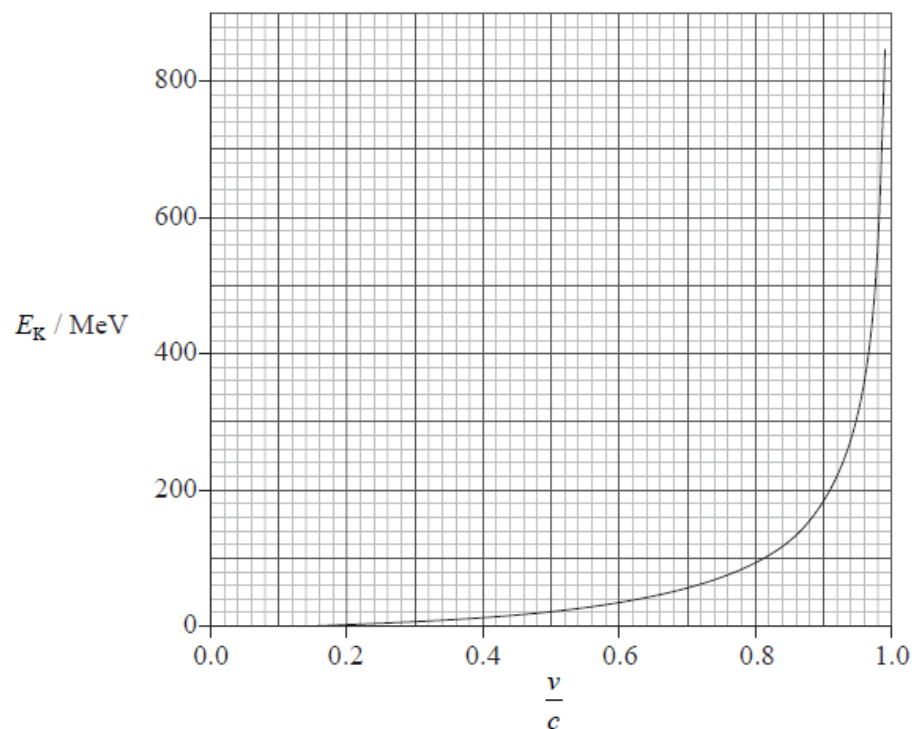
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This question is about mass and energy.

- 37a. The graph shows the variation with the fraction $\frac{v}{c}$, of the kinetic energy E_K of a particle, where v is the speed of the particle. [4 marks]



Determine, using the value $E_K = 360 \text{ MeV}$ from the graph, the rest mass of the particle in MeV c^{-2} .

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- 37b. Determine, using data from the graph, the potential difference required to [2 marks]
accelerate the particle in (a) from a speed of $0.63c$ to a speed of $0.96c$.
The charge of the particle is $+e$.

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This question is about relativistic mechanics.

- 38a. Show that the speed v of a particle of total energy E and momentum p is [2 marks]
given by the following equation.

$$v = \frac{pc^2}{E}$$

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- 38b. Determine, using the answer in (a), the speed of a particle whose rest [2 marks]
mass is zero.

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This question is about the equivalence principle.

39a. State the equivalence principle.

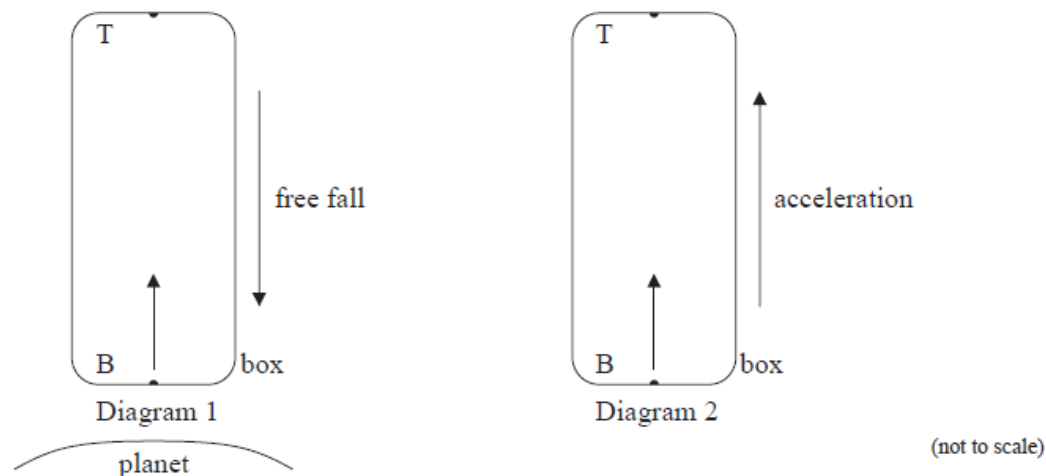
[1
mark]

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39b. The diagram shows two identical boxes in two different states of motion. [4 marks]



In **diagram 1** the box is in free fall close to the surface of a planet. In **diagram 2** the box is accelerating in a region of space far from other masses.

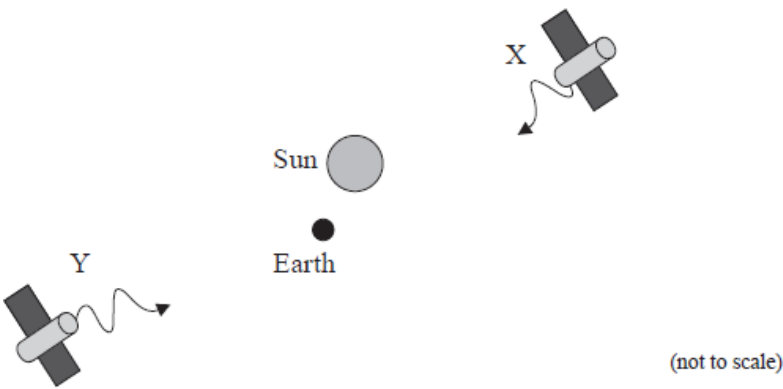
A ray of monochromatic light is emitted from the base B of each box and is received at the top T of each box.

Observers at B measure the frequency of the emitted light to be f_0 .

State and explain, for each state of motion in diagram 1 and 2, if the frequency of light measured by an observer at T will be less than, equal to **or** greater than f_0 .

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There is no handwriting or other markings on the paper.

39c. Radio signals, sent at the same time from Earth, reflect off two satellites X and Y as shown. The satellites are at the same distance from Earth. [2 marks]



The signal from Earth to satellite X and the reflected signal pass close to the Sun. Compare, using the theory of general relativity, the arrival times at Earth of the signal from X and the signal from Y.

40. A ball is thrown horizontally from the top of a high cliff. Air resistance is negligible. [1 mark]

Which of the following correctly describes the changes, if any, to the ball’s vertical speed and horizontal speed?

	Vertical speed	Horizontal speed
A.	no change	increases
B.	increases	no change
C.	no change	decreases
D.	decreases	no change

This question is about escape speed and gravitational effects.

41a. Explain what is meant by escape speed.

[2 marks]

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41b. Titania is a moon that orbits the planet Uranus. The mass of Titania is $3.5 \times 10^{21} \text{ kg}$. The radius of Titania is 800 km. [5 marks]

(i) Use the data to calculate the gravitational potential at the surface of Titania.

(ii) Use your answer to (b)(i) to determine the escape speed for Titania.

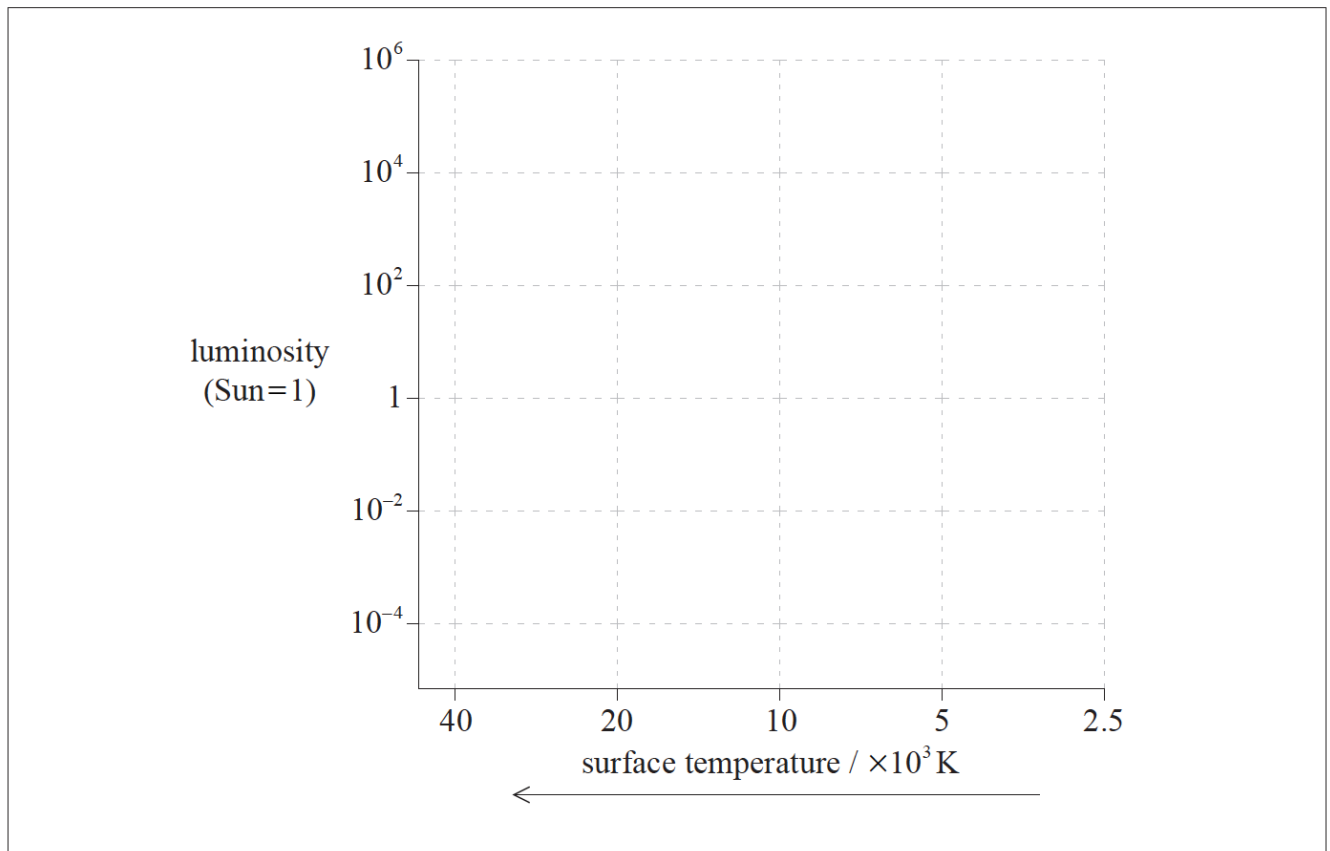
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41c. An astronaut visiting Titania throws an object away from him with an initial horizontal velocity of 1.8 m s^{-1} . The object is 1.5 m above the moon's surface when it is thrown. The gravitational field strength at the surface of Titania is 0.37 N kg^{-1} . *[3 marks]*

Calculate the distance from the astronaut at which the object first strikes the surface.

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This question is about stellar distances and stellar properties.



42a. Evidence for time dilation comes from the decay of muons. A pulse of muons produced by cosmic radiation in the upper atmosphere of Earth travels to Earth with a speed of $0.96c$ as measured by an observer at rest on the surface of Earth. The half-life of the muons, as measured in the frame of reference in which the muons are at rest, is 3.1×10^{-6} s. [3 marks]

(i) Determine for the muons, the distance that Earth will have travelled towards them after half of the muons in the pulse have decayed.

(ii) Calculate for the Earth observer, the distance that the muon pulse will have travelled towards Earth after half of the muons in the pulse have decayed.

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42b. Suggest how your answers to (e)(i) and (e)(ii) provide evidence that supports the theory of special relativity. [3 marks]

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This question is about relativistic energy and momentum.

43a. A proton is accelerated from rest through a potential difference V . The proton reaches a speed of $0.970c$. Determine the value of V . [3 marks]

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43b. Calculate, after acceleration for the proton in (a), its

[2 marks]

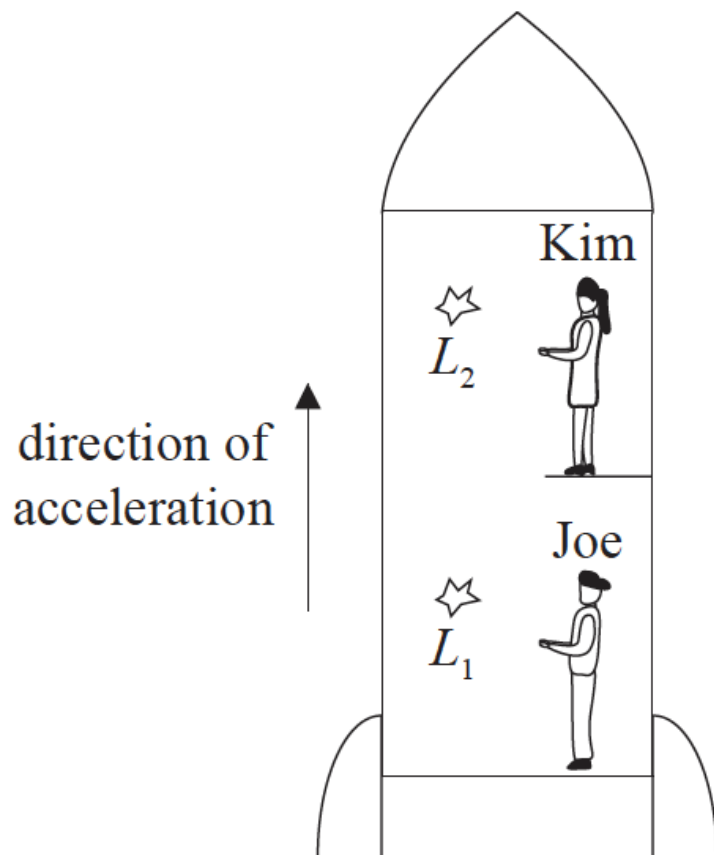
(i) mass.

(ii) momentum.

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This question is about the principle of equivalence and red-shift.

Joe and Kim are travelling in a spaceship.



Joe is next to a light source L_1 and Kim is next to an identical light source L_2 .

The acceleration of the spaceship is zero. Kim measures the frequency of the light from L_1 to be the same as the frequency of the light from L_2 .

44a. Outline why, if the spaceship now accelerates, Kim will measure the light [3 marks] from L_1 to be red-shifted with respect to the light from L_2 .

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- 44b. Suggest, with reference to Einstein's principle of equivalence, how your [2 marks]
answer to (a) leads to the idea that a clock near a massive body runs more slowly
than a clock in free space.

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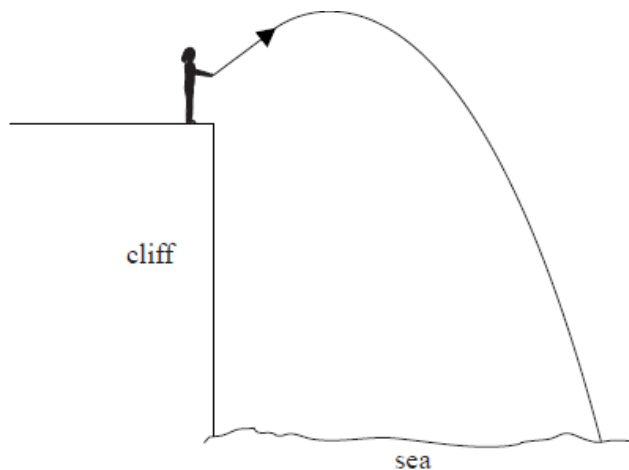
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45. A stone is thrown from a cliff and it lands in the sea as shown below. Air [1
resistance is negligible. mark]

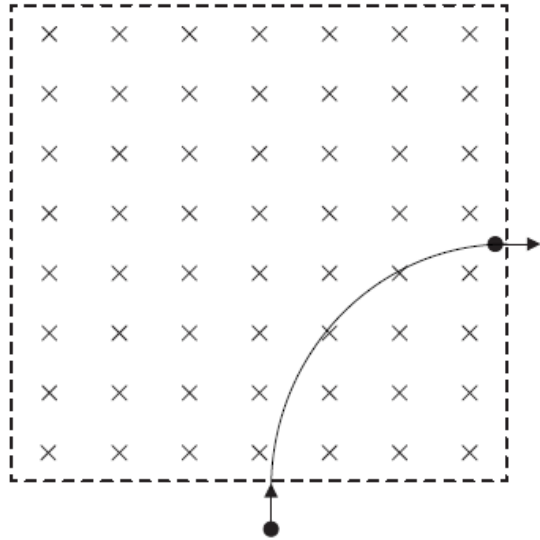


Which of the following statements is correct whilst the stone is in motion?

- A. The vertical component of the stone's displacement is constant.
- B. The horizontal component of the stone's displacement is constant.
- C. The vertical component of the stone's velocity is constant.
- D. The horizontal component of the stone's velocity is constant.

This question is about motion in a magnetic field.

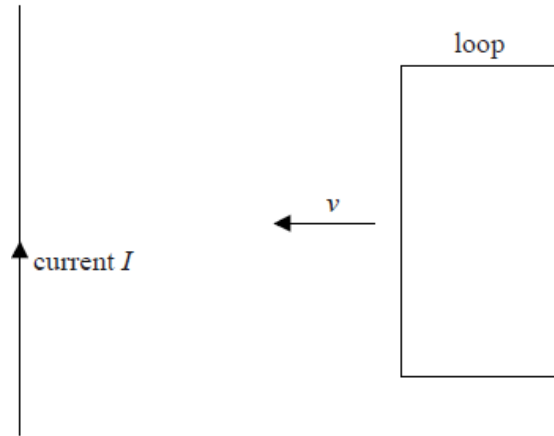
An electron, that has been accelerated from rest by a potential difference of 250 V, enters a region of magnetic field of strength 0.12 T that is directed into the plane of the page.



- 46a. The electron's path while in the region of magnetic field is a quarter circle. [1 mark]
Show that the
time the electron spends in the region of magnetic field is $7.5 \times 10^{-11} \text{ s}$.

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46b. A square loop of conducting wire is placed near a straight wire carrying a constant current I . The wire is in the same plane as the loop. [4 marks]



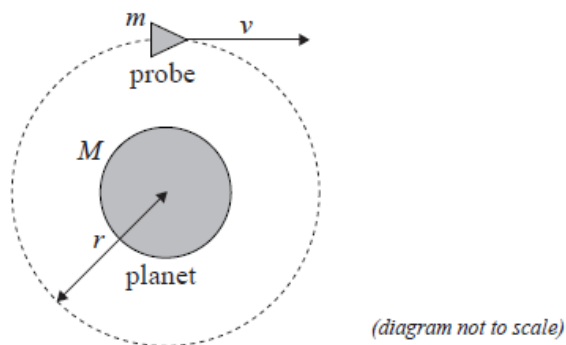
The loop is made to move with constant speed v towards the wire.

- (i) Explain, by reference to Faraday's and Lenz's laws of electromagnetic induction, why work must be done on the loop.
- (ii) Suggest what becomes of the work done on the loop.

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This question is about a probe in orbit.

A probe of mass m is in a circular orbit of radius r around a spherical planet of mass M .



- 47a. State why the work done by the gravitational force during one full revolution of the probe is zero.

[1 mark]

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- 47b. Deduce for the probe in orbit that its

[4 marks]

(i) speed is $v = \sqrt{\frac{GM}{r}}$.

(ii) total energy is $E = -\frac{GMm}{2r}$.

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47c. It is now required to place the probe in another circular orbit further away [2 marks]
from the planet. To do this, the probe's engines will be fired for a very
short time.

State and explain whether the work done on the probe by the engines is positive,
negative **or** zero.

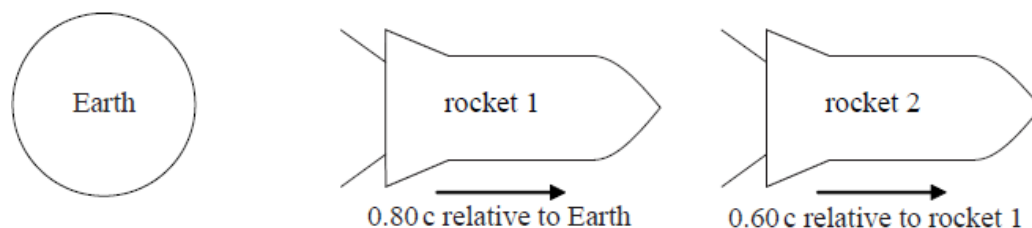
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This question is about relative velocities and energy at relativistic speeds.

Two identical rockets are moving along the same straight line as viewed from Earth.
Rocket 1 is moving away from the Earth at speed 0.80 c **relative to the Earth** and
rocket 2 is moving away from rocket 1 at speed 0.60 c **relative to rocket 1**.



48a. Calculate the velocity of rocket 2 relative to the Earth, using the [3 marks]

- (i) Galilean transformation equation.
- (ii) relativistic transformation equation.

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48b. Comment on your answers in (a).

[2 marks]

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48c. The rest mass of rocket 1 is $1.0 \times 10^3 \text{ kg}$. Determine the **relativistic** kinetic energy of rocket 1, as measured by an observer on Earth.

[2 marks]

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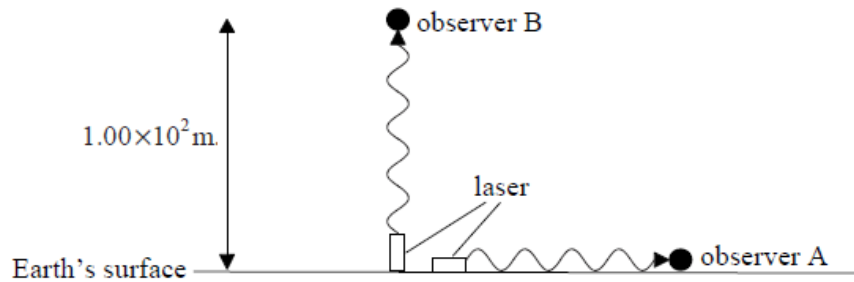
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This question is about gravitational red-shift.

Two identical lasers are situated on the surface of the Earth. One is directed horizontally towards observer A, who measures the frequency to be $4.62 \times 10^{14} \text{ Hz}$. The other is directed vertically upwards towards observer B, who is at a height of $1.00 \times 10^2 \text{ m}$.



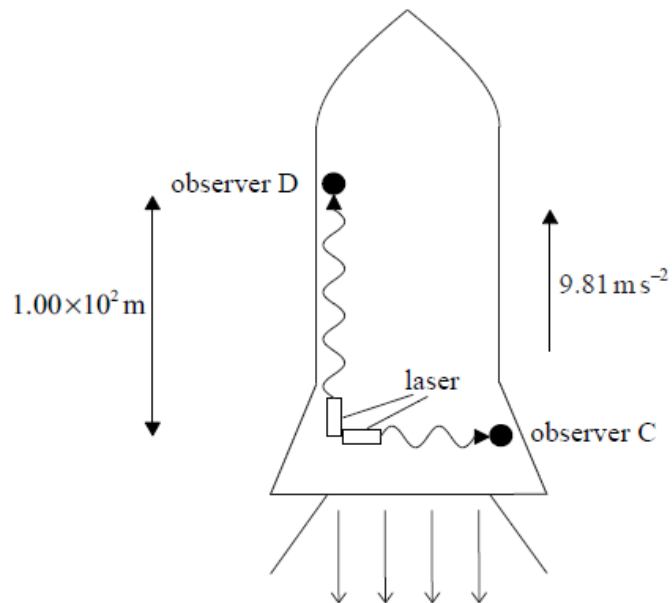
49a. (i) State how the frequency as measured by observer B compares with the frequency as measured by observer A. [4 marks]

(ii) Calculate the difference in frequency between the laser light as measured by observers A and B.

(iii) State **one** assumption that you made in (a)(ii).

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49b. The lasers are now placed on a spaceship, which is accelerating upwards [2 marks]
at a constant rate of 9.81 m s^{-2} , far away from any other masses as
shown below. The distance of observer D from the laser is $1.00 \times 10^2 \text{ m}$. Observer C
is at the bottom of the spaceship.



Explain, with reference to the equivalence principle, the frequencies measured
by observers C and D, as compared to observers A and B.

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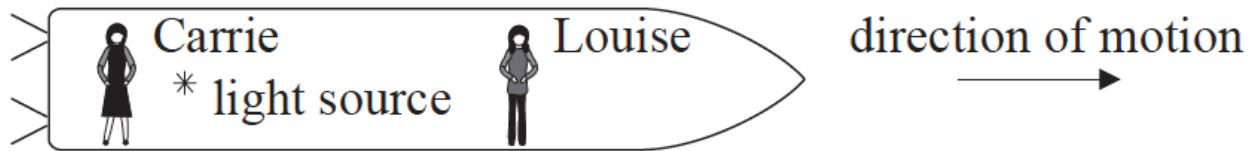
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This question is about relativity.

Carrie is in a spaceship that is travelling towards a star in a straight-line at constant velocity as observed by Peter. Peter is at rest relative to the star.

50. Carrie and Louise, two observers in a spaceship, view a light source placed close to Carrie. When the spaceship is travelling at a constant velocity, they both measure the frequency of the light source and obtain identical values. [4 marks]



The magnitude of the velocity of the spaceship increases.

State and explain any changes to the frequency of the light source, as measured by Louise, that occur during the acceleration.

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This question is about relativistic mechanics.

- 51a. Calculate the potential difference through which a proton, starting from rest, must be accelerated for its mass-energy to be equal to three times its rest mass energy. *[3 marks]*

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- 51b. Calculate the momentum of the proton after acceleration. *[3 marks]*

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This question is about spacetime.

- 52a. Describe what is meant by spacetime. *[2 marks]*

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52b. State the shape of the path in spacetime of a body

[2 marks]

(i) moving at constant velocity.

(ii) orbiting the Earth.

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52c. Explain how spacetime is used to describe the gravitational attraction between Earth and a satellite orbiting the Earth.

[2 marks]

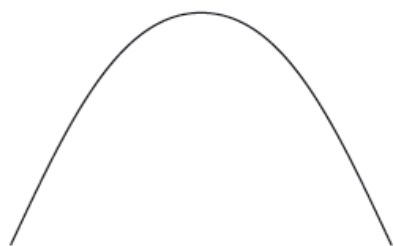
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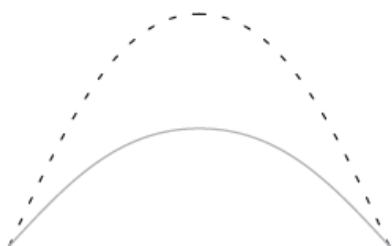
53. The diagram shows the path of a projectile that is launched with velocity v . Air resistance is negligible.

[1 mark]



A second projectile has double the mass of the first projectile and is launched with the same velocity. Air resistance is still negligible. Which of the following paths best represents the path of the projectile? (*The original path is shown as a dotted line*)

A.



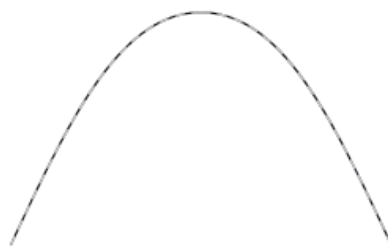
B.



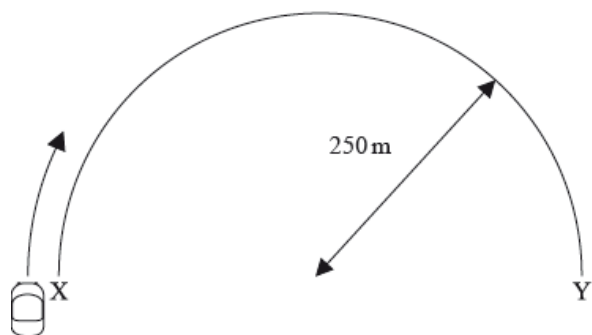
C.



D.



54. A car moves from X to Y along a semicircular path. The radius of the path is 250 m and the time taken to complete the trip is 50 s. [1 mark]



Which of the following correctly shows the magnitude of the average velocity and the magnitude of the average speed?

	Average velocity	Average speed
A.	10 m s^{-1}	10 m s^{-1}
B.	10 m s^{-1}	16 m s^{-1}
C.	16 m s^{-1}	10 m s^{-1}
D.	16 m s^{-1}	16 m s^{-1}