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Activity

Practice-for-exam questions

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Use the questions below either in class or for individual work after students have read the articles in the magazine. Although the questions state the values of constants required, some of the questions require additional data – students should either make reasonable estimates of quantities or look up values using a data book or website. Students should clearly communicate any assumptions made. Suggested outline answers to questions are provided in a separate document.

Thinking about motion: particles and planets (part 1)

1 The speed-time graph for a car that starts moving at t = 0 s and stops moving at t = 24 hours is shown in Figure 1 below. Point F has coordinates (20.0, 87.5). Other coordinates can be easily inferred and thus are not listed. Answer the questions that follow to 3 significant figures.

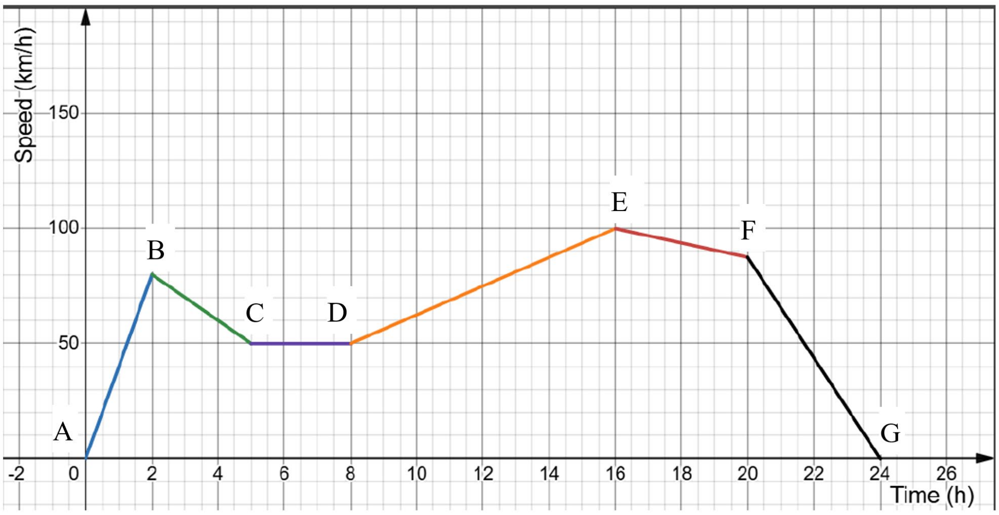

Figure 1 Speed-time graph of a car's journey over 24 hours

a What is the total distance travelled by the car in 24.0 hours?

Hint: Area of a trapezium $= \frac{1}{2}(a + b) \times h$

where a and b are lengths of the parallel sides and h is the distance between these two sides.

b What is the average speed of the car in m/s?

c During which sections of the journey has the car accelerated?

d During which section(s) of the journey has the car neither accelerated nor decelerated?

e During which section of the journey has the car accelerated or decelerated the most?

f What were the highest and lowest accelerations during the journey in km/h^2?

2 A cyclist accelerates uniformly from rest along a straight road. After 10.0 s, the cyclist reaches a velocity of 6.00 ms^{-1}. The cyclist then continues to travel at this constant velocity for the next 30.0 s. Finally, the cyclist decelerates uniformly to rest over a distance of 15.0 m.

a Calculate the acceleration of the cyclist during the first 10 s.

b Determine the total distance travelled by the cyclist during the first 10.0 s.

c Find the deceleration of the cyclist during the final stage of the journey.

d Calculate the time taken for the cyclist to decelerate to rest over the distance of 15.0 m.

e Determine the total distance travelled by the cyclist over the entire journey.

3 A 10.0 kg fireworks shell is launched vertically into the air and reaches a maximum height before exploding into two equal fragments. One fragment (Fragment A) of mass 5.00 kg is observed to fall straight down with an initial velocity of 10.0 m/s immediately after the explosion.

a Calculate the total momentum of the system before the explosion.

b Using the principle of conservation of momentum, determine the initial velocity of the second fragment (Fragment B) immediately after the explosion.

c If the explosion imparts an additional kinetic energy of 500 J to the system, calculate the total kinetic energy of the two fragments immediately after the explosion.

d Discuss the significance of the conservation of momentum in analysing explosive events and how it applies to this situation.

4 Consider a cricket ball with a mass of 0.160 kg that is struck by a bat, causing it to move through the air. The cricket ball is assumed to be a uniform solid sphere with a radius r of 3.50 cm.

When the ball is struck, an external force F is applied by the bat at a point 2.00 cm above the centre of mass of the ball, in a horizontal direction, causing both translational and rotational motion.

a Calculate the initial acceleration of the centre of mass of the cricket ball if the applied force F is 30.0 N.

b Determine the torque τ about the centre of mass due to the applied force F.

c *This question uses the idea of moment of inertia, which is beyond the core A-level specification. It is intended as an extension question or for those taking additional optional modules.*

Given that the moment of inertia I of a solid sphere about an axis through its centre is $\frac{2}{5}mr^2$, calculate the angular acceleration α of the cricket ball immediately after the force is applied.

d Explain how the position of the applied force relative to the centre of mass affects the motion of the cricket ball.

The physics of falling

1 Object A has a mass of 5.00 kg

Object B has a mass of 50.0 kg

Object C has a mass of 500 kg

From a height of 10.0 m, each object is dropped (one at a time) vertically from rest onto a hard surface directly underneath.

Calculate:

a The ratio of potential energy of the three objects. Assume acceleration due to gravity 'g' to be 9.81 ms^{-2}.

b The velocity with which each object will hit the hard surface.

c The time taken for each object to hit the hard surface.

d Assuming perfect inelastic collision and deceleration time of 0.1 s, calculate the force acting on each object when they hit the hard surface.

e For each object, if a padded mat is placed on top of the hard surface that increases time taken for them to come to rest by 10%, then recalculate (d).

f What would the deceleration time need to be to ensure the force acting on Object C is less than or equal to 40.0 kN?

2 A car of mass 1500 kg is traveling on a straight, horizontal road. The car's engine provides a constant forward force of 4000 N. The car is also subjected to a constant resistive force of 1000 N.

a Using Newton's second law, calculate the car's acceleration.

b If the car starts from rest, calculate the time it will take to reach a speed of 20 m/s.

c Once the car reaches a speed of 20.0 ms^{-1}, the driver sees an obstacle 100 meters ahead and applies the brakes, providing a constant decelerative force of 500 N. Determine the stopping distance of the car.

d Discuss how Newton's third law applies to the forces experienced by the car when it is accelerating and when it is decelerating.

3 *This question uses the idea of moment of inertia, which is beyond the core A-level specification. It is intended as an extension question or for those taking additional optional modules.*

A uniform rod of length L = 2.00 m and mass m = 10.0 kg is initially held vertically above a hard surface and then released from rest. The bottom end of the rod makes contact with the surface first. Assume the surface is perfectly rigid and there is no slipping at the point of contact.

a Calculate the angular velocity of the rod just before it makes contact with the surface, assuming the pivot point is at the bottom end that touches the surface. Assume acceleration due to gravity to be 9.81 ms^{-2}.

Hint: the moment of inertia I (measured in kg m^2) of the rod about the pivot point (bottom end) is given by:

$$I = \frac{1}{3}mL^2$$

The rotational kinetic energy is given by the equation below, where ω is the angular velocity of the rod in rad/s.

$$KE_{rotational} = \frac{1}{2}I\omega^2$$

b Determine the linear velocity of the centre of mass of the rod just before impact.

c Given that the collision is perfectly inelastic and the rod comes to rest in 0.1 s after impact, calculate the average force exerted on the rod by the surface immediately upon impact.

d If a padded mat is placed on top of the hard surface, which increases the time taken for the rod to come to rest by 10%, calculate the new average force exerted on the rod by the surface.

Speedy stars

1 S2 is a star in orbit around the supermassive black hole Sagittarius A* at the centre of our galaxy. The star's orbit has a semi-major axis of approximately 5.50 light-days and an orbital period of 16.0 years.

a Using Kepler's first law, describe the shape of S2's orbit and the position of Sagittarius A* in relation to this orbit.

b Apply Kepler's second law to explain how S2's velocity changes as it moves along its elliptical orbit.

c Using Kepler's third law, calculate the mass of Sagittarius A*. Note that this law described in the equation below is applicable for when the mass of the central body is far greater than that of the body orbiting it (which is the case for S2 orbiting Sagittarius A*).

$$T^2 = \frac{4\pi^2 a^3}{GM}$$

Here T is the orbital period, a is the length of the semi-major axis of the orbit and G is the universal gravitational constant (6.67×10^{-11} m^3 kg^{-1} s^{-2}). Assume the speed of light is 3.00×10^8 ms^{-1}.

2 The Earth and the Moon are part of the Earth–Moon system where the Moon orbits the Earth. Use the given parameters to solve the following:

a Calculate the orbital velocity of the Moon around the Earth. The average distance from the Earth to the Moon is approximately 384400 km and the mass of the Earth is 6.00×10^{24} kg.

b Determine the orbital velocity of a satellite placed in a circular orbit around the Earth at an altitude of 300 km. The radius of the Earth is 6370 km and the universal gravitational constant G is 6.67×10^{-11} m^3 kg^{-1} s^{-2}.

c Explain how the concept of orbital velocity is crucial for the functioning of artificial satellites. Discuss the implications of incorrect orbital velocity on the satellite's operation.

3 The maximum orbital velocity for an object in a highly elliptical orbit around a massive body is given by the vis-viva equation below, the circular orbit version of which was presented in Box 2 of the article.

$$v \approx \sqrt{\frac{2GM}{r}}$$

Here r is periapsis distance, which is the shortest distance between the two bodies. M is the mass of the central massive body and G is the universal gravitational constant.

Through calculations, prove that S4714 travels at approximately 8% of the speed of light when it is closest to Sagittarius A* – the black hole located at the centre of the Milky Way galaxy. The following data are given:

Universal gravitational constant G = $6.67 \times 10^{-11}\,\text{m}^3\text{kg}^{-1}\text{s}^{-2}$

Mass of Sagittarius A* black hole = 4.30 × 106 solar mass

Mass of the Sun (solar mass) = 1.99 × 1030 kg

S4714's periapsis distance (shortest distance from Sagittarius A*) = 1.9 × 1012 m

Speed of light in vacuum = 3.00 × 108 ms^{-1}.

Michelson's stellar interferometer

1 In a Young's double-slit experiment, monochromatic light of wavelength λ = 600 nm is used. The slits are separated by a distance d = 0.200 mm and the screen is placed at a distance D = 1.50 m from the slits.

a Calculate the fringe separation (fringe width) on the screen.

b If the distance between the slits is increased to 0.300 mm, keeping all other conditions the same, what will be the new fringe separation?

c Discuss how the fringe separation would change if the wavelength of light used is decreased to 500 nm, keeping the original slit separation of 0.200 mm.

2 A radio telescope with a diameter of 100 meters is used to observe radio waves of wavelength 21.0 cm emitted by hydrogen atoms in space.

a Calculate the angular resolution of the telescope in arcseconds.

Assume 1 radian = 2.06×10^5 arcseconds.

b Describe how the angular resolution of a telescope changes with the wavelength of the observed radiation and the diameter of the telescope.

c A smaller optical telescope with a diameter of 1.00 m is used to observe visible light with a wavelength of 500 nm. Compare the angular resolution (in arcseconds) of this optical telescope with the radio telescope described earlier. Which one has better resolving power?

d Discuss the importance of angular resolution in astronomical observations and explain how it affects the ability to distinguish between close objects in the sky.

3 Betelgeuse, one of the largest known stars and classified as a red supergiant, has an angular diameter of approximately 0.047 arcseconds as observed from Earth. The star is located at about 700 light-years from Earth.

a Calculate the actual diameter of Betelgeuse in km.

Assume 1 light-year (ly) = 9.46×10^{15} m

b Convert the diameter obtained in part (a) to units of solar radii $R_{\odot}$, given the diameter of the Sun is approximately 1.39×10^{6} km.

c Discuss how the diameter of Betelgeuse compares to that of the Sun. What does this tell us about the size and scale of Betelgeuse compared to our Sun?

d If the distance to Betelgeuse were twice as far, how would this affect its angular diameter as observed from Earth? Explain your reasoning.