Chapter 9.1 Exam Q Question 1

(18 marks)

It is generally accepted that around 65 million years ago the Earth was struck by a fast-moving object approximately 10 km in diameter. This impact is believed to have left a scar on the Earth in the form of the Chicxulub Crater and to have been responsible for the extinction of the dinosaurs.

In 2013 the 'Chelyabinsk meteor' entered the Earth's atmosphere over Russia. This meteor had a mass of approximately 12 kilotonnes, measured about 20 metres in diameter and released about 1.8×10^{15} J, causing extensive damage, though mostly to arable land and not populated cities.

Events such as this have sparked interest in cataloguing such Near Earth Objects (NEOs) and then determining if they have an orbit that might put them on a collision course with the Earth. If a NEO is deemed to have an orbit that puts it on a collision course with the Earth then various possibilities exist for preventing the collision. These methods of prevention fall into two categories, either deflection or destruction of the NEO. With either method, early intervention is desirable. The Earth is orbiting the Sun at 30.0 km s^{-1} and to avoid an impact scientists have to ensure that the NEO and the Earth are not in the same position in space at the same time. The section of the Earth's orbit in which a collision is possible is known as the 'impact window'.

Essentially deflection strategies seek to alter the velocity of the NEO so that it intersects the Earth's orbit before or after the Earth is in that position. It is estimated that a velocity change of a NEO of $\frac{3.5 \times 10^{-2}}{t}$ m s^{-1} is sufficient to avoid a collision where 't' is the time in years to impact.

One possible method of deflecting a NEO is to use a 'gravity tractor'. A gravity tractor is a massive spacecraft that is brought near to the NEO. Gravity will act between the spacecraft and the NEO and both objects will mutually attract each other. In time the NEO will gradually change the direction of its orbit. Once the NEO moves out of its normal path and comes close to the spacecraft, thrusters fire, moving the spacecraft further away from the NEO and allowing the spacecraft to continue to act as a gravity tractor. The gravity tractor method requires the earliest of interventions.

(a) Estimate the velocity of the of the Chelyabinsk meteor. Give your answer to an appropriate number of significant figures. Show **all** workings. (4 marks)

(b) (i) The width, in Earth diameters, of the impact window is (circle your answer): (1 mark)

less than one one more than one

(ii) Calculate the length of time that an 'impact window' has for any collision of an object with the Earth to occur. Ignore the size of the object. Show **all** workings. (3 marks)

(c) The NEO Apophis is on an orbit that will bring it close to the Earth in 2036. It has an assumed mass of 4.00×10^{10} kg and diameter of 325 m.

(i) Suppose that a spacecraft arrives and begins interacting with Apophis in 2016. Determine the change in velocity required to avoid a collision with the Earth. (3 marks)

(ii) If a gravity tractor type of intervention is decided upon, and does not begin interacting until 2021, then Apophis will require a change in velocity of 2.33×10^{-3} m s^{-1}. Determine the mass of the gravity tractor spacecraft needed, given that the centres of mass will be 175 m apart. (4 marks)

Do not attempt (c)(ii), but answer may help with answering part (d)
Answer for (c)(ii) is $a = 4.92 \times 10^{-12}$ m s^{-1} and $m = 2260$ kg and $F = 0.197$ N

(d) When using a gravity tractor, explain why 'the earliest of interventions' is desirable if an asteroid is to be deflected sufficiently to avoid collision with the Earth. (3 marks)

Question 2

(13 marks)

Jake is working on the top of a building which is 21.5 m above the ground. He drops both a nut and bolt.

(a) The nut has a mass of 5.55×10^{-2} kg and the bolt has a mass of 2.51×10^{-1} kg. Which of the two will reach the ground first? Explain your reasoning. (2 marks)

(b) Assuming the bolt falls straight to the ground and there is no wind resistance, calculate

(i) the time it takes for the bolt to reach the ground; and (3 marks)

(ii) the final velocity of the bolt as it hits the ground. (3 marks)

(c) The ground consists of soft soil and the bolt enters the soil and stops 2.25×10^{-2} m below the surface. Calculate the magnitude of the force that the ground has exerted on the bolt. If you were unable to determine an impact velocity in Part (b), use the value 25.0 m s^{-1}. (5 marks)

Question 3

(4 marks)

A 0.250 kg ball bounces on a hard surface after being dropped from a height. The ball retains 80% of its kinetic energy in the collision and rises to a maximum height of 0.870 m above the ground. Calculate its potential energy at A.