8 Read the passage below and answer the questions that follow.

DART – Planetary Defence against Catastrophic Asteroid Impacts

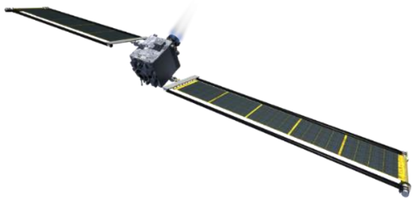
Asteroid 2024 YR4 is a large near-Earth asteroid that when it was first discovered, it appeared to have a very small chance to impact Earth on Dec. 22, 2032. Owing to the trajectory and size of 2024 YR4 (estimated to have a diameter of 53 to 67 m), its discovery initially sparked concerns of heavy, localised destruction potentially capable of levelling a city. Its impact could potentially release energy worth about 7.7 megatonnes of TNT. This is equivalent to about 500 times the energy released by “Little Boy”; the atomic bomb dropped on Hiroshima. As observations of 2024 YR4 continued through early 2025, NASA concluded that the asteroid poses no significant impact risk to Earth in 2032 and is no longer considered a threat. However, in the event that the asteroid’s impact is highly probable, an asteroid deflection mission, similar to the Double Asteroid Redirection Test (DART) craft, might have been sent to 2024 YR4 to avert its impact.

DART is a NASA-funded technology demonstration of a kinetic impactor technology that could be used to mitigate the threat of a hazardous asteroid. The kinetic impactor is currently the simplest and most technologically mature method available to defend against asteroids. In this technique, a spacecraft is launched that simply slams itself into the asteroid at several km per second speed, thereby putting the asteroid in a slightly different orbit around its companion body. The DART project, which was launched in 2021, successfully demonstrated that a spacecraft can navigate itself to a successful impact on the target and alter the target’s orbit. In the project, DART was sent on a roughly 11-million-kilometre journey towards its target: a near-Earth binary asteroid system where a smaller asteroid named “Dimorphos” orbits in a nearly circular orbit with a period of 11.9 hours around a larger asteroid called “Didymos”. The two asteroids are separated by a distance of 1189 m. In 2022, NASA confirmed that DART’s impact successfully altered Dimorphos’s orbital period to 11.4 hours, thereby confirming that its orbit has been altered.

The main structure of the DART spacecraft is a box from which other structures are housed and can extend from. The DART payload consists of a single instrument, the Didymos Reconnaissance and Asteroid Camera for Optical Navigation (DRACO) which is a high-resolution imager to support navigation and targeting. DRACO is a narrow-angle telescope with a 208-millimeter aperture and field of view of 0.29 degrees. The spacecraft components and DART’s low thrust engine are powered by two Roll-Out Solar Arrays (ROSA), each with a power-to-mass ratio of 120 W kg^{-1}.

Data for DART is shown in Table 8.1.

Table 8.1

	dimensions of main body (box)	1.3 m × 1.2 m × 1.3 m (length × width × height)
	dimensions of main body (with other structures fully extended)	1.9 m × 1.8 m × 2.6 m (length × width × height)
	dimensions of each solar array (ROSA)	8.5 m × 2.4 m (length × width)
	mass of each solar array (ROSA)	16.95 kg
	mass at launch	610 kg
	mass at impact	580 kg
	speed of DART at impact	6580 km s^{-1}

For space travel and navigation, the DART spacecraft used and demonstrated the NASA Evolutionary Xenon Thruster Commercial (NEXT-C) electric propulsion system, which allowed for tremendous flexibility in trajectory design. The most popular choice of fuel used by ion thrusters is the noble gas Xenon ($^{131}_{54}\mathrm{Xe}$). However, other noble gases such as Argon ($^{40}_{18}\mathrm{Ar}$) or Krypton ($^{84}_{36}\mathrm{Kr}$) may also be used. In the NEXT-C ion thruster, Xenon is first ionised through electron bombardment where high energy electrons collide with Xenon atoms, stripping away an electron and turning the neutral Xenon atoms into Xenon ions. The Xenon ions are then accelerated to speeds of up to 40 km s^{-1} with respect to the thruster through a potential difference between two electrodes, creating ion jets. The ions are then expelled from the engine, creating thrust. The NEXT-C offers improved performance compared to other ion propulsion systems and is capable of producing up to 235 mN of thrust.

(a) Determine the percentage uncertainty in the diameter of Asteroid 2024 YR4.

percentage uncertainty = ……………………………….. % [2]

(b) **(i)** By considering the orbital motion of Dimorphos around Didymos, show that the period T of Dimorphos's orbit is related by the following expression

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

where G is the gravitational constant, r is the distance between the two asteroids and M is the mass of Didymos.

[2]

(ii) Hence, state and explain the change in the orbital radius of Dimorphos after DART's impact.

……………………………………………………………………………………..........

……………………………………………………………………………………..........

……………………………………………………………………………………..........

…………………………………………………………………………………….......... [2]

(c) **(i)** Define Rayleigh's Criterion.

……………………………………………………………………………………..........

…………………………………………………………………………………….......... [1]

(ii) Using Rayleigh's Criterion, determine the distance of DART from the Didymos-Dimorphos binary asteroid system for the two bodies to be just resolvable by DRACO before impact.

distance = …………………………………. m [2]

(d) **(i)** Suggest what is meant by a 'power-to-mass ratio of 120 W kg^{-1}.

……………………………………………………………………………........

……………………………………………………………………………........ [1]

(ii) Determine the power output delivered to DART by ROSA.

power output = …………………………………. W [2]

(e) **(i)** Suggest and explain a reason why Xenon is preferable as a fuel source compared to Argon or Krypton in ion thrusters.

……………………………………………………………………………........

……………………………………………………………………………........ [2]

(ii) Fig. 8.1 shows the two parallel electrodes in the NEXT-C ion thruster.
On Fig. 8.1, sketch 6 lines to represent the electric field between the plates.

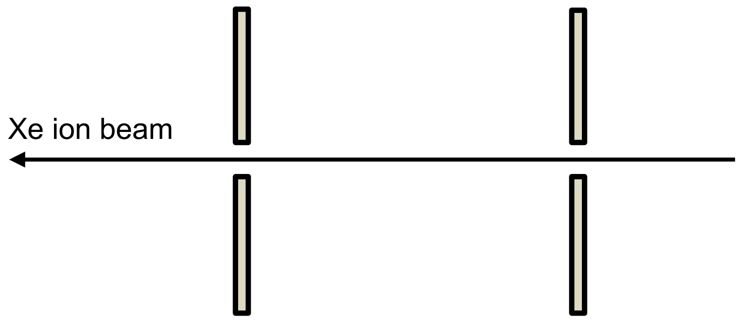


Fig. 8.1 [1]

(iii) Determine the potential difference between the two plates when Xenon ions are accelerated to its maximum exhaust speed.

potential difference = ... V [2]

(iv) Determine the number of Xenon ions being expelled per second by the NEXT-C ion thruster in order to achieve its maximum thrust.

number of Xenon ions expelled per second = ... s^{-1} [3]

[Total: 20]