**7** Read the passage below and answer the questions that follow.

Orbiting at about 1.52 times the average distance between the Earth and the Sun, Mars is the fourth planet from the Sun. Mars' diameter is approximately 53% of Earth's diameter and its mass is 11% of Earth's mass. Mars is covered by ice and dust, with surface temperature ranging from -140°C to +20°C. Compared to Earth, the atmosphere of Mars is quite rarefied with a mean pressure of 600 Pa at the surface.

On Feb 18 2021, after a 7-month journey, NASA's Perseverance rover touched down on Mars and began a mission that's meant to store up evidence of past life on Mars. Entry, Descent, and Landing (EDL), often referred to as the 7 minutes of terror, was the most intense phase of the mission. Due to limited bandwidth and an 11-minute delay in receiving signals, there was no live video footage of the landing.

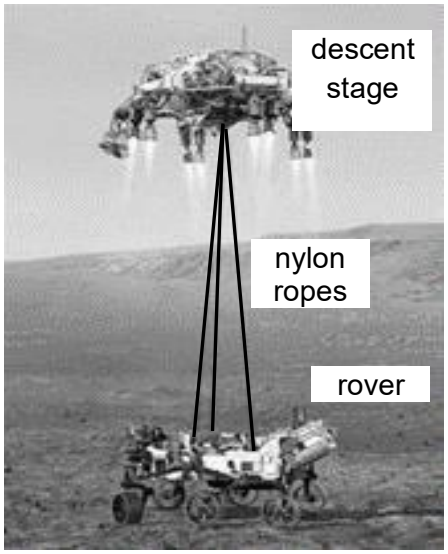


**Fig. 7.1**

EDL began when the spacecraft reached the top of the Martian atmosphere, travelling at nearly 20000 km $h^{-1}$. At about 11 km above the ground, the spacecraft deployed a parachute to slow itself to about 320 km $h^{-1}$. The parachute subsequently dropped away, and for a short time, the 1025-kg rover, which was still attached to a 1070-kg descent stage, fell freely towards the ground.

At about 2100 m above the surface, the descent stage fired its 8 retrorockets to level itself out and slow its final descent speed to about 2.7 km $h^{-1}$. At 20 m above the surface, the "skycrane" manoeuvre was initiated (see Fig. 7.1): the hovering descent stage lowered the rover at a constant speed on three nylon ropes. Once touchdown is detected, it cut the ropes, and made its own uncontrolled landing a safe distance away.

The rover carries a radioisotope power system that generates electricity from the heat of radioactive decay of Plutonium-238. Plutonium-238 is an alpha-emitter which generates about 0.57 W $g^{-1}$ and has a half-life of 87.7 years. At launch, the rover carried 4.1 kg of Plutonium-238 and generated approximately 110 W of electrical power.

Among other things, the rover will collect samples of rock and soil, study Mars' geology and explore the production of oxygen from carbon dioxide in the atmosphere. In addition, a drone-like helicopter

named Ingenuity will be deployed to demonstrate the first powered flight on Mars. Perseverance will explore Jezero Crater, near the planet's equator, for at least one Martian year.

**(a)** **(i)** Show that the gravitational field strength on the surface of Mars is 3.8 m $s^{-2}$.

[2]

**(ii)** Calculate the orbital period of Mars.

orbital period = ……... years [3]

**(b)** Based on the time delay in receiving signals on EDL, estimate the distance between Earth and Mars.

distance = …… km [1]

**(c)** Calculate the difference between the maximum and minimum surface temperature of Mars in kelvin.

temperature difference = …….. K [1]

**(d)** Use Newton's 2nd and 3rd Laws of Motion to explain how the interaction between the parachute and the atmospheric molecules generates a retardation force on the parachute.

……..……..……...

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……..……..……..

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……..……..……..

[2]

**(e)** **(i)** Assume that the drag force is negligible. Using your answer in **a(i)**, show that the thrust generated by each retrorocket during the "skycrane" manoeuvre is 1000 N.

[2]

**(ii)** If each retrorocket were ejecting its propellant at 1.7 kg $s^{-1}$, calculate the speed at which the propellant was being ejected.

speed = ..... m $s^{-1}$

[2]

**(iii)** Calculate the initial acceleration of the descent stage the moment the nylon ropes are cut.

acceleration = …….. m $s^{-2}$ [2]

**(f)** **(i)** Calculate the efficiency of the radioisotope power system in converting the heat of radioactive decay into electrical power.

efficiency = …….. % [1]

**(ii)** Calculate the energy released by each alpha decay of plutonium-238.

**DO NOT ATTEMPT!**

energy released = …… eV [2]

**(iii)** Besides its high power density, suggest, with brief explanation, another reason plutonium-238 was chosen as the radioactive isotope to be used.

**DO NOT ATTEMPT!**

……..……..…… [1]

**(g)** Compared to conditions on Earth, certain conditions on Mars are advantageous while others are disadvantageous, to the powered flight of a helicopter. State, with brief explanation, one condition for each.

Advantage:

……

……

……

Disadvantage:

……

……

……

[2]

[Total: 21; 18 to be attempted]

**End of paper**