9 In 2022, the European Space Agency (ESA) launched the Solar Orbiter, a spacecraft designed to study the Sun's surface and its radiation. The spacecraft operates in an elliptical orbit, with its closest approach (perihelion) at 0.28 AU (1 AU = 1.5×10^{11} m) from the Sun on 15 March 2023. The Solar Orbiter observed a significant solar flare, during which its distance from the Sun varied slightly, affecting the power received by its solar panels.

The Sun emits electromagnetic waves where the power output is approximately 3.8×10^{26} W from these waves, excluding other high-energy particles. The Solar Orbiter's solar panels capture this radiation to power its instruments, with the power received depending on the intensity, panel area, and efficiency.

Radiation pressure P_r due to electromagnetic waves is given by:

$$P_r = \left(\frac{I}{c} + R\right)$$

where I is the intensity, c is the speed of light and R is the reflectivity. $R = 0$ for perfect absorption and $R = 1$ for perfect reflection.

The Sun also emits high-energy particles, including alpha particles from nuclear fusion, contributing to radiation pressure on the spacecraft.

The Solar Orbiter's radiation detector measures alpha particle flux from short-lived isotopes produced in solar flares, such as Nitrogen-13, which undergoes alpha decay with a half-life of 20 minutes and beta-plus decay with a half-life of 10 minutes. Beta-plus decay is a process where a proton in a nucleus transforms into a neutron, releasing a positron ${}^{0}_{+1}e$ and a neutrino. For a given sample size, the probability of an alpha decay is 1% and beta-plus decay is 99%.

During the solar flare, the Solar Orbiter's distance from the Sun varied from 0.28 AU to 0.30 AU over 10 hours due to its orbital motion. Data for the Solar Orbiter is provided in Table 9.1.

Table 9.1

parameter	value
distance from Sun	0.28 AU
solar panel area	6.5 m^2
efficiency of solar panels	28%
radiation detector sensitivity	1.2×10^4 counts s^{-1} GBq^{-1}

Table 9.2 shows the percentage contribution of radiation pressure at perihelion.

Table 9.2

source	percentage contribution (%)
electromagnetic waves	99.8
alpha particles	0.15
other particles (Beta, Protons)	0.050

(a) **(i)** Show that the intensity of solar radiation at the Solar Orbiter's perihelion due to electromagnetic waves is 1.7×10^{4} W m^{-2}.

intensity = …………………..……….. W m^{-2} [2]

(ii) Determine the power output by the Solar Orbiter's solar panels at perihelion due to electromagnetic waves, accounting for their efficiency. Assume that there is perfect absorption.

power output = ………………….…………. W [2]

(b) Radiation pressure is the force per unit area from momentum transfer by electromagnetic waves or particles.

(i) Show that the radiation pressure exerted by alpha particles on the Solar Orbiter's solar panels at perihelion is 8.5×10^{-8} Pa . Assume that there is perfect absorption.

[1]

(ii) Show that kinetic energy

$$E_k = \frac{p^2}{2m}$$

where p and m refer to the momentum and mass respectively.

[2]

(iii) Alpha particles from solar flares typically have energies of 5.0 MeV upon reaching the Solar Orbiter's solar panels. Use the value in **(b)(i)** and the expression in **(b)(ii)**, determine the rate at which alpha particles are incident on the panels.

rate = …………………….……… particles s^{-1} [3]

(c) At one point in time, the radiation detector measures a count rate of 3.6×10^5 counts s^{-1} due to Nitrogen-13 decay during a solar flare. Calculate the activity of the Nitrogen-13 source in GBq.

activity = ……………………………… GBq [2]

(d) A sample of 2.2×10^{-11} kg of Nitrogen-13 is collected for a study.

(i) Calculate the decay constants λ_α and λ_β of Nitrogen-13 undergoing alpha decay and beta decay respectively.

λ_α = ……………………………… min^{-1} [1]

λ_β = ……………………………… min^{-1} [1]

(ii) Show that the effective decay constant λ_{eff} of Nitrogen-13 is 6.9×10^{-2} min^{-1}. [1]

(iii) Using the value in **(d)(ii)**, calculate the number of Nitrogen-13 nuclei remaining after 15 minutes.

number of nuclei = …………………………………… [3]

(iv) ${}^{13}_{7}N$ decays to form a stable isotope ${}^{13}_{6}C$. Write the nuclear equation for this decay process.

…….. [1]

(e) Suggest why the Solar Orbiter's power output from its solar panels varies significantly during its orbit around the Sun.

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

[Total: 20]