Oxford Cambridge and RSA

A level Physics B

H557/01 Fundamentals of physics

Question Set 22

1 (a) This question is about propulsion systems for spacecraft.

A solar sail uses the momentum of photons in solar radiation for propulsion.

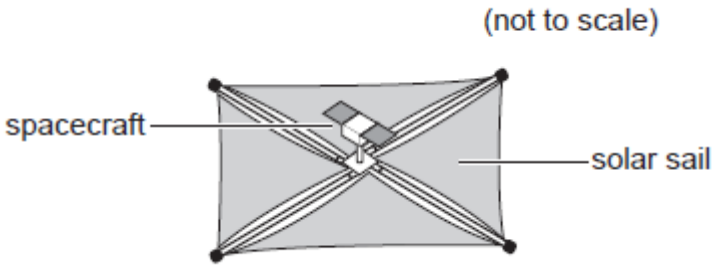

Fig.1.1

Relativity shows that a photon of energy E has momentum $p = \frac{E}{c}$.

(i) Show that $\frac{E}{c}$ has the units of momentum.

[1]

(ii) The total photon power of the radiation received from the Sun on a 1.0 m^2 area of solar sail is P.

Show that the thrust force T from photon reflection is given by $T = \frac{2P}{c}$.

Assume that the Sun's rays are normal to the sail and all the radiation is reflected.

[3]

(iii) The total photon power density is 1400 $W\,m^{-2}$.
The 1.0 tonne spacecraft has a 10^6 m^2 solar sail.

Calculate the acceleration of the spacecraft.

acceleration = ……..$m\,s^{-2}$ **[2]**

(b) An ion drive uses the momentum of ions for propulsion. It ionises a gas and uses an accelerating field to accelerate the positive ions to a high velocity.

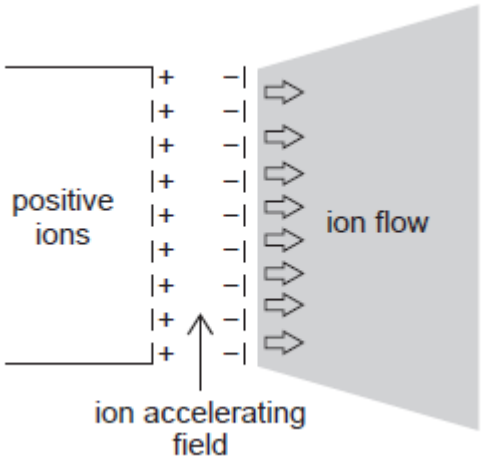

Fig. 1.2

(i) A positive ion of charge Q and mass m is accelerated through a p.d. V. Show that the momentum per unit mass $\frac{p}{m}$ it gains is given by the expression

$$\frac{p}{m} = \sqrt{2V\left(\frac{Q}{m}\right)}.$$

[2]

(ii) Discuss an advantage of using ions of hydrogen $^{1}H^{+}$ as propellant instead of xenon $^{130}Xe^{+}$.

[2]

(iii) An ion drive with accelerating p.d. $V = 2000\,V$ must produce a thrust of $0.24\,N$.

Show that the mass flow rate $\frac{\Delta m}{\Delta t}$ is less than $4 \times 10^{-7}\,kg\,s^{-1}$.

$\frac{Q}{m}$ for $^{1}H^{+}$ ions $= 9.6 \times 10^{7}\,C\,kg^{-1}$.

[2]

Total Marks for Question Set: 12