9 **(a)** The Sun is a star that comprises mainly of hydrogen nuclei (protons). It derives its large radiative power from nuclear fusion. The nuclear reactions responsible for energy generation in the Sun, collectively known as the proton-proton chain reactions, are listed as follows:

I. $^{1}_{1}\text{H} + ^{1}_{1}\text{H} \rightarrow ^{2}_{1}\text{H} + ^{0}_{1}e + \text{ other radiations}$

II. $^{2}_{1}\text{H} + ^{1}_{1}\text{H} \rightarrow ^{3}_{2}\text{He} + \text{energy}$

III. $^{3}_{2}\text{He} + ^{3}_{2}\text{He} \rightarrow ^{4}_{2}\text{He} + n\ ^{A}_{1}\text{Y} + \text{ energy}$

where $^{0}_{1}e$ denotes a positron. A positron is a particle with the same mass as an electron but having a charge of $+e$.

(i) For reaction III, identify the number *n* and name the particle Y

n = ... [1]

Y = ... [1]

(ii) Deuterons ($^{2}_{1}\text{H}$) are produced in reaction I. Suggest a reason why reactions II and III are observed in the formation of helium-4 instead of the following one:

$$^{2}_{1}\text{H} + ^{2}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + \text{ energy}$$

.... [1]

(iii) Reactions I to III can be combined into one overall reaction:

$$4\,^{1}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + 2\,^{0}_{1}e + \text{ energy}$$

It is given that

mass of proton:	1.007276 *u*
mass of alpha particle:	4.001506 *u*
mass of positron:	0.000585 *u*

where *u* is the atomic mass unit.

Calculate the amount of energy released in one such reaction.

energy = ... J [3]

(b) The Earth is at a distance of 1.5×10^{11} m away from the Sun. The maximum intensity of sunlight at the Earth's surface can reach as high as 1400 W m^{-2} at normal incidence.

(i) Use the above information to determine the amount of energy generated by the Sun in one second.

energy generated per second = ... W [2]

(ii) Hence, determine

1. the number of nuclear reactions described in **(a)(iii)** that occur in the Sun every second.

reactions per second = ... [1]

2. the time taken for the Sun to be depleted of hydrogen, assuming that the total mass of the hydrogen in the Sun is now 2.0×10^{30} kg and the rate of nuclear reactions remain constant until all the hydrogen is depleted.

time taken = ... s [2]

(c) Apart from electromagnetic radiation, the Sun also showers the Earth with a large number of protons with very high kinetic energy. When these protons collide with the atoms in the atmosphere, they produce neutrons which in turn react with nitrogen in the air to form carbon-14:

$$^{14}_{7}\mathrm{N} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{14}_{6}\mathrm{C} + {}^{1}_{1}\mathrm{H}$$

Carbon-14 is radioactive with a half-life of 5730 years. In atmospheric carbon dioxide, about 1 out of 10^{12} carbon atoms are carbon-14. During photosynthesis, green plants take in carbon dioxide and convert them into carbon compounds. Because the mixing of carbon-14 with carbon-12 is efficient, all living things have the same ratio of carbon-14 to carbon-12.

(i) Define *half-life*.

.... [1]

(ii) Carbon-14 decays spontaneously into nitrogen-14. Write down the equation for this reaction.

[1]

(iii) The radioactivity of a 33.3 g piece of charcoal, assumed to be pure carbon, found from the remains of an ancient campfire is measured to be 0.4 counts per second. This value was derived from a measurement of 240 decays over 10 minutes.

1. Explain why, for this piece of charcoal, it is a good experimental practice to measure the number of decays over 10 minutes rather than 1 minute or 1 second.

.... [2]

2. In living wood, 1 out of 10^{12} carbon atoms are carbon-14.
Show that the number of carbon atoms in this piece of charcoal is about 1.67×10^{24}.
Hence estimate the age of this piece of charcoal.

age = ... years [5]

[Total: 20]