18 At the Culham Centre for Fusion Energy (CCFE) experiments are carried out to investigate nuclear fusion and the properties of plasmas. A plasma consists of ionised gas, containing positive ions and electrons.

(a) In a fusion experiment at CCFE, ions of two isotopes of hydrogen fuse to produce helium ions and fast-moving neutrons.

$$^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

Show that a single fusion reaction releases about 3×10^{-12} J of energy.

mass of $^{2}_{1}\mathrm{H}$ = 2.013553 u

mass of $^{3}_{1}\mathrm{H}$ = 3.015501 u

mass of $^{4}_{2}\mathrm{He}$ = 4.001506 u

mass of $^{1}_{0}\mathrm{n}$ = 1.008665 u

(4)

(b) Fusion occurs naturally in the core of stars.

Explain why very high densities of matter and very high temperatures are needed to bring about and maintain nuclear fusion in stars.

(2)

(c) In a plasma experiment 5.0 mg of deuterium, an isotope of hydrogen, occupies a volume of 98 m^3. The temperature of deuterium is raised to 1.3×10^{8} K. In this experiment, the deuterium behaves as an ideal gas.

(i) Calculate the pressure due to the deuterium ions.

mass of deuterium ion = 3.3×10^{-27} kg

(3)

Pressure = ...

(ii) Calculate the root mean square speed of the deuterium ions at this temperature.

(2)

Root mean square speed = ...

(iii) The temperature of the plasma is monitored using the Doppler effect. Light from a laser is directed into the plasma and the wavelength of the light reflected is measured.

The Doppler shift observed when light is reflected by a deuterium ion is twice the Doppler shift that would be observed for a source of light moving at the same speed as the deuterium ion.

Calculate the maximum wavelength of light that would be detected after reflection from a deuterium ion moving at 1.5×10^{6} m s^{-1}.

wavelength of laser light = 1064 nm

(3)

Maximum wavelength detected = ...

(Total for Question 18 = 14 marks)