The core collapses and, by a means not well understood, the outer layers of the star are flung off in a huge explosion – a Type II supernova. [4.3]

(b) The neutrinos will interact with the gas hardly at all, so virtually all of them pass through the gas. Therefore the energy they deposit in the gas is negligible. The electromagnetic radiation carries 100 times less energy than the kinetic energy of the ejected shell of gas, and a smaller fraction of it is absorbed, so the radiation can be ignored. [5.3.1]

We are thus left with 5×10^{-5} of the shell kinetic energy.

We use the given equation

$$e_k = 3kT/2$$

where e_k is the thermal translational kinetic energy of the gas particles, which we can take to be hydrogen atoms mass of m_H. If the increase in temperature is ΔT, then the average increase in kinetic energy per hydrogen atom is given by

$$\Delta e_k = 3k\Delta T/2$$

The number of hydrogen atoms is $10M_\odot/m_H$, so the total increase in the kinetic energy of the gas is given by

$$\Delta E = (10M_\odot/m_H)(3k\Delta T/2)$$

and so

$$\Delta T = \Delta E \times \frac{2}{3k} \times \frac{m_H}{10M_\odot}$$

Using the values given in the question and elsewhere in the paper,

$$\Delta T = (5 \times 10^{-7} \times 10^{46}\,\text{J}) \times \frac{2}{3 \times 1.38 \times 10^{-23}\,\text{J K}^{-1}} \times \frac{1.67 \times 10^{-27}\,\text{kg}}{10 \times 1.99 \times 10^{30}\,\text{kg}}$$

$$= 2 \times 10^4\,\text{K}$$

[It is likely that your method would differ in detail from ours – full marks would be given for any valid approach.]

PART III

Question 4

[Book 2 (sub)sections are given.]

(a) Impacts between planetary embryos (giant impacts) will have involved sufficient kinetic energy for the resulting body to be largely or entirely melted. This is known as accretional heating. [3.3.2]

This will have allowed denser, iron-rich material to segregate inwards, and less-dense silicate material to rise upwards, probably forming a magma ocean at first. [3.3.2]

Differentiation will have been further accentuated by radiogenic heating. [3.3.2 and 3.5.2]

[No marks would be given for tidal heating, which is not applicable to Mars, or for core formation, which is a consequence rather than a cause of differentiation.]

Material crystallizing at the top of the magma ocean after the final giant impact would be the primitive crust, though the present crust is probably much modified by volcanism. [3.3.2]

(b) The innermost layer is the core. In Mars this is likely to be iron-rich. [Nickel–iron, or iron and sulphur, are equally acceptable.] This is overlain by a mantle of silicate composition, probably peridotite. This in turn is overlain by a crust, also silicate, but richer in silica (SiO_2) than the mantle. [3.2.3 and 3.3.1]