ASTROPHYSICS

2-4 Supernovae, neutron stars and black holes

1. (a) The collapse of a giant star occurs when there are no longer any nuclei in the core that release energy when fused. This happens when fusion creates iron nuclei which are more stable than any other nuclei so no further energy release by fusion is possible. There is then not enough outward pressure to counteract the gravitational attraction pulling inwards and the star therefore collapses inwards.
For masses less than 1.4 solar masses the star stabilises as a white dwarf as there is sufficient electrostatic repulsion in the core as it is compressed to counteract the gravitational attraction.

   For masses greater than 1.4 solar masses the electrons are forced into combination with protons to form neutrons and there is therefore no electrostatic repulsion to counteract the gravitational attraction.

   $$p + e^- \rightarrow n + \nu_e$$

   (b) When the neutrons formed as a result of collapse of the core can no longer be forced any closer, the core becomes rigid. The matter collapsing inwards towards the core hits the rigid core and then rebounds off it.

2. (a) A neutron star

- has a size much smaller than that of the Sun
- has a much stronger gravitational force at its surface than the Sun (> 2×10^9 times stronger)
- for the same mass, is much, much smaller (d ~ 30 km)
- can produce beams of radio waves (pulsars)

(b) (i) The mass has to be greater than 1.4 solar masses otherwise the electrons would not be forced to react with protons and form neutrons (a white dwarf would be formed instead).

(ii) If the mass exceeds 3 solar masses then the neutron star undergoes further collapse to become a black hole.

3. (a) Supernovae are observed when a star suddenly becomes about 1×10^9 times more luminous than the Sun within 24 hours. A sudden change of about 20 magnitudes in the absolute magnitude is a tell-tale sign.

(b) A white dwarf supernova is characterised by a strong silicon line in the spectrum.

4. (i) A black hole is an object that is so dense that not even light can escape from it.

- it emits no light
- it absorbs any photons incident on it
- it attracts and traps any surrounding matter
- it has mass
- it may be charge
- it may rotate

(ii) Supermassive black holes can be found by looking at the centre of galaxies and observing the stars close to the centre.

(b) (i) $M = 2.0 \times 10^{30}$ kg, $c = 3.00 \times 10^{8}$ ms^{-1}, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

Schwarzchild radius $R_S = \dfrac{2GM}{c^2} = = \dfrac{6.67 \times 10^{-11} \times 2.0 \times 10^{30}}{(3.00 \times 10^{8})^2}$ = 2964 m = 3.0×10^3 m to 2 sf

(ii) Volume of a sphere = $\frac{4}{3}\pi r^3$

Density = $\dfrac{\text{mass}}{\text{volume}} = \dfrac{2.0 \times 10^{30}}{\frac{4}{3}\pi \times (3.00 \times 10^{3})^{3}}$ = $1.83... \times 10^{19}$ kgm^{-3} = 1.8×10^{19} kgm^{-3} to 2 sf

(c) New black hole mass = 10 million solar masses

= 1.0×10^7 times the previous black hole

= 2.0×10^{37} kg

New Schwarzchild radius = 1.0×10^7 x old radius = 3.0×10^{10} m

Hence new density = $\dfrac{2.0 \times 10^{37}}{\frac{4}{3}\pi \times (3.00 \times 10^{10})^{3}}$ = 1.8×10^5 to 2 sf

(i.e. changes by a factor of $\dfrac{1.0 \times 10^{7}}{(1.00 \times 10^{7})^{3}}$ or 1.0×10^{-14})