at this time has been shifted to a longer wavelength that now peaks at around 7cm – in the microwave region of the spectrum. At earlier times the photons would have been much more energetic and of far shorter wavelengths, peaking in the visible or ultraviolet region of the electromagnetic spectrum.

The CMB in the sky looks the same in all directions (isotropic) and does not vary with the time of day; this provides compelling support for the Big Bang model.

State two features of the CMB radiation which are consistent with the Big Bang model.

CMB has a black-body spectrum.
Wavelength is stretched by expansion.
Is highly isotropic/homogenous.
But, has minor anisotropies predicted by Big Bang model.

[2 marks]

Describe how the CMB provides evidence for the Hot Big Bang model of the universe.

The universe is expanding and so the wavelength of the CMB in the past was much smaller, which indicates a very high temperature at the beginning.

[2 marks]

The redshift equation and the Cosmic Scale Factor

$$z = \frac{\Delta \lambda}{\lambda_0} \approx \frac{v}{c}$$

Where,
z = Redshift ratio
λ_0= The wavelength when it was emitted
$\Delta \lambda$= The amount by which the wavelength has stretched by

$$z = \frac{\Delta \lambda}{\lambda_0} = \frac{\Delta R}{R_0} = \frac{R - R_0}{R_0} = \frac{R}{R_0} - 1$$

Type Ia supernovae and the accelerating universe:

In the late 1990s, type Ia supernovae were found to offer key evidence regarding the expansion of the universe. By using type Ia supernovae as standard candles to estimate galactic distances up to around 1000 Mpc and measuring their redshifts, strong evidence was obtained suggesting the universe might currently be undergoing an accelerated expansion. The universe is known to contain a significant amount of ordinary matter that tends to slow down its expansion. Acceleration, therefore, would require some sort of invisible energy source and, although none had been directly observed, it has been named 'dark energy'.

- S-process (slow neutron capture)

These stars provide a fairly small neutron flux as a by-product of carbon, oxygen and silicon burning. This means there is time for the nuclides to under-go beta decay before further neutron captures build up their nucleon number – producing successively heavier isotopes of the original element.

- R-process (rapid neutron capture)

There is insufficient time for beta decay to occur so successively heavier isotopes are built very quickly, one neutron at a time. Type II supernova produce a very high neutron flux and form very heavy nuclides. This is something that does not appear to happen in the massive stars. There is also a high neutrino flux in a supernova and this has the effect of causing neutrons to convert into protons through the weak interaction, forming new element.

Massive stars that have left the main sequence have a layered structure with different chemical elements in different layers. Discuss this structure with reference to the nuclear reactions taking place in such stars.

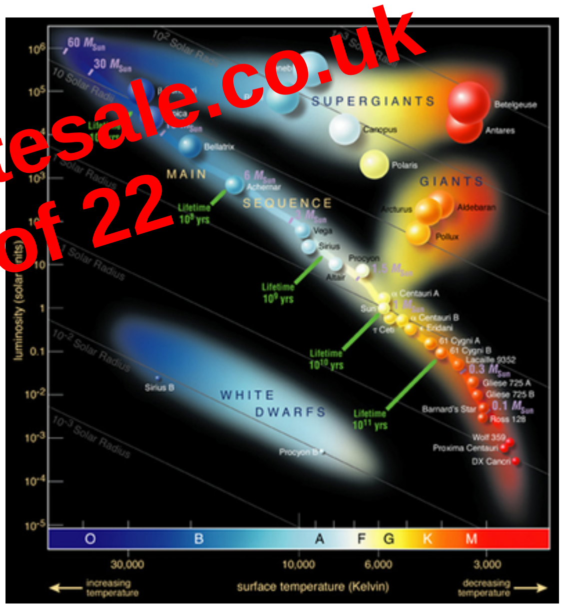
Nuclear fusion reactions produce ever heavier elements depending on the mass of the star/temperature of the core. The elements/ nuclear reactions arrange themselves in layers, heaviest at the core, lightest in the envelope.

[2 marks]

<u>Lifetimes of main sequence stars</u>

- The more mass a star has, the shorter its lifetime. This is because they need higher core temperatures and pressures to prevent them from collapsing under gravity. This means that fusion proceeds at a faster rate than in stars with lower mass. Therefore, massive stars use up their core hydrogen more quickly and spend less time on the main sequence than stars of lower mass.

$$L \propto M^{3.5}$$



Luminosity is the total energy, E, released by the star per unit time while hydrogen is being fused or

$$L = \frac{E}{t}$$

While fusion occurs, the energy emitted is accompanied by a loss of mass. This will amount to a proportion, k of the total star mass during its lifetime – so a star of mass, M, loses a mass kM. Since E = mc^2, the energy emitted during the hydrogen burning phase of a star's life gives E = kmc^2. It average luminosity is given by:

$$L = \frac{kMc^2}{\tau}$$

Where,
τ = the Lifetime of a star

Using these equations, we can deduce that;

The type II emits light up to 10^9 times the luminosity of the Sun; however, the burst falls a little before reaching a slight plateau where it stays for some days before falling away more rapidly.

Explain how the observation of type Ia supernovae led to the hypothesis that dark energy exists.

Distant supernovae were dimmer/further away than expected.
Hence, the universe is accelerating.
Dark energy is a hypothesis that explains this.

[3 marks]