ASTROPHYSICS

3-2 Hubble's law and beyond

1. (a) Hubble's law states that the speed of recession of a galaxy, v, is proportional to its distance away (e.g. from Earth), d.

i.e. $v = Hd$ where H is the Hubble constant.

(b) This law leads to the conclusion that the Universe is expanding because the further away the galaxy is, the faster it's moving. This would apply everywhere so all the galaxies are moving away from each other hence the Universe is expanding.

2. laboratory $\lambda = 589.6 \text{ nm} = 589.6 \times 10^{-9} \text{ m}$

Galaxy $\lambda = 597.2 \text{ nm} = 597.2 \times 10^{-9} \text{ m}$

So $\Delta\lambda = (597.2 - 589.6) \text{ nm} = 7.6 \times 10^{-9} \text{ m}$

$\Delta\lambda = \frac{v\lambda}{c}$ therefore $v = \frac{\Delta\lambda\, c}{\lambda} = \frac{7.6 \times 10^{-9} \times 3.0 \times 10^{8}}{589.6 \times 10^{-9}}$ $= 3.867\ldots \times 10^{6}$ $= 3.9 \times 10^{6} \text{ ms}^{-1}$ to 2 sf

$= 3.9 \times 10^{3} \text{ km s}^{-1}$

$v = Hd$ therefore $d = \frac{v}{H} = \frac{73.9 \times 10^{3} \text{ km s}^{-1}}{65 \text{ km s}^{-1} \text{ Mpc}^{-1}} = 59.4\ldots = 59 \text{ Mpc}$ to 2 sf

3. The Big Bang Theory was accepted because:

- the theoretical spectrum from an object at 2.7 K matched the actual microwave spectrum from space and was the same in all direction (2.7 K corresponds to the mean temperature of the Universe). This is because the radiation has been travelling since the Big Bang and expansion has increased the wavelength.

- calculations from the Big Bang Theory predicted a proton-neutron ratio of 7:1, which is what is found from the abundance of helium and hydrogen in the Universe which makes up most of matter.

4. (a) apparent magnitude, m = +24

Absolute magnitude, M = -18

$$m - M = 5 \log\left(\frac{d}{10}\right)$$

$$+ 24 - (-18) = 5 \log\left(\frac{d}{10}\right)$$

$$5 \log\left(\frac{d}{10}\right) = \frac{42}{5}$$

$$\frac{d}{10} = 2.51\ldots \times 10^{8} \text{ pc}$$

$$d = 2.5 \times 10^{9} \text{ pc} = 2500 \text{ Mpc}$$

(b) Hubble's law measurements of the redshift of 1a supernovae and luminosity measurements for 1a supernovae using M = -18 give different results for the supernova distances. That indicates that they are dimmer and further away than their red shift indicates. This suggests that the expansion of the Universe is accelerating rather than decelerating, as these distant objects are further away than expected.