Question 19 **(19 marks)**

Hubble's law states:

From this law comes Hubble's equation:

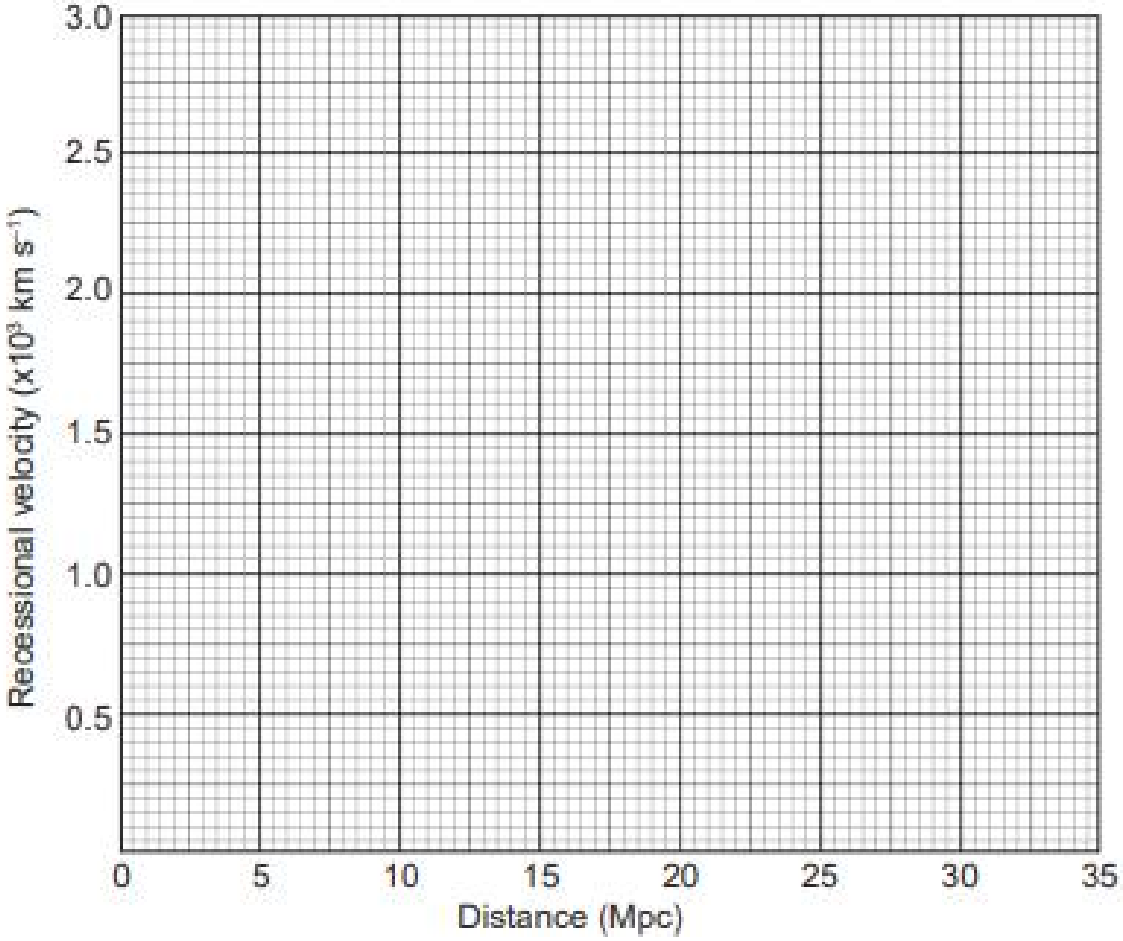
$$v = H_0 d$$

where v = recessional velocity
d = distance from the Earth
H_0 = Hubble's constant.

Below is some data Hubble used to graphically determine his constant.

Galaxy	Distance (Mpc)	Velocity (x10^3 km s^{-1})
NGC 1357	24.7	2.19
NGC 1832	31.0	2.82
NGC 2775	17.9	1.46
NGC 2903	6.96	0.45
NGC 3368	11.9	0.88

(a) Graph the recessional velocity versus distance on the set of axes provided below and draw a line of best fit. Do not take your line through the origin. (3 marks)



(b) Use two **non-data** points on your line of best fit to calculate Hubble's constant. Circle the two points you used and give your answer to two significant figures. (4 marks)

_____ 10^3 km s^{-1} Mpc^{-1}

Hubble measured the red shift of the galaxies to calculate their recessional velocities.
The equation for the Doppler effect is shown below:

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

$\Delta\lambda$ = wavelength shift
λ_0 = wavelength of source not moving
v = velocity of source – line of sight
c = speed of light.

(c) (i) The galaxy NGC 2013 is 7.42 x 10^7 ly away from the Earth. Convert this distance into megaparsecs (Mpc). (2 marks)

_____ Mpc

(ii) Using your line of best fit and the value from part (c)(i), calculate the observed red-shifted wavelength emitted from NGC 2013 if λ_0 is 840.0 nm. (6 marks)

_____ nm

(d) In Hubble's early data, he noticed that one particular spiral galaxy close to the Earth, seen edge on, had two values of v at its extremes. One was positive and one was negative. Assuming this was not an instrumental or human error, explain how this could occur. (4 marks)