HOLY CROSS COLLEGE

12 ATAR Physics

Hubble's Law (Part 1) 2019

Name: SOLUTIONS **Mark:** 27

The Big Bang Theory & Hubble's Law

The Big Bang Theory is the prevailing cosmological model for the universe from the earliest known periods through its subsequent large-scale evolution. The model accounts for the fact that the universe expanded from a very high density and high temperature state (called a singularity) and offers a comprehensive explanation for a broad range of phenomena, including the abundance of light elements, the cosmic microwave background, large-scale structure and Hubble's Law.

Since Georges Le Maître first noted, in 1927, that an expanding universe might be traced back in time to an originating single point, scientists have built on his idea of cosmic expansion. In 1929, from analysis of galactic redshifts, Edwin Hubble concluded that galaxies are drifting apart. This is important observational evidence consistent with the hypothesis of an expanding universe.

1. Research the following points, including appropriate formulae.

   - What is Hubble's Law and how was it determined?
   - What did Hubble find about the expanding universe?
   - How was the Doppler effect important in Hubble's work? Include information about "red-shift" and its measurement.
   - How can Hubble's Law be used to calculate the age of the universe?
   - How is the recessional velocity of a galaxy calculated?
   - What is the currently-accepted value for Hubble's constant?

2. Use the table below and your digital device to collect your data. This data will be required for completion of the second stage of this investigation.

https://en.wikipedia.org/wiki/NGC_5001

New General Catalogue (NGC) Table

NGC #	Distance (ls)	Recessional Speed (kms^{-1})	Distance (Mpc)
5005	65×10^6	946	20
5010	140×10^6	2975	43
5055	37×10^6	484	11
5078	94×10^6	2168	29
5248	59×10^6	1151	18
5408	15.7×10^6	506	5

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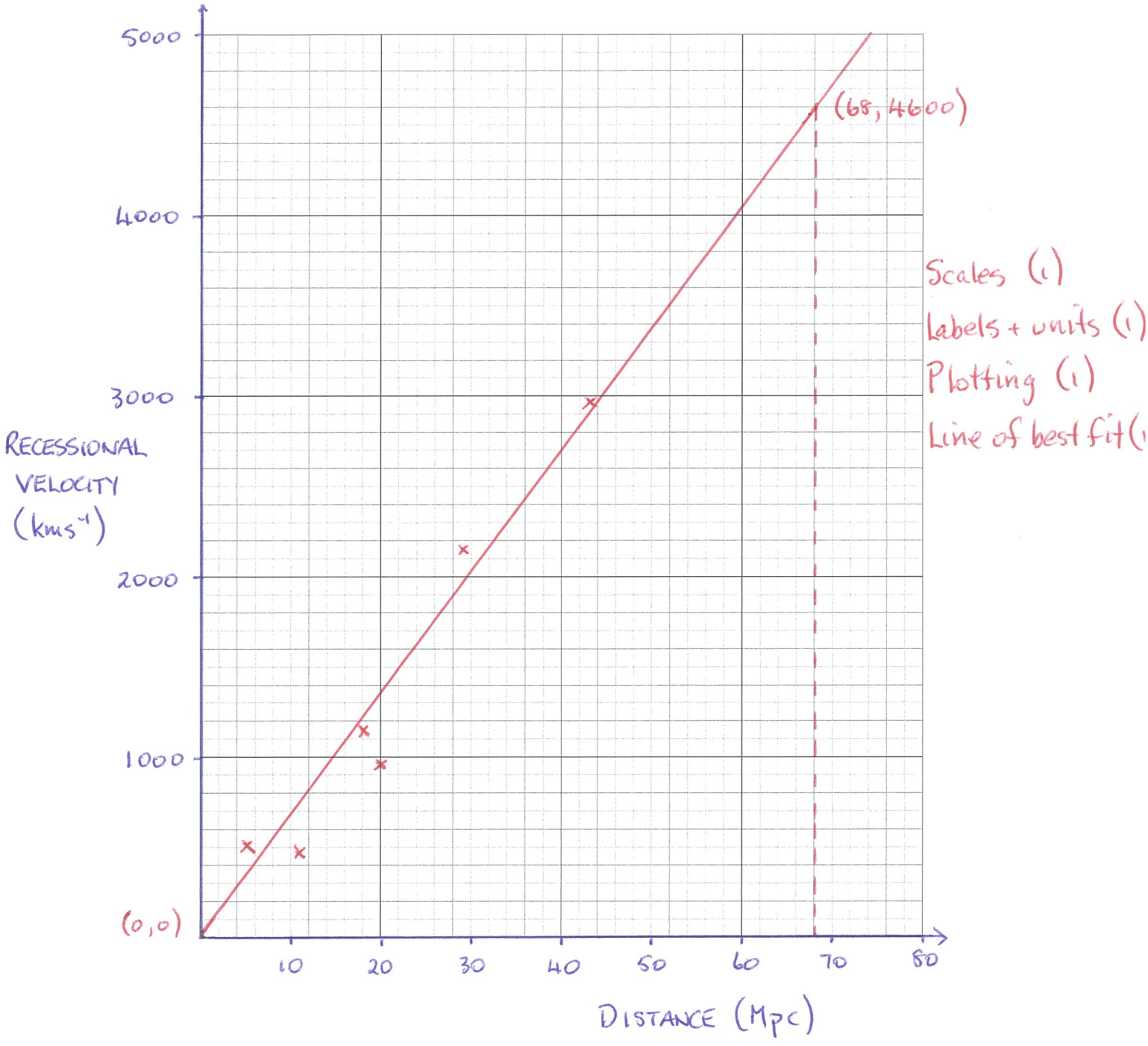
Hubble's Law (Part 2) 2019

Name: SOLUTIONS **Mark:** 27

The Big Bang Theory & Hubble's Law

1. Using the data points collected previously in part 1, plot a correctly-labelled graph to determine an accurate value of Hubble's constant.

[4 marks]



2. Use the graph to calculate a value for Hubble's constant, including the correct units.

[4 marks]

gradient = H_0 = $\frac{(4600-0)}{(68-0)}$ (1) (1)

= 68 $kms^{-1} Mpc^{-1}$ (1) (1) [Units worth 1 mark]

3. Determine the age of the universe (in billions of years) according to the data you have graphed.

[4 marks]

$t_{universe} = \frac{1}{H_0}$ (1)

$= \frac{1}{68}$

$= 1.47 \times 10^{-2}$ s Mpc km^{-1} (1)

As 1.00 Mpc = 3.09×10^{19} km:

$t_{universe} = (1.47 \times 10^{-2})(3.09 \times 10^{19})$ (1)

$= 4.54 \times 10^{17}$ s

$= 1.44 \times 10^{10}$ yr

= 14 billion years (2 sig. fig) (1)

4 A line in the spectrum of ionised potassium has a wavelength of 422.3 nm when measured in the laboratory. When similar light from the galaxy NGC 5170 is measured, its wavelength is 424.4 nm.

(a) Calculate the red-shift of this galaxy. [3 marks]

$$z = \frac{\Delta\lambda}{\lambda} \quad (1)$$

$$= \frac{(424.4 - 422.3) \times 10^{-9}}{422.3 \times 10^{-9}} \quad (1)$$

$$= 4.97 \times 10^{-3} \quad (1)$$

(b) Calculate the recessional speed of this galaxy in kms^{-1}. [3 marks]

$$z = \frac{v}{c} \quad (1)$$

$$\Rightarrow v = (4.97 \times 10^{-3})(3.00 \times 10^{8})$$

$$= 1.49 \times 10^{6}\ ms^{-1} \quad (1)$$

$$= 1.49 \times 10^{3}\ kms^{-1} \quad (1)$$

(c) For the recessional speed previously calculated, use your graph to determine the distance to this galaxy in Mpc. [1 mark]

22 Mpc ($\pm$ 3 - depends on line of best fit)
(1)

(d) Determine how many years it takes for light from galaxy NGC 5170 to reach Earth. [2 marks]

distance $= (22)(3.26 \times 10^6)$ (1)

$= 7.2 \times 10^7$ ly.

$\therefore t = 7.2 \times 10^7$ yr (1)

5. (a) What is meant by the term "red-shift"? Use the following diagram to assist your explanation. [2 marks]

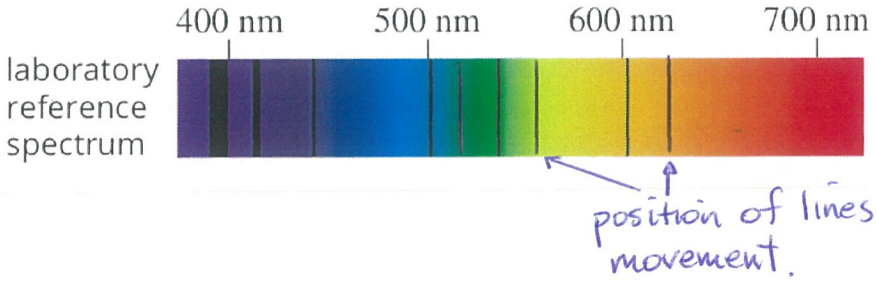


Diagram used appropriately. (1)

- The absorption lines appear to move towards the red end of the spectrum. (1)

(b) What did Hubble find when he observed the light from distant galaxies, as compared to light from closer galaxies? [2 marks]

- Light from distant galaxies is more red-shifted than that from closer galaxies. (1)
- Distant galaxies are moving faster and away from us. (1)

(c) How do Hubble's observations support the concept of an expanding universe?
[2 marks]

- Hubble postulated that space was expanding faster at greater distances from the Earth. (1)
- By running this expansion backwards, the origin of the universe is seen as a singularity. (1)