Physics 12: Second-hand Data Test 2017.

Name: Solutions. (18 marks)

When source of waves moves, the waves it emits change frequency relative to a stationary observer. This applies to both transverse and longitudinal (sound) waves. As a car moves away from you the frequency of the sound you hear is lower than the frequency it is emitting. A similar effect using radar waves is used by police to measure the speed of cars.

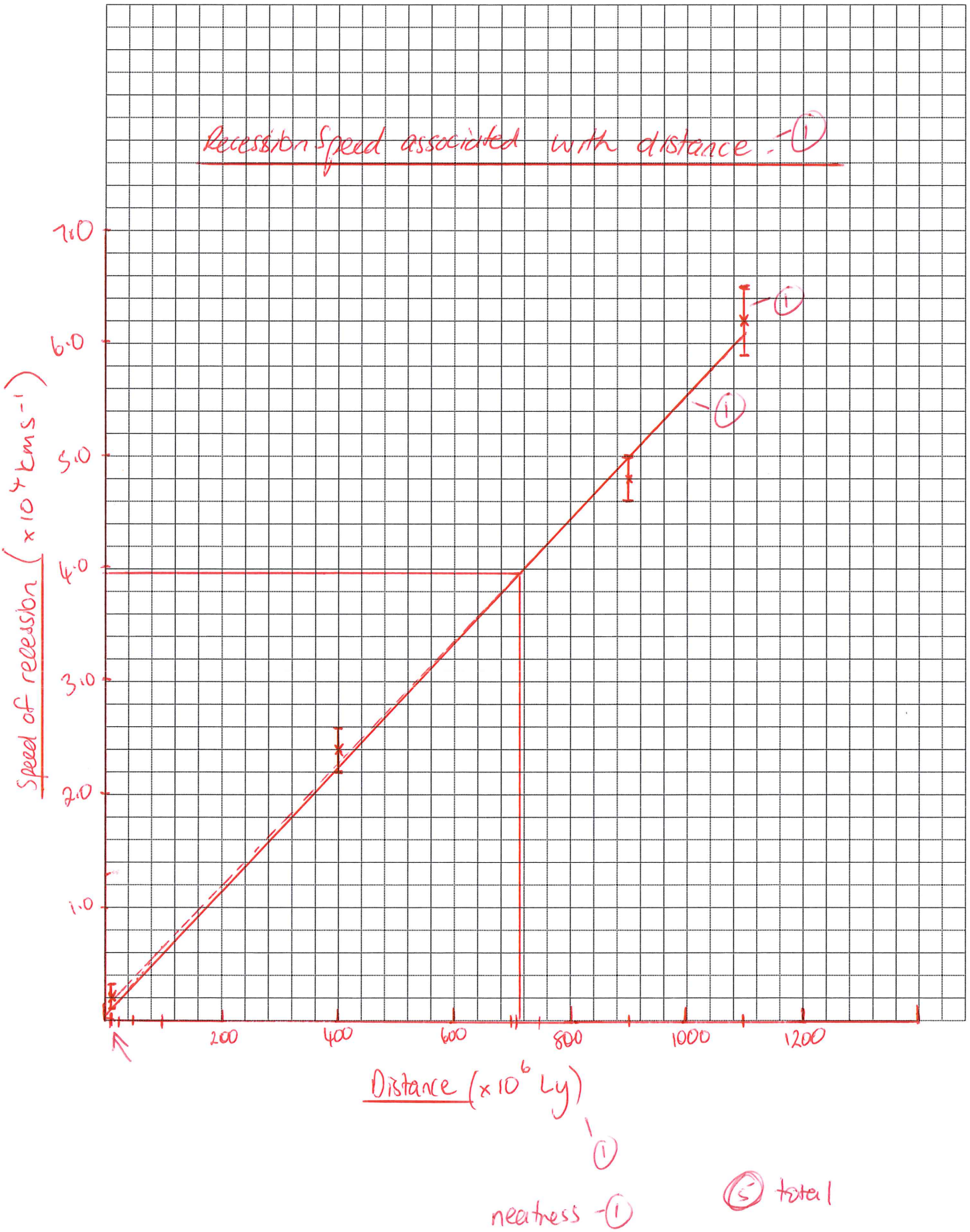
Thus if a source of electromagnetic waves such as a star is moving away from an observer on Earth then the frequencies of the lines in the star's emitted electromagnetic spectrum are shifted to lower values. This is known as red shift.

In 1920, Edwin Hubble measured the red shifts of several galaxies and discovered that most galaxies are moving away from the Earth, suggesting that the Universe is expanding. Hubble also found that the further away a galaxy is, the larger its red shift; that is, the faster it is moving.

The following data together with the associated errors were recorded by Hubble at Mount Wilson in California in the 1940s using an optical telescope.

Object name	Speed of recession ($\times 10^4$ km s^{-1})	Distance ($\times 10^6$ light years)
Virgo	0.2 ± 0.1	10.2
Corona Borealis	2.4 ± 0.2	400
Hydra	6.2 ± 0.3	1100
Kip	4.8 ± 0.2	900

(a) Graph these data on the graph paper below, including error bars. Plot recession speed (y-axis) against distance (x-axis) and draw a line of best fit. (5 marks)



(b) Use the graph to predict the recession speed of a galaxy that is 710×10^6 light years from Earth. (2 marks)

Graph evidence – (1)

$\approx 4.0 \times 10^4$ kms^{-1} – (1).

(c) Hubble's Law can be stated as

$$v_{galaxy} = (H_o)(\text{distance})$$

where the term H_o is called Hubble's constant.

Use your graph to calculate a value for H_o. Take care with the units. (4 marks)

H_o -> gradient. Relationship between distance and velocity. gradient = $\frac{\text{rise}}{\text{run}} = \frac{6.1 \times 10^4 \text{ kms}^{-1}}{1100 \times 10^6 \text{ ly}} = 5.54 \times 10^{-5}$ kms^{-1}/ly – (1) – (1)

or

$H_o = 5.54 \times 10^{-2}$ ms^{-1}/ly.

$\pm 1 \times 10^{-2}$.

(d) The shift in wavelength $\Delta\lambda$ due to recession of a spectral line of wavelength λ is given by the formula

$$v_{galaxy} = \left(\frac{\Delta\lambda}{\lambda}\right)c$$

where c is the speed of light, 3×10^8 m s^{-1}.

A line in the spectrum of ionised calcium has wavelength 393.3 nm when measured in the laboratory. When similar light from the elliptical galaxy NGC 4889 is measured its wavelength is 401.8 nm.

Determine the recession speed of this galaxy. (3 marks)

$v = \frac{401.8 - 393.3}{393.3} c = \frac{8.5}{393.3} c$ – (1)

(cancel $\times 10^{-9}$)

$v = 0.0216\, c$ – (2).

$v = 6.48 \times 10^6$ ms^{-1}

(e) Edwin Hubble could estimate the age of the Universe from his data by calculating the time for which one of the galaxies has been receding. Determine Hubble's value for the age of the Universe by using the data for Corona Borealis. (4 marks)

Additional working space

Corona Borealis $v = 2.4 \times 10^4$ kms^{-1}

$s = 400 \times 10^6$ Ly

$s_{total} = v_c \times time = (3 \times 10^8) \times (365.25 \times 24 \times 60 \times 60) \times (400 \times 10^6)$

$s_{total} = (3 \times 10^8) \times (31557600) \times (400 \times 10^6)$

$s_{total} = (9.467 \times 10^{15}\ m) \times (400 \times 10^6)$

$s_{total} = 3.7869 \times 10^{24}\ m$

$v = \frac{s}{t} \quad \therefore \quad t = \frac{s}{v} = \frac{s_{total}}{v_{CB}}$

time = ?

$s = 3.78 \times 10^{24}$ m

$v = 2.4 \times 10^4$ kms^{-1} $= 2.4 \times 10^7$ ms^{-1}

$t = \frac{s}{v_{CB}} = \frac{3.7869 \times 10^{24}\ m}{2.4 \times 10^7\ ms^{-1}}$

$t = 1.58 \times 10^{17}$ seconds

$t = 5.00 \times 10^9$ years

Physics Stage 3: Practical Exam 3B

Question 22 **(18 marks)**

When source of waves moves, the waves it emits change frequency relative to a stationary observer. This applies to both transverse and longitudinal (sound) waves. As a car moves away from you the frequency of the sound you hear is lower than the frequency it is emitting. A similar effect using radar waves is used by police to measure the speed of cars.

Thus if a source of electromagnetic waves such as a star is moving away from an observer on Earth then the frequencies of the lines in the star's emitted electromagnetic spectrum are shifted to lower values. This is known as red shift.

In 1920, Edwin Hubble measured the red shifts of several galaxies and discovered that most galaxies are moving away from the Earth, suggesting that the Universe is expanding. Hubble also found that the further away a galaxy is, the larger its red shift; that is, the faster it is moving.

The following data together with the associated errors were recorded by Hubble at Mount Wilson in California in the 1940s using an optical telescope.

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(a) Graph this data on the graph paper below, including error bars. Plot recession speed (*y*-axis) against distance (*x*-axis) and draw a line of best fit. (5 marks)

Description	Marks
Graph axes labelled correctly	2
Points plotted correctly	1
Error bars include to size	1
Line of best drawn thru 0,0	1
	Total 5

(b) Use the graph to predict the recession speed of a galaxy that is 710 × 10^6 light years from Earth. (2 marks)

Description	Marks
Evidence they have used graph to predict the recession speed	1
Value 4 × 10^7 m s^{-1}	1
	Total 2

(c) Hubble's Law can be stated as

$$v_{galaxy} = (H_o)(\text{distance})$$

where the term H_o is called Hubble's constant.

Use your graph to calculate a value for H_o. Take care with the units. (4 marks)

Description	Marks
Gradient of graph= 4 × 10^7 m s^{-1} H_o= 5.6 × 10^{-2} m s^{-1} Ly^{-1}	2 2
(allow range of answers 4.5 to 6.5 due to line of best fit)	
	Total 4

(d) The shift in wavelength $\Delta\lambda$ due to recession of a spectral line of wavelength λ is given by the formula

$$v_{galaxy} = \left(\frac{\Delta\lambda}{\lambda}\right)c$$

where c is the speed of light, 3 × 10^8 m s^{-1}.

A line in the spectrum of ionised calcium has wavelength 393.3 nm when measured in the laboratory. When similar light from the elliptical galaxy NGC 4889 is measured its wavelength is 401.8 nm.

Determine the recession speed of this galaxy. (3 marks)

Description	Marks
$\text{recession speed} = \frac{(4.108\times10^{-9})-(3.93\times10^{-9})}{3.93\times10^{-9}}\times3\times10^8$	2
= 6.48 × 10^6 m s^{-1}	1
	Total 3

(e) Edwin Hubble could estimate the age of the Universe from his data by calculating the time for which one of the galaxies has been receding. Determine Hubble's value for the age of the Universe by using the data for Corona Borealis. (4 marks)

Description	Marks
1 light year = 3 ×10^8 × 365 × 60 × 60 × 24 = 1.58 × 10^{15} m	1
$\text{time} = \frac{(400\times10^6)(1.58\times10^{15})}{2.2\times10^3\times10^4}$	2
= 1.37 × 10^8 years	1
	Total 4