Mark schemes

1 (a) use of z = v/c

to give $v = zc = 0.057 \times 3 \times 10^8$ ✓

$= 1.71 \times 10^7 ms^{-1} = 1.71 \times 10^4 kms^{-1}$

use of v = Hd

to give $d = v/H = 1.71 \times 10^4 / 65$ ✓

= 263 ✓ Mpc ✓

4

(b) (Strong) radio sources ✓

1

[5]

2 (a) (use of $\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$ gives) $\frac{(660.86 - 656.28)}{656.28} = (-)\frac{v}{3.0 \times 10^8}$ **(1)**

$v = (–)2094 \text{ km s}^{-1}$ **(1)**

2

(b) graph to show:
correct plotting of points **(1)**
straight line through origin **(1)**
$H = \frac{v}{d}$ = gradient = 70 km s^{-1} Mpc^{-1} **(1)**

(must show evidence of use of graph in calculation)

3

[5]

3 (a) The quasar is a bright radio source. ✓

Allow strong / intense / powerful for bright.

Ignore reference to pulses

Other incorrect properties, eg red shift, loses the mark.

1

(b) (i) Using $I = I_0/d^2$ with some evidence of substitution ✓

$P_q = 4 \times 10^{11} P_s$

$I_s = 1.4 \times 10^{17} I_q$ at Earth

$P_s/1^2 = 1.4 \times 10^{17} (4 \times 10^{11} P_s/d^2)$ ✓

$d^2 = 4 \times 10^{11} \times 1.4 \times 10^{17}$

$=5.6 \times 10^{28}$

$d = 2.4 \times 10^{14}$ AU ✓

The first mark is for some evidence of using the inverse square law. Do not condone equation the wrong way up.

The second is for an attempt to compare the two stars using the inverse square law.

The third is for the final answer.

3

(ii) Dark energy

Evidence of hedging bets eg dark energy / dark matter etc. loses the mark

1

[5]

4 (a) (use of $m - M = 5\log(d/10)$ gives)
$3.54 - (-20.62) = 5\log(d/10)$ **(1)**

$d = 6.7(9) \times 10^5$pc **(1)**

2

(b) use of $\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$ **(1)**

$$\Delta\lambda = -\frac{0.21121 \times 105 \times 10^3}{3.0 \times 10^8} = -7(.4) \times 10^{-5}$$

$\lambda' = 0.21121 - 7(.4) \times 10^{-5} = 0.21114m$ **(1)**

(allow C.E. for incorrect value of Δλ)

2

(c) $t\left(= \frac{d}{v}\right) = \frac{6.79 \times 10^5 \times 3.08 \times 10^{16}}{105 \times 10^3}$ **(1)**

$= 2.0 \times 10^{17}$s **(1)**

(1.99×10^{17}s)

(allow C.E. for value of d from (a))

2

[6]

5 (a) an object with an escape velocity greater than the speed of light ✓

Ignore references to singularity and density etc.

Allow gravity so strong light cannot escape.

1

(b) mass of black hole = $1 \times 10^{10} \times 1.99 \times 10^{30} = 2 \times 10^{40}$ kg ✓

M correct for the first mark

Use of

$R = 2GM / c^2$

$= 2 \times 6.67 \times 10^{-11} \times 2 \times 10^{40} / (3.00 \times 10^8)^2$

$= 3 \times 10^{13}$ m ✓ allow 2.9 or 2.95 etc.

Final answer correct for the second mark.

Allow ce for the mass.

No sf penalty.

2

(c) V= Hd

v (in kms^{-1}) = 6300

D (in MPc) = $3.3 \times 10^8 / 3.26 \times 10^6$

= 101 ✓

H = v / d = 6300 / 101 = 62 kms^{-1} Mpc^{-1} ✓

Alternatively.

Age of universe = 1 / H

= D / v

$= 3.3 \times 10^8 \times 9.47 \times 10^{15}$ ✓ $/ 6.3 \times 10^6$ ✓

$= 5.0 \times 10^{17}$ s ✓

age of Universe = 1 / H

= 1 / 62

$= 1.6 \times 10^{-2}$ Mpc s km^{-1}

$= 1.6 \times 10^{-2} \times 3.1 \times 10^{16} \times 10^6 / 10^3$

$= 5.0 \times 10^{17}$ s ✓

The first mark is for calculating D, the second for substituting correctly to find H

The third is for determining 1 / H in seconds.

If other value of H used, 1 mark max.

3

[6]

6

(a) (i) increase in wavelength (of em radiation) due to relative recessive velocity between observer and source ✓

1

(ii) use of v = Hd

to give v = 65 × 25 ✓

= 1.6×10^3 (km s^{-1}) ✓

2

(b) (i) all type 1a supernovae have same **peak** absolute magnitude ✓

apparent magnitude can be measured ✓

ref to m-M log (d/10) or inverse square law ✓

max 2

(ii) use of m-M = 5 log (d/10)

gives 12.9 – (–19.3) = 5 log (d/10) ✓

log (d/10) = 6.44

d = 27.5 (Mpc) ✓

2

(c) to make the accepted value for the distance more reliable ✓

1

[8]

7

(a) (i) $d = \frac{50 \times 10^6}{3.26} = 15.3 \times 10^6$ (pc)

(ii) (use of $v = Hd$ gives) $v = 65 \times 10^{-6}$ (km s^{-1} pc^{-1}) × 15.3×10^6 **(1)**

≈ (1000 km s^{-1})

(iii) (use of $\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$ gives) $\Delta\lambda = \frac{1000 \times 10^3}{3 \times 10^8} \times 656.3$ (nm) = 2.19 (nm) **(1)**

(allow C.E. for value of v from (ii)

λ_{galaxy} = 656.3 + 2.19 = 658.5 nm **(1)**

4

(b) for the furthest point of the Universe, $d = \frac{c}{H}$ **(1)**

age of Universe = $\frac{d}{c} = \frac{1}{H}$ **(1)**

[or use of $v = Hd$ and $t = \frac{d}{v}$ **(1)**

if all started from same point t = age of Universe = $\frac{1}{H}$ **(1)**]
assumption: that H remains constant

3

[7]

8 (a) Gives the ratio of the (recessional) velocity (of galaxies) to distance from Earth

Accept equation with terms defined

not

v depends on d,

the relationship between them, shows the relationship between them

B1

1

(b) d changed to Mpc (2.45×10^2)
or 1.8×10^4 / their attempt to convert distance

Or d change to m and v to m s^{-1}

B1

(H=) 73.35 or 73.47 seen to at least 3 sf

B1

2

(c) (i) $T = 1 / H$ or $H = 2.4 \times 10^{-18}$ s seen

e.g. $3.08 \times 10^{-19} / 73$

C1

Value in s calculated (4.2×10^{17})

A1

Correct conversion to years 1.3×10^{10}

Allow their value in s

B1

3

(ii) Universe is expanding at constant / steady rate

B1

1

[7]

9 (a) (i) correct shape of graph (steeper on left of peak) **(1)**

(ii) region to left of peak **(1)**

(iii) ozone **(1)**

(iv) lower temperature, shifts peak (λ_{max}) to longer wavelengths **(1)** $\lambda_{max} T$ = constant **(1)**

max 4

(b) (i) (use of $f = \frac{c}{\lambda}$ gives) $f \left(= \frac{3 \times 10^8}{2.7} \right)$ 8 Hz,

(in range) **(1)**

(ii) (double) Doppler **(1)**

(iii) (reflection off moving object gives double Doppler), frequency shift = 150 Hz

$$v = \frac{150 \times 3 \times 10^8}{1.1 \times 10^8} \quad \textbf{(1)}$$

(allow C.E. for shift = 300 Hz)

= 4.1×10^2 m s^{-1} (towards each other) **(1)**

5

[9]

10 (a) (i) $\Delta\lambda = \frac{\lambda v}{c}$ **(1)**

(ii) $\Delta\lambda = -\frac{\lambda v}{c}$ **(1)**

(2)

(b) (i) total difference in wavelength = $\frac{2\lambda v}{c}$ **(1)**

$$v = \frac{7.8 \times 10^{-12} \times 3.0 \times 10^8}{589 \times 10^{-9} \times 2}$$ = 1986 [or 2.0×10^3] m s^{-1} **(1)**

(ii) $\omega = \frac{v}{r} = \frac{1986}{7.0 \times 10^8}$ **(1)**

$= 2.8 \times 10^{-6}$ rad s^{-1} **(1)**

(4)

[6]

11 (a) Star much brighter than reflected light from planet ✓

Or

Planet very small and distant – subtends very small angle compared to resolution of telescopes

1

(b) Planet and star orbit around common centre of mass that means the star moves towards/away from Earth as planet orbits ✓

1

Causes shift in wavelength of light received from star ✓

1

(c) Light curve showing constant value with dip ✓

1

When planet passes in front of star (as seen from Earth), some of the light from star is absorbed and therefore the amount of light reaching Earth reduced ✓

1

Apparent magnitude is a measure of the amount of light reaching Earth from the star ✓

1

[6]

12 (a) correct use of parsec conversion

C1

correct use of $v = Hd$

C1

$= 9.43 \times 10^6$

A1

3

(b) (i) use of $\Delta\lambda/\lambda = v/c$

C1

$\Delta\lambda = 5.8 \times 10^{-7} \times 9.43 \times 10^6/3 \times 10^8$

C1

$= 18.2 \times 10^{-9}$ m

A1

3

(ii) **adds** wavelengths…

C1

correctly; cand ans to b + 580.0 [ecf]

A1

2

[8]

13 (a) (i) change in (apparent) frequency [or wavelength] **(1)**
due to relative motion between source and observer **(1)**

(ii) from spectrum obtain change in wavelength, $\Delta\lambda$, <u>for a spectral line</u> **(1)**
using known wavelength measured on Earth **(1)**

calculate υ from $\frac{\Delta\lambda}{\lambda} = (-)\frac{\upsilon}{c}$ **(1)**

(iii) radar or rotation of star **(1)**
double Doppler effect because body acts as source for return signal **(1)**
[for rotation, one limb moves towards Earth, one away]

(max 6)

(b) (i) use of $\upsilon = Hd$ **(1)**

$$\upsilon = \frac{5 \times 10^4 \times 4.9 \times 10^7}{3.26 \times 10^6} = 7.5 \times 10^5 \text{ m s}^{-1}$$

(ii) $$\Delta\lambda \left(= \frac{\lambda\upsilon}{c}\right) = \frac{7.5 \times 10^5 \times 6.5647 \times 10^{-7}}{3 \times 10^8} = 1.64 \times 10^{-9} \text{ (m)}$$ **(1)**

$\lambda_{obs} = (6.5647 + 0.0164) \times 10^{-7} = 6.58 \times 10^{-7}$ m **(1)**

(4)

[10]

14 (a) (i) Similarity both would appear the same brightness
As the apparent magnitudes are the same ✓

Description and explanation needed for mark.

Any references to same size gets zero for 1st mark.

Difference Kocab would appear orange / red, Polaris yellow / white
Due to their spectral classes / different temperatures ✓

Allow different colours + ref to spectral class for second mark

If colour named, should be correct.

2

(ii) Polaris is further from Earth:

Alternative:

Polaris hotter and same size

Both stars same size and Polaris is hotter ✓

As $P = \sigma AT^4$

Hence, Polaris has brighter absolute magnitude / is intrinsically brighter

Same A, would mean that Polaris has greater power output. ✓

Polaris must be further from Earth to appear same brightness as Kocab. ✓

Same apparent brightness, therefore Polaris is further away.

3

(b) (i) $v = Hd$

$v = 0.025 \times 3 \times 10^5 = 7.5 \times 10^3$ km s^{-1} ✓

1st mark is for calculating v

$d = 340 \times 10^6$ l yr $= 340 / 3.26$ Mpc $= 104$ Mpc ✓

2nd mark is for working out d in Mpc

$H = 7.5 \times 10^3 / 104 = 72$ kms^{-1} Mpc^{-1} ✓

3rd mark is for calculating H in the correct unit.

3

(ii) Age of Universe = 1 / H

1st mark is for the equation

= 0.014 × 10^6 × 3.26 × 9.5 × 10^{15} / 1000

2nd is for the answer with working

= 4.3 × 10^{17} seconds

(= 13.6 billion years)

Unit consistent with calculation.

3rd is for a time unit consistent with their answer / working

3

[11]

15 (a) (i) galaxy moving away from Earth **(1)**
gives Doppler-shift or red shift **(1)**

(ii) $\left(\frac{\delta\lambda}{\lambda} = \frac{v}{c}\right)$ numerically since two lines from same source **(1)**

$\left(\frac{\delta\lambda}{\lambda}\right)_h = \left(\frac{\delta\lambda}{\lambda}\right)_k$ **(1)**

since $\lambda_h \neq \lambda_k$ then $\Delta\lambda_h \neq \Delta\lambda_k$ **(1)**

$\frac{0.198 \times 10^{-7}}{3.968 \times 10^{-7}} = \frac{\Delta\lambda_k}{3.93 \times 10^{-7}}$ gives $\Delta\lambda_k = 0.196 \times 10^{-7}$ m **(1)**

(max 5)

(b) (i) (Doppler shift gives) $\frac{\delta\lambda}{\lambda} = \frac{v}{c}$, (so if $\delta\lambda$ and λ known), v calculated **(1)**

$v = Hd$, d calculated **(1)**

(ii) $\delta\lambda = 0.799 \times 10^{-7}$ (m), $\frac{0.799}{3.934} = \frac{v}{3 \times 10^8}$ **(1)**

gives $v = 6.09 \times 10^7$ m s^{-1} **(1)**

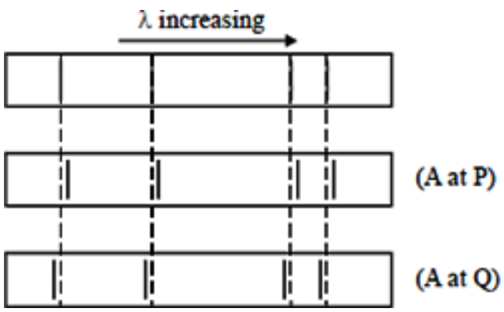
(iii) $d = \frac{6.09 \times 10^7}{65 \times 10^3}$ **(1)** × 3.26 × 10^6

= 3.05 × 10^9 ly **(1)**

(6)

[11]

16 (a)



P moving away, Q towards **(1)**

λ increasing and decreasing respectively **(1)**

(4)

(b) (i) $\left(\frac{\Delta\lambda}{\lambda} = \frac{v}{c} \text{ gives}\right) \; v = \frac{3 \times 10^8 \times 0.8462 \times 10^{-7}}{3.9342 \times 10^{-7}}$ **(1)**

$= 6.5 \times 10^7$ m s^{-1} **(1)**

away from Earth **(1)**

(ii) correct $\lambda = 4.7804$ ($\times 10^{-7}$ m) **(1)**

$v = \frac{3 \times 10^8 \times 0.0132 \times 10^{-7}}{4.7804 \times 10^{-7}}$ **(1)**

$= 8.30 \times 10^5$ (m s^{-1}) **(1)**

period $T = 240$ (day) **(1)**

$r \left(= \frac{Tv}{2\pi}\right) = \frac{(240 \times 24 \times 60 \times 60) \times (8.3 \times 10^5)}{2\pi}$ **(1)**

$= 2.73 \times 10^{12}$ m **(1)**

(max 8)

[12]

17 (a) (i) Spectral line moved to longer wavelength position (allow 'to red end of spectrum')

B1

(ii) Mention of Doppler effect

B1

Expansion of universe / Big Bang

B1

Wavelength increased (or frequency decreased)

B1

Successive ‘peaks’ of wave emitted at increasing distance from Earth [allow ‘wave stretched’]

B1

Wavelength observed on Earth increases compared with source stationary

B1
max 4

the use of physics terms is accurate, the answer is fluent / well argued with few errors in spelling, punctuation and grammar

B2

award for 2+
the use of physics terms is accurate, but the answer lacks coherence or the spelling, punctuation and grammar are poor

B1

award for 1
the use of physics terms is inaccurate, and the answer is disjointed with significant errors in spelling, punctuation max 2 and grammar

B0
max 2

(b) (i) use of $c = f\lambda$
$\Delta f = 3 \times 10^8 /(561 \times 10^{-9}) - 3 \times 10^8 / (540 \times 10^{-9})$

C1

$= (5.348 - 5.556) \times 10^{14}$ [$= 2.08 \times 10^{13}$ Hz]

M1

[explicit subtraction or to 3+ s.f. required for A mark]

A1

(ii) $\Delta f / f = v / c$

$V = c * \Delta f / f$ [or $\Delta\lambda / \lambda$] $= 3 \times 10^8 \times 2.08 \times 10^{13} / 5.556 \times 10^{14}$

C1

[ecf from bi]

M1

$= 1.12 \times 10^7$ m / s

A1

(iii) [$d = v / H$]
conversion to km / s

C1

$d = 11.2 \times 10^3 / 65$ = [172 Mpc] [ecf from bii]

B1

$= 172 \times 10^6 \times 3 \times 10^{16} = 5.17 \times 10^{24}$ m

A1

[16]

Examiner reports

1 The calculation in part (a) was answered correctly by many students. Marks were lost by students who had problems matching the speed and distance units to the Hubble constant. There were also several students who made simple algebraic errors rearranging the Hubble equation. Credit was given to unit answers consistent with their calculation, but only “Mpc” or megaparsec was given a mark if there was no calculation performed.
In part (b), only a minority of students were aware that quasars were discovered due to their powerful radio wave emissions. This is explicit on the specification, but many students would probably benefit from learning the story of how the first quasar was discovered.

2 The Doppler shift question in part (a) was generally done well, although it was quite common to see the wrong wavelength being used. It is the laboratory value which should be used as the denominator in the equation, not the wavelength obtained from the galaxy, as this has been shifted due to the relative velocity of the galaxy and observer. Although this resulted in only a slight difference in the final answer, it was penalised.

In part (b), the points were usually plotted correctly in the graph and many candidates were aware that the line should be drawn through the origin in order to obtain Hubble’s constant. The best answers showed a large triangle used to calculate the gradient and also gave a correct value with the appropriate unit. Several candidates tried to manipulate their calculations to obtain the value given in the Data sheet for Hubble’s constant. A unit mark was lost if the M (in Mpc) was lower case rather than upper case.

3 (a) There were several recall questions on this paper. Despite this being explicit on the specification relatively few students knew the property that led to the discovery of the first quasar.

(b) The inverse square law is a useful idea in many different branches of physics. It was clear, however, that few students had had little practice in its use with questions of this kind. The best answers often started from first principles, using the equation for the surface of a sphere, which was given full credit. Far too often answers were seen that made very little or no progress.

(c) It was expected that many students would be able to give the correct answer for this but some lost the mark by stating two answers, or demonstrated some confusion by simply writing “the big bang”.

4 This question was answered well by the majority of candidates. In part (a) most candidates had clearly been well prepared for calculations involving apparent and absolute magnitudes. Rearranging the equation proved to be straightforward for many candidates except that a significant number worked out their answer using logs to base e rather than base ten. Loss of a mark through unit error was usually due to candidates writing their answer in pes rather than pc, or, in some cases, metres or light years.

The Doppler shift equation, in part (b) was correctly used by most candidates to obtain the change in wavelength, although a significant number added this to the original wavelength despite being told that Andromeda is approaching the Milky Way. Some candidates made no attempt to work out the final wavelength.

Finally in part (c), the first mark was given for converting the answer to 5 (a) into metres. The majority of candidates did this. Simply dividing this value by the speed (given in part (b)) gave the correct answer. There was much evidence to suggest that some candidates do not think at all about the answers obtained. Clearly the event described in the question is a long way off (about six billion years), but answers suggesting a few years or less were often not checked or commented on. Any answer which tried to use Hubble's Law was treated as a physics error and obtained no marks.

5 On this specification, the defining property of a black hole is that it has an escape velocity greater than the speed of light. References to singularities were ignored.

The calculation of the radius of the event horizon was the most accessible question on the paper, with 84% of students getting both marks.

The calculation of the age of the Universe caused more problems for some students. Many gained full marks by simply converting the distance into metres and dividing it by the speed, removing the need to calculate Hubble's constant and convert the units into seconds.

6 Many answers to part (a)(i) simply restated what was in the question, ie a shift to the red end of the spectrum. This did not gain credit. Although many other candidates made a correct reference to an increase in wavelength, several did not get the mark for suggesting that it was the light itself that was moving away, rather than the source of the light.

The calculation in part (a)(ii) was very straightforward with the majority of candidates getting both marks. Generally, those who failed to gain the mark attempted to change the units of distance or Hubble's constant. Poorer answers were seen where candidates attempted to use the red shift equation substituting random data, and this gained no credit.

Part (b)(i) had three marking points, with a maximum of two marks available. The best answers correctly stated that the maximum absolute magnitude was known to have a value of –19.3, that the maximum apparent magnitude could be measured and that the inverse square law, or $m- M = 5 \log (d/10)$, could be used to calculate the distance. The first mark was not given for answers that did not make it clear that it was the maximum value that was known.

Calculations similar to that asked for in part (b)(ii) have been asked many times before. Although some very good answers were seen, many candidates incorrectly confused m and M, failing to include the minus sign for the absolute magnitude, or using natural logarithms in the calculation. Failure to express their answers in parsec, rather than Mpc, was also a mistake that cost some candidates a mark.

Part (c) assessed candidates understanding of one aspect of *How Science Works*. Many candidates realised that using several methods would improve, or at least test, the reliability of the distance value.

Incorrect answers made reference to improvements in accuracy, or the need to have other methods, including parallax as not all distance methods can be applied in all situations. Although in general this is correct, the question was specifically related to galaxies and therefore this answer did not gain credit.

7 The calculations in part (a) were usually correct. Many candidates gave the distance in part (i) in megaparsecs, which made handling the units in part (ii) a little easier. There was a tendency for weaker candidates to work backwards in part (ii) and thus doctor their answer to part (i). In effect, these candidates made two errors, one with the units of Hubble's constant and the second with the velocity of the galaxy. This was despite the fact that the unit of Hubble's constant is given on the data sheet. These efforts were not awarded. The unit of km s^{-1} also caused problems in part (iii) and many candidates obtained a value of 2×10^{-12} m for the change in wavelength. Some credit was still given if the candidates showed that this wavelength was added to the laboratory based wavelength (red shift) and not subtracted.

In part (b) it was clear that many candidates knew that $t = \frac{1}{H}$ and hence obtained $v = Hd$ and

$v = \frac{d}{t}$, but very few explained how t gave the age of the Universe.

The expected assumption was associated with the value of the Hubble constant, as this is the value quoted in the specification. Credit was given to some alternatives. Candidates who described a graphical method to explain how the age of the Universe could be obtained, showed the best understanding of the topic.

8 (a) Only small minority were able to express what is meant by the Hubble constant clearly. Most gave vague answers such as that it gives the relationship between velocity and distance of galaxies.

(b) Here the first requirement was to show the change the distance from ly to Mpc. Those who could do this usually managed the next step without difficulty.

(c) (i) There were many who were unable to make any progress with this calculation. Some clearly had a number for the age of the Universe ($\approx 10^{10}$y) in mind and made an incomprehensible series of calculations to arrive at that number. Converting between units was a problem for many.

(ii) Relatively few candidates gave an acceptable response to this part.

9 This was a question that many candidates found difficult, with only a few scoring maximum, or near maximum marks. In part (a) (i) awarding marks to the black body radiation curve for the Sun was often generous, but there were many candidates who had no idea of the shape or the main feature of the curve. Examiners were looking for a steep curve on the left hand side of the peak, with a much more gradual curve towards zero on the right hand side. Good answers showed an intercept on the low frequency side of a fairly narrow peak. There were many different positions given in part (ii) for the region of ultraviolet absorption. Candidates were rewarded for marking a region to the left of the peak, within the overall curve. In part (iii) the fairly common answer that absorption was due to the ozone (frequently spelt o-zone) seems to suggest that some candidates believe that this is a region of the atmosphere rather than a gas. Benefit of the doubt however was given for this answer. Many candidates in part (iv) could not link ultraviolet absorption with the effect on the wavelength of the peak and therefore on the calculated temperature using Wien's Law. There was much evidence that candidates were not familiar with the problem. Many discussed, for example, the absorption of the light by the atmosphere of the star. Some credit was given for answers which could explain why the absorption of light could suggest the star was cooler, without reference to Wien's Law.

The fairly straightforward calculation in part (b)(i) was usually answered well, although there was evidence of some confusion between the prefixes G and M in the frequency values. The identification of the Doppler effect in part (ii) was an easy mark that was gained by almost all candidates. The calculation in part (iii) identified more difficulties. Although the process actually involves a double Doppler shift because the Moon acts both as a receiver and a source (reflecting the received signal) this was ignored when marking and full marks were awarded if candidates only calculated the single shift. There was much confusion over the use of the equation however. Some candidates apparently believed that the v in the equation was a variable. Very few candidates answered fully and stated that the increase in frequency meant that the Moon and Earth were getting closer. Some errors led to answers at or greater than the speed of light. There was no evidence of candidates being wary of these answers or suggestions that they may have made a mistake. Credit was not awarded for consequential errors leading to these answers as candidates should realise, particularly with speed calculations, that when an answer is ridiculous or impossible they should be encouraged to comment on it.

10 Most candidates gave the correct expression in part (a), but many got the signs wrong.

In part (b)(i) the majority of candidate forgot to halve the wavelength difference in calculating the velocity. Credit was given to those candidates who used a wrong answer correctly in part (b)(ii), but many candidates gave an incorrect unit and some used speeds greater than or equal to c without comment.

12 (a) Candidates seem to be getting used to this calculation now. Even so, candidates rarely showed clearly, *explaining their steps,* how they could calculate the galactic speed.

(b) (i) This was carried through better; candidates often manipulated the equation appropriately and substituted correctly to arrive at a correct answer.

(ii) Many failed to recognise that the light is red shifted to longer wavelengths (in other words, they subtracted the (b)(i) answer). An even greater number could not handle the subtraction when it was couched in exponent form.

13 This question required concise, detailed answers and it was probably the most difficult on the paper but it is satisfying to record that there were many worthwhile attempts which earned high marks.

Answers to part (a)(i) tended to deal with specific examples rather than a general description of the Doppler effect and many were loosely worded. The main defect in the answers was that the statements referred loosely to a wave between an object and an observer, without making it clear that the object was the source of the waves. In general, answers to part (a)(ii) were poor. Although the Doppler equation was known, there was a vagueness about the descriptions and very few candidates referred to the need to consider a particular line or element in the spectrum. There were also comparatively few references to the need to measure the wavelength in the laboratory and the implication given was that the true wavelength and the spread could be obtained from the observed spectrum. Acceptable examples of the double Doppler effect in part(a)(iii) were radar astronomy and rotation of planets. Many candidates quoted binary stars but this was not acceptable because the speeds of the two stars are different and thus the double effect is not applicable. To many candidates, the double effect means simply that the factor 2 appears in the equation and for this reason the examiners accepted rotation of planets. When explaining why it was necessary to apply the effect to radar, the majority of candidates were under the impression that the double effect occurred because the signal had to travel in both directions, and not because the planet acted as a source for the return signal. Examiners were concerned that many candidates believed that signals could be sent to distant stars and the return signal examined.

The calculation in part (b)(i) contained an involved manipulation of units but again it is pleasing to record that many candidates obtained the correct value for the speed of the M87 galaxy. The true value for the speed was 7.5×10^5 m s^{-1} which approximated to the value given in the question. Many candidates worked backwards from the value for the speed given in the question (8×10^5 m s^{-1}) and obtained a value of 16 Mpc for the distance instead of 15 Mpc which would have been obtained from the Hubble constant. No credit was given for this approach.

The calculation in part (b)(ii) was done well with the majority of candidates calculating the spread of wavelength correctly. Many candidates at this stage rounded the answer to 1×10^{9} m (instead of the correct value of 2×10^9m) and penalised themselves because using data to one significant figure with values of wavelengths given to five significant figures is not sensible. Furthermore, many candidates lost the final mark by subtracting instead of adding the spread of wavelength from that given. The examiners assumed that candidates at this level should know that the change was a red shift.

14 Many students could state the differences required for the answers to part (a) (i), but made no attempt to link them to the properties of the stars. Answers which simply stated same brightness and different colours obtained no marks.

There were some difficulties encountered by students answering (a) (ii). The best answers made it clear that Polaris is hotter and, as it has the same radius and therefore surface area, emits more power, from Stefan's Law. The majority of candidates that failed to get all three marks made no reference to the radius. Other incorrect answers simply stated that hotter stars must be further away without any reference to brightness. Other answers were seen that referred to the magnitude of the stars without making it clear whether it was the absolute or apparent magnitude. Similarly, students who referred to bigger magnitudes often failed to state whether they meant more positive or brighter. It would be much less ambiguous if students could be encouraged to refer to *brighter* and *dimmer* magnitudes rather than just bigger and smaller.

Part (b) (i) was correctly answered by the majority of students. Some students had difficulties converting the distance into megaparsecs. There was also evidence that students attempted to work backwards from the accepted value of 65, rather than calculate the value from the data.

Part (b) (ii) proved to be more challenging. Although the majority of students knew that the age of the universe could be calculated from 1 / H, there were many answers seen where the student could not convert the Hubble's constant to s $_{-1}$. Credit was given to answers that used the Hubble's constant to calculate a size for the Universe, and calculated its age from the speed of light. This question included the unit mark and it was only awarded if it was clear that the unit quoted was consistent with the calculation.

16 The examiners found it necessary to alter the section totals in parts (a) and (b) from the printed totals of 5 and 7, to 4 and 8 respectively. This was done to give extra credit to candidates who had made a reasonable, but incomplete, attempt at the demanding calculation in part (b).

Part (a) proved to be straightforward with the majority of candidates drawing the correct spectrum in the boxes. Some candidates went as far as to try to show a progressive increase or decrease in the spectral lines, although this was not necessary to gain maximum credit. The description usually supplemented the drawing, although a handful of candidates managed to give the correct description with incorrect drawings.

The calculation in part (b)(i) was usually performed correctly, although the majority failed to state the direction of travel of the source with respect to Earth. Incorrect calculations invariably used the wavelength obtained from the spectrum of the star as the reference wavelength, rather than the wavelength measured in the laboratory.

The first stage of part (b)(ii) involved the calculation of the orbital speed. Here the most common errors were not using the mean of the two given wavelengths as the reference wavelength, and not realising that the difference of the two wavelengths in this case gave $2\Delta\lambda$ and not $\Delta\lambda$. Incorrect values of the orbital speed were allowed as an error carried forward into the second stage of the calculation of the orbital radius. The error which occurred here was not realising that the period of rotation was 240 days rather than 120 days. Attempts at the entire problem were commendable and examiners were pleased to see many completely correct solutions.

17 (a) (i) English usage was careless here and lost candidates credit.

(ii) Few candidates gained all 6 marks in their explanations of red shift in the context of astronomical movement. Common features of the accounts were correct statements that '*wavelength*' increases and that the movement of the *object 'stretches the wavelength'*. Most candidates focussed on the Doppler shift for their physical description. Accounts of the reason for the cosmological red shift were rare, but both descriptions gained credit.

(b) (i) There were two routes to the answer: one via two separate identical calculations of the frequencies leading to a subtraction for the difference, the other using $\Delta f / f = \Delta\lambda / \lambda$. Those opting for the former usually obtained full credit. The second route proved more tricky for some reason.

(ii) A large number were unable to use the $\Delta f / f = v / c$ relationship successfully. Failure points were often the use of the wrong (observed) frequency or a unit penalty.

(iii) Again, units were the downfall here, with a large number of candidates being unable to convert m s^{-1} into km s^{-1} or (more understandably) unable to cope with km s^{-1} Mpc^{-1}.