Mark schemes

1 (a) boundary where the escape velocity = c ✓

1

(b) (i) use of $R_s = 2GM/c^2$

to give $R_s = 2 \times 6.67 \times 10^{-11} \times 60 \times 10^6 \times 1.99 \times 10^{30}/(3 \times 10^8)^2$ ✓

$= 1.8 \times 10^{11}$ m ✓

2

(ii) use of D = M/V

to give $D = 60 \times 10^6 \times 2 \times 10^{30}/(4/3\pi\ (1.78 \times 10^{11})^3)$ ✓

$= 5.1 \times 10^3$ kg m^{-3} ✓

2

[5]

2 (a) (i) supernova: star whose luminosity increase enormously due to it exploding **(1)**

(ii) neutron star: star with the density of nuclear matter **(1)**

(iii) black hole: an object whose escape velocity is greater than speed of light **(1)**

3

(b) $\left(\text{use of } R = \dfrac{2GM}{c^2} \text{ gives}\right) \quad R = \dfrac{2 \times 6.67 \times 10^{-11} \times 10 \times 2 \times 10^{30}}{(3 \times 10^8)^2}$ **(1)**

2

[5]

3 (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

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

= 5.0×10^{17} s ✓

age of Universe = 1 / H

= 1 / 62

= 1.6×10^{-2} Mpc s km^{-1}

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

= 5.0×10^{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]

4 (a) An object that produces a rapid increase in brightness ✓

Allow lowering in value of absolute magnitude

1

(b) Extremely dense ✓

Ignore descriptions of Neutron star surface

1

Made up of neutrons ✓

Ignore refs to spinning or producing radio waves

1

(c) Use of $R_s = 2GM / c^2$

To give

$R_s = 2 \times 6.67 \times 10^{-11} \times 2 \times 2 \times 10^{30} / (3 \times 10^8)^2$ ✓

First mark is for substitution

1

= 5.9×10^3 m ✓

Second mark for answer

1

(d) Collapsing star can produce gamma ray bursts with energy similar to total output of Sun ✓

First mark is for gamma ray burst and an idea of the amount of energy

1

Highly collimated – if in direction of Earth, could cause mass extinction event ✓

Second mark is for consequence.

1

[7]

5 (a) x-rays are absorbed by the Earth's atmosphere **(1)**

1

(b) (i) an object whose escape velocity is greater than the speed of light **(1)**

1

(ii) use of $R_s = 2GM/c^2$

to give $R_s = 2 \times 6.67 \times 10^{-11} \times 7 \times 2 \times 10^{30}/(3 \times 10^8)^2$ **(1)**

$= 2.08 \times 10^4$ (m) **(1)**

2

(c) CCD consists of silicon (chip) **(1)**

incident photons cause electrons to be released **(1)**

electrons are trapped in potential wells in the CCD **(1)**

3

[7]

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 $v = 65 \times 25$ ✓

$= 1.6 \times 10^3$ (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 ✓

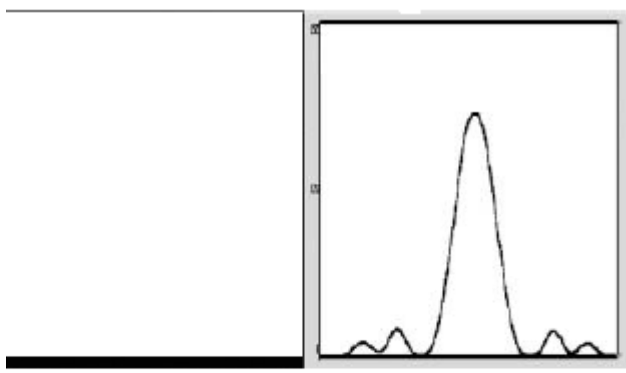
1

[8]

7 (a) (i) central maximum at least twice the height of adjacent maxima ✓

Allow graph to be above angle axis

Subsequent narrower maxima ✓



Any further maxima should not get bigger.

2

(ii) Two sources will be (just) resolved if the central maximum of the diffraction pattern of one coincides ✓

Central max and first min may be labelled on diagram in ai

with the first minimum of the other. ✓

If they use the term 1st maximum it must be clear that it is the central maximum

Second mark is for correct part of the second diffraction pattern.

Clearly labelled diagram can get both marks.

2

(b) Use of $Rs = 2GM/c^2$

*Allow ce for **one** from:*

missing out million; missing out mass of Sun; square in equation, but no square of speed of light in calculation

to give $Rs = 2 \times 6.67 \times 10^{-11} \times 4.1 \times 10^{6} \times 2 \times 10^{30} / (3 \times 10^{8})^{2}$ ✓

$= 1.2 \times 10^{10}$m ✓

2sf ✓

Sf mark stands alone but must be a number (not just stated 2 sf)

3

(c) (i) use of $\theta = \lambda/D$

The first mark is for calculating the wavelength

to give $\theta = (3 \times 10^{8} / 230 \times 10^{9})$ ✓ $/ 5000 \times 10^{3}$

$= 2.6 \times 10^{-10}$ (rad) ✓

The second mark is for the use of the equation to give the final answer

Allow c.e. for an a.e. in the first mark.

If frequency used treat as p.e. – no marks

2

(ii) use of $s = r\theta$

First mark is for the angle subtended (5.12×10^{-11})

to give $\theta = 5 \times 1.2 \times 10^{10} / (25\,000 \times 9.46 \times 10^{15})$ ✓

$= 2.5 \times 10^{-10}$ (rad) ✓

Second mark is for showing that this is 5 × answer to c(i).

which is (approximately) the answer to ci

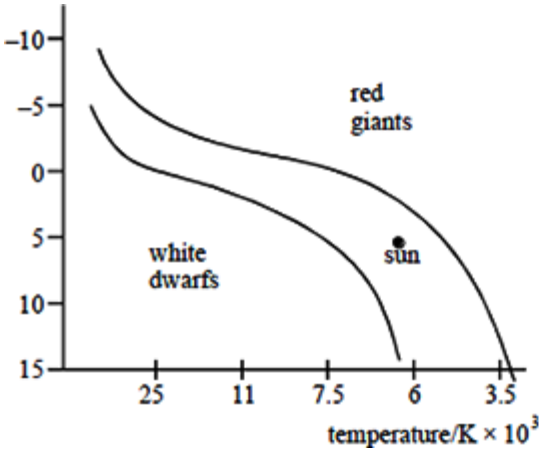
Alternatives:

Calculate size of object that could just be resolved at this distance, and showing that this is 5 × radius of black hole.

2

[11]

8 (a)



correct position of main sequence **(1)**

correct position of White Dwarfs and Red Giants **(1)**

correct position of Sun labelled **(1)**

(3)

(b) (i) brightness when Red Giant > brightness when in main sequence **(1)**

(ii) hydrogen exhausts itself **(1)**

core collapses causing temperature to increase **(1)**

outer part of star expands **(1)**

causes decrease in temperature **(1)**

causing star to appear red **(1)**

(max 4)

(c) (i) very large gravitational field **(1)**

prevents light escaping **(1)**

(ii) event horizon is boundary or surface at which escape speed = c **(1)**

radius $\left(= \frac{2GM}{c^2}\right) = \frac{2 \times 6.67 \times 10^{-11} \times (3 \times 2 \times 10^{30})}{9 \times 10^{16}}$ **(1)**

$= 8.9 \times 10^3$ m **(1)**

(5)

[12]

Examiner reports

1 Answers to part (a) demonstrated that there continues to be much confusion or careless thinking when it comes to black holes. Answers suggesting that the event horizon is a point or a distance were given no credit. Other incorrect answers suggested that light was somehow unable to escape without any reference to gravity. The best answers stated that that it is a boundary where the escape velocity is equal to the speed of light.

The calculation in part (b)(i) proved to be very straightforward. It is clear that most centres prepare their candidates for calculations of this type. Some careless errors were still evident. Most commonly, candidates forgot to square the velocity of light, missed out the factor of 60 million or used the incorrect value for the mass of the Sun.

The density calculation in part (b)(ii) was also shown to be relatively straightforward, although many candidates used the incorrect equation for the volume of a sphere.

2 Part (a) gave candidates an opportunity to show what they knew about some of the more spectacular phenomena in the Universe. Most knew that a supernova was short lived and referred to explosions. It was not sufficient to state that they were bright or gave out a lot of energy without a reference to a time scale. There are many possible properties of neutron stars, although the high density was deemed to be the one that all neutron stars had in common. Stating that they were made up of neutrons was interpreted as an example of tautology. The significant property of a black hole is the fact that its escape velocity is greater than the speed of light. References to high density (or singularities) were not credited. The concept of a black hole predates the ideas of singularities and there are other objects which are also extremely dense.

Part (b) was well answered, although careless mistakes were common. As stated in previous reports, candidates often fail to look up the correct mass from the data sheet or forget to square the speed of light when carrying out the calculation.

3 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.

5 Unsurprisingly, perhaps, part (a) was one of the most accessible questions on the paper. There was some evidence of confusion. For example some answers discussed problems of interference with Earth based sources of X-rays.

For part (b), within this specification, the defining property of black hole that it has an escape velocity greater than, or equal to, the speed of light. References to singularities were ignored. No credit was given to answers which referred to things being 'sucked in' *.*

Part (b) (ii) was the most accessible question on the paper. Candidates who did not get both marks tended to forget to square the speed of light, or left out the factor of seven.

In part (c), the question on the CCD was a fairly regular feature of the legacy paper, and there was some evidence to suggest that many candidates simply learned the mark scheme from previous exams. However, there was a lot of confusion with the photoelectric effect and even with absorption spectra. Some answers also suggested that the electrons were promoted *from* potential wells, or that somehow the photons themselves were being stored.

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 single slit diffraction pattern required for part (a) (i) was drawn satisfactorily by the majority of students, although there was some carelessness. Students should be encouraged to take more care with diagrams of this kind to show that the central maximum is twice as wide as the subsequent maxima, and that the height of the central maximum is significantly higher, and that the height decreases for each maximum.

Part (a) (ii) proved to be a little more challenging. There was some confusion related to how much overlap was appropriate. The best answers included a clear diagram showing two overlapping diffraction patterns with the central maximum of one pattern coinciding with the first minimum of the other. Students who did not include a diagram generally had difficulties describing the situation fully.

The formula in Part (b) has been tested many times before. Unfortunately a significant number of students lost marks by missing out the mass of the Sun, or failing to square the speed of light. This question also carried the significant figure mark. Students should be reminded that the answer should have the same number of significant figures as the poorest piece of data in the question.

Part (c) (i) was answered correctly by the majority of students. The calculation of the wavelength proved difficult for some students, however. A common error was simply using 1 / frequency or even using the frequency itself. The latter was treated as a physics error and gained no marks.

The comparison in part (c) (ii) again proved to be quite challenging. Some students found it difficult to convert the distances involved into a common unit. Many students made no attempt to refer to the answer to (c) (i).

8 Attempts at completing the Hertzsprung-Russell diagram in part (a) were sloppy and disappointing. The mark awarded was usually two out of the three available. Candidates should have paid attention to the correct form of the main sequence belt and correct position of red giants. The position of the white dwarfs was usually given reasonably accurately, but the red giants were often shown with a much higher temperature than the Sun. The position of the Sun itself was not indicated correctly in many cases.

Although many candidates wrote at length in answer to part (b), it was unusual to find a fully correct description of the sequence of events. In part (b)(i) most candidates were aware that the brightness increased when the star evolved from the main sequence to a red giant. This answer was meant as a guide to answering part (b)(ii) but the connection was usually missed or ignored. Candidates were generally aware that the sequence of events began when the hydrogen supply was exhausted but the next stage, namely the core collapsing with an increase in temperature, was usually missing. There was very little reference throughout to change in temperature. The expansion of the outer part of the star was also not reported, but accounts usually stated that the whole star expanded which is not correct. The conclusion that the expansion of the outer layer, together with a decrease in its temperature, led to a red giant was only given occasionally.

In part (c)(i) the majority of candidates knew that the gravitational field produced the black hole and prevented light from escaping. The definition of event horizon was poor, with too many candidates referring to it as a point, a radius, a distance or a region. None of these answers were acceptable because it should be defined as a surface or boundary at which the escape speed equalled the speed of light. The calculation in part (c)(ii) was usually correct, but too many candidates used too many significant figures and incurred a penalty.