P8b Red-shift and the Expanding Universe

AQA 8463 · Calculator allowed · about 75 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

Key words: red-shift and the expanding universe (P8b)

Revision Library

The Doppler effect describes how the observed frequency (or wavelength) of a wave changes when there is relative motion between the source and the observer, for example the change in pitch of a passing ambulance siren. A similar effect happens with light from distant galaxies: light from almost all distant galaxies is observed to have a longer wavelength than expected, shifted towards the red end of the visible spectrum. This effect is called red-shift, and it shows that these galaxies are moving away from the Earth. The further away a galaxy is, the greater its observed red-shift, showing that more distant galaxies are moving away faster. Since this pattern is seen in every direction, it suggests that the whole universe is expanding, which is the basis of the Big Bang theory: the universe began from a very small region that was extremely hot and dense, and has been expanding and cooling ever since. Cosmic microwave background radiation (CMBR) is further evidence supporting this theory: it is electromagnetic radiation, in the microwave part of the spectrum, detected coming from every direction in space, believed to be radiation released shortly after the universe began and stretched to much longer wavelengths as the universe has expanded. Scientific models such as the Big Bang theory are provisional: they are accepted because they currently best explain the available evidence, and they continue to be tested, refined or replaced as new evidence is found.

1 The pitch of an ambulance siren appears to change as the ambulance passes a stationary observer.

(a) State what happens to the observed pitch (frequency) of the siren as the ambulance approaches the observer, and as it moves away. **(2)**

(b) State the general name for this effect, in which the observed frequency of a wave changes due to relative motion between a source and an observer. **(1)**

(Total for Question 1 is 3 marks)

2 A similar effect happens with light from distant galaxies, called red-shift.

(a) State what happens to the observed wavelength of light from most distant galaxies, compared with light from a stationary source. **(1)**

(b) State the direction, in terms of colour, that this shift moves the light towards within the visible spectrum. **(1)**

(c) Explain what this observation tells us about the motion of most distant galaxies relative to the Earth. **(2)**

(Total for Question 2 is 4 marks)

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3 Astronomers have observed red-shift in light from many galaxies at different distances from Earth.

(a) State how the amount of observed red-shift changes as the distance to a galaxy increases. **(1)**

(b) State what this tells us about the recession speed of more distant galaxies compared with closer galaxies. **(2)**

(Total for Question 3 is 3 marks)

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4 Almost every galaxy observed shows red-shift, in every direction we look.

(a) Explain what this observation suggests about the universe as a whole. **(2)**

(b) State the name of the widely accepted theory, based on this evidence, that describes the origin and expansion of the universe. **(1)**

(Total for Question 4 is 3 marks)

5 The Big Bang theory describes both the origin and the ongoing evolution of the universe.

(a) Describe what the Big Bang theory says about the initial state of the universe. **(2)**

(b) Describe what has happened to the universe since this initial state, according to the theory. **(2)**

(Total for Question 5 is 4 marks)

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6 Cosmic microwave background radiation (CMBR) is observed coming from all directions in space.

(a) State what CMBR is. **(1)**

(b) State when, according to the Big Bang theory, this radiation was created. **(1)**

(c) Explain why the discovery of CMBR provided strong evidence to support the Big Bang theory. **(2)**

(Total for Question 6 is 4 marks)

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7 As the universe has expanded, the wavelength of the CMBR has also changed since it was first created. Explain how the wavelength of the CMBR has changed over time, and why.

(Total for Question 7 is 3 marks)

8 The table shows the approximate distance and recession speed (found from red-shift measurements) for five galaxies.
Distance (millions of light years): 60, 120, 180, 240, 300
Recession speed (km/s): 1300, 2600, 3900, 5300, 6500

(a) Describe the relationship shown by the data between distance and recession speed. **(2)**

(b) One of the five results does not fit this pattern as closely as the others. Identify this result. **(1)**

(Total for Question 8 is 3 marks)

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9 Using the data from the previous question (ignoring the anomalous result), describe and explain the shape of a graph of recession speed (y-axis) against distance (x-axis).

(a) Describe the shape of the graph. **(1)**

(b) Explain what the gradient of this graph would represent. **(2)**

(Total for Question 9 is 3 marks)

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10 Higher Tier only. Scientists' current best explanation for the origin of the universe is the Big Bang theory.

(a) State the two main pieces of observational evidence that support the Big Bang theory. **(2)**

(b) Explain why scientists continue to look for new evidence and refine this model, rather than treating it as a fixed, final theory. **(2)**

(Total for Question 10 is 4 marks)

11 Evaluate how the observations of red-shift and cosmic microwave background radiation (CMBR) support the Big Bang theory of the origin of the universe. In your answer, you should refer to: what each piece of evidence shows; how each piece of evidence links to the predictions of the Big Bang theory.

(Total for Question 11 is 6 marks)

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12 A small number of nearby galaxies, such as Andromeda, show blue-shift rather than red-shift.

(a) State what blue-shift indicates about the motion of a galaxy, relative to red-shift. **(1)**

(b) Suggest why the existence of a small number of blue-shifted, nearby galaxies does not contradict the overall theory that the universe is expanding. **(1)**

(Total for Question 12 is 2 marks)

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13 Red-shift is described in terms of an increase in the wavelength of light.

(a) State the equation linking wave speed, frequency and wavelength. **(1)**

(b) All electromagnetic waves, including light from distant galaxies, travel through the vacuum of space at the same speed. Explain what must happen to the frequency of red-shifted light, given that its wavelength has increased. **(2)**

(Total for Question 13 is 3 marks)

14 Before the discovery of CMBR, some scientists supported a different theory (the steady state theory), which proposed that the universe has always looked the same, without a definite beginning.

(a) State what effect the discovery of CMBR had on scientific support for the steady state theory. **(1)**

(b) Explain what this shows about how scientific theories can change over time. **(2)**

(Total for Question 14 is 3 marks)

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15 Explain why red-shift observations alone would still provide some evidence that the universe is expanding, but combining this with CMBR gives scientists much greater confidence in the Big Bang theory.

(Total for Question 15 is 2 marks)

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16 Astronomers can identify the elements present in a distant galaxy by analysing the pattern of dark lines in its light spectrum (absorption spectrum lines), because each element produces its own characteristic set of lines at specific wavelengths. Explain how astronomers can use these characteristic spectral lines to identify red-shift in the light from a distant galaxy.

(Total for Question 16 is 3 marks)

17 The Doppler effect for sound (e.g. a passing ambulance siren) and red-shift for light from distant galaxies are both caused by relative motion between a source and an observer.

(a) State one similarity between the Doppler effect for sound and red-shift for light. **(1)**

(b) A galaxy moving away from Earth shows red-shift (an increase in wavelength). State what would be observed if a galaxy were instead moving towards the Earth. **(1)**

(c) Explain why red-shift observations can only tell us about the recession speed of a galaxy along the direct line between the galaxy and the Earth, not about any sideways motion. **(2)**

(Total for Question 17 is 4 marks)

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18 Higher Tier only. Two galaxies, A and B, are observed. Galaxy A is twice as far from Earth as Galaxy B. Assume recession speed is directly proportional to distance, as shown by red-shift observations.

(a) Galaxy B has a recession speed of 1800 km/s. Calculate the expected recession speed of Galaxy A. **(2)**

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(b) Galaxy C is observed with a recession speed of 900 km/s. State how the distance to Galaxy C compares with the distance to Galaxy B. **(2)**

(Total for Question 18 is 4 marks)

19 A student summarises the key stages of evidence and theory as follows: 'Red-shift shows galaxies are moving apart. This means the universe must be expanding. If the universe is expanding now, it must have been smaller, hotter and denser in the past. This idea is the basis of the Big Bang theory.'

(a) State whether this is a valid summary of how red-shift evidence supports the Big Bang theory. **(1)**

(b) Explain how the discovery of CMBR added an independent test of this reasoning, beyond just red-shift. **(3)**

(Total for Question 19 is 4 marks)

Mark scheme · P8b Red-shift and the Expanding Universe

Question 1

- (a) **B1** as it approaches, the observed pitch/frequency is higher than the true pitch
- (a) **B1** as it moves away, the observed pitch/frequency is lower than the true pitch
- **(a) Answer: Higher pitch as it approaches; lower pitch as it moves away.**
- (b) **B1** the Doppler effect
- **(b) Answer: The Doppler effect.**

Question 2

- (a) **B1** the observed wavelength is increased (longer)
- **(a) Answer: It is increased.**
- (b) **B1** towards the red end of the spectrum
- **(b) Answer: Towards the red end.**
- (c) **B1** by comparison with the Doppler effect, an increase in wavelength (red-shift) shows the source is moving away from the observer
- (c) **B1** therefore, most distant galaxies are moving away from the Earth, oe
- **(c) Answer: Most distant galaxies are moving away from the Earth.**

Question 3

- (a) **B1** red-shift increases (gets greater) as distance increases
- **(a) Answer: Red-shift increases with distance.**
- (b) **B1** more distant galaxies have a greater observed red-shift
- (b) **B1** which means more distant galaxies are moving away from Earth at a greater (recession) speed than closer galaxies, oe
- **(b) Answer: More distant galaxies are moving away faster.**

Question 4

- (a) **B1** galaxies are moving apart from each other/from Earth in every direction
- (a) **B1** this suggests that the whole universe is expanding, oe
- **(a) Answer: It suggests the whole universe is expanding.**
- (b) **B1** the Big Bang theory (model)
- **(b) Answer: The Big Bang theory.**

Question 5

- (a) **B1** the universe began from a very small region of space
- (a) **B1** which was extremely hot and extremely dense, oe
- **(a) Answer: The universe began from a very small, extremely hot and dense region.**
- (b) **B1** the universe has been continuously expanding ever since (and is still expanding today)
- (b) **B1** as it has expanded, the universe has been cooling, oe
- **(b) Answer: It has been expanding and cooling ever since.**

Question 6

- (a) **B1** electromagnetic radiation, in the microwave region of the spectrum, spread throughout (filling) the universe
- **(a) Answer: Microwave electromagnetic radiation filling the universe.**
- (b) **B1** shortly after the beginning of the universe (the Big Bang itself), oe
- **(b) Answer: Shortly after the beginning of the universe.**
- (c) **B1** the Big Bang theory predicted that leftover radiation from the very early, hot, dense universe should still be detectable today, spread throughout all of space
- (c) **B1** CMBR was found to closely match this prediction, coming from every direction at the predicted wavelength/temperature, providing strong observational support, oe
- **(c) Answer: CMBR matches a specific prediction of the Big Bang theory, so its discovery strongly supported the theory.**

Question 7

- **B1** the wavelength has increased (stretched) over time
- **B1** because the space through which the radiation travels has been expanding along with the universe
- **B1** as the universe expanded, the original very short wavelength/high-energy radiation was stretched to the much longer microwave wavelengths observed today, oe
- **Answer: The wavelength has increased (stretched) as the expanding universe has stretched the space the radiation travels through.**

Question 8

- (a) **B1** as distance increases, recession speed increases
- (a) **B1** the relationship is approximately directly proportional, e.g. doubling the distance from 60 to 120 approximately doubles the speed from 1300 to 2600, oe
- **(a) Answer: Recession speed increases with distance, and is approximately directly proportional to it.**
- (b) **B1** the result at 240 million light years (recession speed 5300 km/s); a value closer to 5200 km/s would be expected from the pattern
- **(b) Answer: The 240 million light year result (5300 km/s).**

Question 9

- (a) **B1** a straight line passing through the origin, oe
- **(a) Answer: A straight line through the origin.**
- (b) **B1** the gradient shows how recession speed changes per unit distance - a constant ratio between speed and distance that applies to all the galaxies in the data
- (b) **B1** this constant reflects the rate at which the universe is expanding, oe
- **(b) Answer: The gradient represents the constant ratio between recession speed and distance, reflecting how fast the universe is expanding.**

Question 10

- (a) **B1** red-shift (evidence that galaxies are moving apart / the universe is expanding)
- (a) **B1** cosmic microwave background radiation (CMBR)
- **(a) Answer: Red-shift and cosmic microwave background radiation.**
- (b) **B1** scientific models/theories are provisional and are always open to being tested, refined or replaced as new evidence becomes available
- (b) **B1** testing the model against new observations (e.g. of more distant galaxies, more precise measurements) increases confidence in it, or could reveal limitations needing a better model, oe
- **(b) Answer: Scientific theories are provisional, and continued testing either strengthens confidence in the model or reveals where it needs improvement.**

Question 11

- **Level 0** (0): No relevant content.
- **Level 1** (1-2): Isolated statement(s) are made about red-shift and/or CMBR, with little or no link to the Big Bang theory.
- **Level 2** (3-4): Relevant points are made about both red-shift and CMBR, with some explanation of how they relate to the Big Bang theory, but the evaluation may be incomplete or not fully linked.
- **Level 3** (5-6): A detailed, well-linked evaluation of both pieces of evidence is given, clearly explaining how each supports the Big Bang theory, with correct scientific vocabulary throughout.
- **Indicative content:**
  - Red-shift is the observed increase in wavelength of light from distant galaxies, shifted towards the red end of the spectrum.
  - By comparison with the Doppler effect, red-shift shows that distant galaxies are moving away from the Earth.
  - More distant galaxies show greater red-shift, meaning they are moving away faster, and this pattern is seen in every direction.
  - This is consistent with the whole universe expanding uniformly, a key prediction of the Big Bang theory.
  - The Big Bang theory predicts that the universe began as a very small, hot, dense region and has been expanding and cooling ever since.
  - CMBR is electromagnetic radiation, in the microwave region, detected coming from every direction in space.
  - The Big Bang theory predicts that radiation released shortly after the beginning of the universe would have been stretched to much longer (microwave) wavelengths by the universe's expansion, and would now be detectable throughout all of space.
  - The discovery of CMBR, matching this prediction closely, provides strong, independent evidence supporting the Big Bang theory, in addition to red-shift.
  - Together, the two pieces of evidence support each other and are not currently explained equally well by any competing model, giving scientists confidence in the Big Bang theory.

Question 12

- (a) **B1** blue-shift indicates the galaxy is moving towards the Earth, rather than away from it as with red-shift
- **(a) Answer: The galaxy is moving towards the Earth.**
- (b) **B1** the large-scale expansion of the universe is only clearly observed over very large distances; nearby galaxies can have their own local gravitational motion (e.g. towards each other) that outweighs the much smaller expansion effect at short range, oe
- **(b) Answer: Local gravitational effects between nearby galaxies can outweigh the small expansion effect over short distances.**

Question 13

- (a) **B1** wave speed = frequency x wavelength
- **(a) Answer: wave speed = frequency x wavelength**
- (b) **B1** since wave speed = frequency x wavelength, and the wave speed (speed of light) stays constant
- (b) **B1** an increase in wavelength must be accompanied by a decrease in frequency, oe
- **(b) Answer: The frequency must decrease, since wave speed stays constant while wavelength increases.**

Question 14

- (a) **B1** it provided strong evidence against the steady state theory, since it could not explain the existence of CMBR, and support shifted towards the Big Bang theory, oe
- **(a) Answer: It provided strong evidence against the steady state theory.**
- (b) **B1** scientific theories/models are accepted based on the evidence available at the time, and are not necessarily permanent or certain
- (b) **B1** new evidence, such as the discovery of CMBR, can lead the scientific community to reject or revise a previously accepted theory in favour of a better-supported one, oe
- **(b) Answer: Theories are accepted based on current evidence, and can be revised or replaced when new evidence emerges.**

Question 15

Question 16

- **B1** the same element present in a distant galaxy produces the same pattern of spectral lines as it does in a laboratory on Earth
- **B1** astronomers compare the wavelengths of these lines in light from the galaxy with their known wavelengths measured on Earth
- **B1** if the lines from the galaxy are found at longer wavelengths than expected, shifted towards the red end of the spectrum, this shows the light is red-shifted, oe
- **Answer: Astronomers compare the wavelengths of known spectral lines in a galaxy's light with their laboratory values; if they are shifted to longer wavelengths, the light is red-shifted.**

Question 17

- (a) **B1** e.g. both involve a change in the observed wavelength/frequency of a wave due to relative motion between the source and the observer, oe
- **(a) Answer: Both involve a change in observed wavelength/frequency due to relative motion.**
- (b) **B1** blue-shift (a decrease in wavelength, shifted towards the blue end of the spectrum)
- **(b) Answer: Blue-shift.**
- (c) **B1** red-shift depends on the change in wavelength caused by motion directly towards or away from the observer (motion along the line of sight)
- (c) **B1** any sideways (transverse) motion of the galaxy does not change the wavelength of the light reaching Earth in the same way, so it is not detected by red-shift, oe
- **(c) Answer: Red-shift only detects motion directly towards or away from Earth (along the line of sight), not sideways motion.**

Question 18

- (a) **M1** recognises that recession speed doubles as distance doubles (direct proportion)
- (a) **A1** recession speed of Galaxy A = 3600 km/s, cao
- **(a) Answer: 3600 km/s**
- (b) **B1** Galaxy C's recession speed (900 km/s) is half that of Galaxy B (1800 km/s)
- (b) **B1** so, by direct proportion, Galaxy C's distance must be half the distance to Galaxy B (Galaxy C is closer to Earth than Galaxy B), oe
- **(b) Answer: Galaxy C is half as far away as Galaxy B.**

Question 19

- (a) **B1** yes, it is a valid summary of the reasoning
- **(a) Answer: Yes.**
- (b) **B1** the reasoning above (based on red-shift) predicts that radiation released very early in the universe's history should still be detectable today, spread throughout space and stretched to microwave wavelengths by the expansion
- (b) **B1** CMBR was subsequently observed and found to closely match this prediction, coming from every direction as expected
- (b) **B1** because this evidence was independent of (not used to derive) the original red-shift reasoning, and still supported the theory, it significantly increased scientific confidence in the Big Bang theory, oe
- **(b) Answer: CMBR was an independent, later-tested prediction of the same theory, and matching it gave much stronger confidence than red-shift alone.**