AQA

A Level

A Level Physics

ASTROPHYSICS: Cosmology

(Answers)

Name:

MME

Mathsmadeeasy.co.uk

Total Marks: /30

1. The Doppler effect is something simple that you witness on a daily basis. Yet, it is also holds the key to estimating galaxies' velocities and to obtaining an estimate for the age of the universe.

Total for Question 1: 10

(a) What are meant by the following?

i. The Doppler effect. [2]

Solution: The Doppler effect is the change in frequency/wavelength seen when a wave source moves relative to an observer: if the source moves away from (towards) the observer, the wavelength will increase (decrease).

ii. Red shift. [1]

Solution: The Doppler effect can be used to determine cosmological bodies' relative velocities. If A is receding from B, its absorption line spectra will be shifted to higher wavelengths i..e. closer to the red end of the spectrum. This is red shift.

The centre of a far-away, receding galaxy has an absorption spectra in which the hydrogen line has been Doppler shifted by 2.00 nm relative to laboratory measurements. Its apparent left edge, at a distance of 5 kpc from the centre, has only been shifted by 1.00 nm. In the laboratory, the absorption line for hydrogen occurs at a wavelength of 656.4 nm.

(b) Calculate the recessional velocity of the galaxy relative to the laboratory on Earth. [2]

Solution: 914 kms^{-1}

(c) Calculate the recessional velocity of the left edge. [2]

Solution: 457 kms^{-1}

(d) What angular velocity does the far-away galaxy have? [2]

Solution: 2.95×10^{-12} rad s^{-1}

(e) What Doppler shift would you expect the hydrogen line of the apparent right edge of the galaxy to have? [1]

Solution: 3.00 nm

2. The table below gives the velocities and distances for seven galaxies.

Total for Question 2: 10

Velocity / kms^{-1}	Distance / Mpc
6800	89
3000	45
4600	68
4000	58
3600	53
1100	20
6500	85

(a) State Hubble's law, both in words and mathematically. [2]

Solution: A galaxy's recessional velocity is proportional to its distance.
$v = H_0 d$

(b) Plot the data above on a graph of recessional velocity against distance and hence estimate the age of the universe. [5]

Solution: $\approx 4.3 \times 10^{17}$ s

Solution:

(c) What is the primary piece of evidence that supports the theory of an expanding universe. [1]

Solution: Galactic red shift: almost all galaxies' light is red-shifted i.e. they are moving away from us in every direction.

(d) The notion that the universe is expanding is not sufficient to confirm the Big Bang Theory, which predicts a cosmic microwave background. In what two ways can the cosmic microwave background be explained? [2]

Solution:
1/ The young, hot universe was saturated with gamma photons. These have been red-shifted due to the expansion of space itself and are now in the microwave region of the EM spectrum.
2/ The universe was extremely dense and hot when it was young. Expansion has cooled it to a low temperature (2.7 K). If it is a black body, the universe would emit a peak wavelength of approximately 1 mm - microwaves.

3. Quasars and exoplanets both reside outside of our solar system. The methods we use to study bodies that are so far away have only been developed relatively recently.

Total for Question 3: 10

(a) How is it known that quasars are amongst the most distant objects in the universe? [1]

> **Solution:** Their spectra are very red-shifted.

(b) Which two of the following are correct? [2]

1. Quasars emit electromagnetic radiation for a very short period of time before acting as the centres of stable galaxies.
2. Quasar is short for quasi-stellar x-ray sources.
3. Quasars are thought to be caused by very massive, active black holes.

> **Solution:** 1, 4

(c) How can an exoplanet be detected by a nearby star's Doppler shift? Why can the exoplanet's mass not be estimated using this technique? [2]

> **Solution:** A planet and a star both orbit around a common centre of mass. The planet must have a mass greater than about 0.001 times that of the star if the COG is to lie outside of the star. If this is the case, the star's distance from Earth will change and so too will it's Doppler shift. Thus, the presence of an exoplanet can be inferred. However, its distance from the star is unknown and so its mass cannot be calculated.

(d) Briefly explain one method that can be used to estimate an exoplanet's mass. [2]

> **Solution:** When an exoplanet transits a star, the brightness of the star decreases. This decrease is proportional to the change in the star's visible area i.e. the area of the exoplanet. Thus, the diameter of the exoplanet can be calculated. If assumptions are made about its 3d shape and its composition then its mass can be estimated.

(e) An exoplanet passes in front of a spherical star. A 6% decrease in the observable brightness is recorded. Given that the star is the same size as our sun and that the mean density of the exoplanet is 3940 kgm^{-3}, estimate the mass of the exoplanet. [3]

Solution: 8.18×10^{28} kg