inkPhysics

ANSWER BOOK

The Doppler effect and Hubble's law

Astrophysics · Year 13

AQA 3.9.3.1, 3.9.3.2

10 questions · 31 marks

NAVY EDITION

SECTION A · Warm-up

A1 Every line in the spectrum arrives at a longer wavelength than the same line measured in the laboratory, the whole pattern stretched by one factor. The galaxy is receding, with $z = \Delta\lambda/\lambda$ giving $v = zc$ for speeds well below c. [2]

A2 The recession speed of a galaxy is proportional to its distance: $v = Hd$. H is the gradient, about 65 km s^{-1} Mpc^{-1}: every megaparsec of distance adds 65 km/s of recession speed. [2]

A3 The cosmic microwave background, a 2.7 K black-body glow from every direction, the cooled afterglow of the hot early universe; and the roughly three-to-one hydrogen-helium mass ratio, matching fusion in the universe's first minutes. [2]

SECTION B · Standard

B1 $z = (490.0 - 486.1)/486.1 = 8.0 \times 10^{-3}$. $v = zc = 2.4 \times 10^{6}$ m s^{-1}, receding. [3]

B2 $v = c\,\Delta\lambda/\lambda = 3.0 \times 10^{8} \times 0.080/550 = 4.4 \times 10^{4}$ m s^{-1}. The period of the wavelength oscillation is the orbital period of the binary. [3]

B3 $d = v/H = 8800/65 = 135$ Mpc. Keeping v in km/s and H in km/s per Mpc delivers the answer in megaparsecs directly. [4]

B4 The Doppler shift responds only to the velocity component along the line of sight. Edge-on, each star's full orbital speed alternately points toward and away from Earth, giving the largest, cleanest wavelength swing; tilt the orbit and the measured shifts shrink. [3]

SECTION C · Stretch

C1 $t = d/v = 1/H$ for every galaxy. In SI units $H = 65\,000/3.08 \times 10^{22} = 2.1 \times 10^{-18}$ s^{-1}, so $t = 1/H = 4.7 \times 10^{17}$ s ≈ 15 billion years. The assumption of constant speed makes this an estimate; the modern value is 13.8 billion years. [5]

C2 Space itself expands, carrying the galaxies apart: there is no centre and no edge, and an observer in any galaxy sees the same Hubble law. The student's picture cannot explain why the recession looks the same in every direction from here (and would from anywhere), nor why the microwave background arrives uniformly from the whole sky. [3]

C3 $v = zc = 0.30 \times 3.0 \times 10^8 = 9.0 \times 10^7$ m s^{-1}; $d = 90\,000/65 = 1385$ Mpc. At nearly a third of light speed the small-shift approximation $z = v/c$ is strained, so both figures are estimates. [4]