2005

HIGHER SCHOOL CERTIFICATE
EXAMINATION

Cosmology
Distinction Course
Modules 4, 5, 6 and 7 (including Residential 2)

General Instructions

- Reading time – 5 minutes
- Working time – 2 hours
- Write using black or blue pen
- Board-approved calculators may be used
- A data sheet is provided at the back of this paper

Total marks – 120

(Section I) Page 2

20 marks

- Attempt FIVE questions from Questions 1–7
- Allow about 20 minutes for this section

(Section II) Pages 3–4

40 marks

- Attempt FOUR questions from Questions 8–13
- Allow about 40 minutes for this section

(Section III) Page 4

60 marks

- Attempt Questions 14–15
- Allow about 60 minutes for this section

028

Section I

20 marks
Attempt FIVE questions from Questions 1–7
Allow about 20 minutes for this section

Answer each question in the writing booklet provided. Extra writing booklets are available.

Question 1 (4 marks)

Einstein's Theory of General Relativity initially predicted a universe that should be either expanding or contracting.

How did he deal with this?

Question 2 (4 marks)

What is meant by the term *look-back time* in cosmology?

Question 3 (4 marks)

Distinguish between the Hubble length and the Hubble constant.

Question 4 (4 marks)

Describe the characteristics of a de Sitter universe.

Question 5 (4 marks)

What observations might reveal that a galaxy hosts a supermassive black hole?

Question 6 (4 marks)

The Wilkinson Microwave Anisotropy Probe (WMAP) measured irregularities in the intensity of the cosmic microwave background radiation. Discuss the significance of this result.

Question 7 (4 marks)

Outline the main differences in the concepts of time and space held by Einstein and Newton.

Section II

40 marks
Attempt FOUR questions from Questions 8–13
Allow about 40 minutes for this section

Answer each question in the writing booklet provided. Extra writing booklets are available.

Question 8 (10 marks)

The density of the Universe is thought to be close to the critical value described by omega $(\Omega) = 1$.

List the major constituents that contribute to this density, and outline briefly how their proportions may change over the life of the Universe.

Question 9 (10 marks)

There are three ways that radiation may have a change in wavelength between emission and detection.

Explain the essential differences between Doppler shift, gravitational redshift and cosmological redshifts.

Question 10 (10 marks)

A distant quasar at redshift of 4 radiates an optical continuum, as well as a broad emission line from hydrogen at a wavelength of 121.6 nm. The radiation passes through hydrogen in a galaxy at redshift 2 on its way to Earth, where a spectrum is observed.

(a) Calculate the wavelength at which the line emission is received on Earth.

(b) What is the wavelength at which hydrogen in the intervening galaxy affects the radiation?

(c) What is the wavelength at which this intervening effect is observed?

(d) Sketch the shape of the received spectrum, marking the features associated with the quasar, and the effects of the intervening galaxy.

Question 11 (10 marks)

Discuss the observational evidence suggesting that the Universe is accelerating. What does this tell us about the composition of the Universe?

Question 12 (10 marks)

The early measurements of galaxy spectra showed an increase in recession velocity with distance to the galaxy. From these measurements, Hubble derived a value for H_0 of 540 km s^{-1} Mpc^{-1}.

(a)   Use this H_0 to calculate the value for the age of the Universe assuming a Big Bang model.

(b)   Compare this age with the accepted age of the Earth obtained by radiometric dating of rocks.

Question 13 (10 marks)

The arrival times of pulses from pulsars can be measured very accurately.

Describe how the discovery of two pulsars in a binary system provides a rigorous test of the Theory of General Relativity.

Section III

60 marks
Attempt Questions 14–15
Allow about 60 minutes for this section

Answer each question in the writing booklet provided. Extra writing booklets are available.

Question 14 (30 marks)

Developments in cosmology arise because of a close interaction between theory and experiment.

Describe and discuss current and planned observations and experiments that could have relevance to theories of cosmology. Include in your discussion the relationship of these results to current cosmological theories.

Question 15 (30 marks)

Describe the sequence of epochs that are postulated in the Big Bang Theory of the Universe's evolution.

Discuss how surveys of galaxies, quasars, radio sources and hydrogen clouds have given observational evidence to refine our models of the large-scale structure of the Universe.

End of paper

Data Sheet

Physical Constants and Conversion Factors

Recommended values

Abstracted from the consistent set of constants in CODATA Bull. No. 63 (1986) by the Royal Society, the Institute of Physics, and the Royal Society of Chemistry.

The number in parenthesis after each value is the estimated uncertainty (standard deviation) of the last digit quoted.

speed of light in a vacuum	c	$2.997\,924\,58 \times 10^8$ m s^{-1} (exact)
permeability of a vacuum	μ_0	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of a vacuum, $[\mu_0 c^2]^{-1}$	ϵ_0	$8.854\,187\,817\ldots \times 10^{-12}$ F m^{-1}
elementary charge (of proton)	e	$1.602\,177\,33(49) \times 10^{-19}$ C
gravitational constant	G	$6.672\,59(85) \times 10^{-11}$ N m^2 kg^{-2}
Planck constant	h	$6.626\,0755(40) \times 10^{-34}$ J s
Avogadro constant	N_A	$6.022\,1367(36) \times 10^{23}$ mol^{-1}
molar gas constant	R	$8.314\,510(70)$ J K^{-1} mol^{-1}
Boltzmann constant	k	$1.380\,658(12) \times 10^{-23}$ J K^{-1}
unified atomic mass constant	m_u	$1.660\,5402(10) \times 10^{-27}$ kg
rest mass of electron	m_e	$9.109\,3897(54) \times 10^{-31}$ kg

SI secondary units

astronomical unit	AU	$1.495\,978 \times 10^{11}$ m
parsec	pc	3.0856×10^{16} m = 3.262 ly
Gregorian calendar year	y	365.2425 days = 31 556 952 s
jansky	Jy	10^{-26} W m^{-2} Hz^{-1}

Indicative values

earth mass	5.977×10^{24} kg
solar mass, $M_\odot$	1.989×10^{30} kg
galaxy mass	$10^{11}\,M_\odot$
Hubble constant, H_0	$100\,h$ km s^{-1} Mpc^{-1} (typically h ranges from 1 to 0.5)

Conversion factors

distance (light-year)	ly	9.460×10^{15} m = 63 240 AU
energy (erg)	erg	10^{-7} J
magnetic field (gauss)	G	10^{-4} T
wavelength (angstrom)	Å	10^{-10} m

BLANK PAGE