BOARD OF STUDIES
NEW SOUTH WALES

2004
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

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)

Describe the concept of curved space, using, as a particular example, a hyperbolic space.

Question 2 (4 marks)

(a) What is a universal scaling factor?

(b) Define how redshift may be expressed in terms of scaling factors.

Question 3 (4 marks)

Define and explain the principle of equivalence used in General Relativity.

Question 4 (4 marks)

How did Bondi, Gold and Hoyle reconcile their Steady State model of the universe with the Hubble redshift observations of galaxies?

Question 5 (4 marks)

Discuss the origin of the widespread confusion between Doppler redshifts and expansion redshifts.

Question 6 (4 marks)

Explain briefly what is meant in cosmology by the term *expansion time*.

Question 7 (4 marks)

When we observe quasars we look back to an early age of the universe. At what age (in terms of the present age) did light leave a quasar which we observe at redshift 6.3?

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)

Explain why the existence of supermassive black holes in quasars at high redshift poses difficulties for models that describe the formation of large-scale structure in the universe.

Question 9 (10 marks)

Compare and contrast the characteristics of the cosmological models for a Newtonian universe and a Friedmann-Lemaitre universe.

Question 10 (10 marks)

(a) List three astronomical observations that have tested predictions of the General Theory of Relativity.

(b) Discuss briefly the observations and results for ONE of these tests.

Question 11 (10 marks)

For every atom of iodine in the universe there are about one million iron atoms, 10 million carbon atoms and 3000 million hydrogen atoms. All these elements are essential for life on earth.

(a) Discuss the processes that formed atoms of iodine, iron and carbon.

(b) How did some of each of these elements reach our biosphere?

Question 12 (10 marks)

In the optical spectrum of a distant source, two features are identified as caused by hydrogen. One is a broad Lyman alpha peak at wavelength 535 nm, and the other is a damped Lyman alpha line at wavelength 438 nm in a Lyman alpha forest.

(a) Make a rough sketch of this spectrum and label the two features.

(b) Given that the laboratory wavelength for Lyman alpha is 121.6 nm, calculate the redshift for each feature.

(c) Discuss the probable origin of each feature.

Question 13 (10 marks)

Discuss the observational evidence that has persuaded most astronomers to accept the Big Bang model of the universe.

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)

The satellite observatories COBE and WMAP have measured the temperature of the Cosmic Microwave Background (CMB) radiation from most of the sky.

(a) Describe the magnitude and angular scale of variations seen in the CMB.

(b) Discuss what may be learned from these angular fluctuations in CMB radiation.

Question 15 (30 marks)

(a) Outline some of the events in the universe that might produce gravitational waves.

(b) Describe one possible experimental method by which gravitational waves may be detected.

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

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