BOARD OF STUDIES
NEW SOUTH WALES

2002
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 3

20 marks

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

Section II Pages 4–5

40 marks

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

Section III Page 6

60 marks

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

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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)

The Hubble constant is listed in the data sheet attached to this paper. Explain what this constant measures, and why its typical value is uncertain.

Question 2 (4 marks)

Describe TWO of the processes that are thought to generate gravitational waves in space.

Question 3 (4 marks)

What is the relationship between expansion redshift and the universal scaling factor?

Question 4 (4 marks)

List FOUR possible forms of dark matter that seem to be required by observations of stable clusters of galaxies.

Question 5 (4 marks)

The cosmological constant Lambda (Λ) introduced by Einstein has become a significant factor in current descriptions of the Universe. Explain how the value of Lambda affects the predicted future of our Universe.

Question 6 (4 marks)

After some simplifying assumptions, Friedmann was able to describe the evolution of the Universe in mathematical terms. Discuss the main assumptions in the Friedmann model universes.

Question 7 (4 marks)

The deceleration term q_0 appears in most cosmological models. Discuss the function of this term in the models.

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 General Theory of Relativity has been tested by a range of astronomical observations. Discuss THREE major tests, and describe the conditions for which the theoretical predictions were made.

Question 9 (10 marks)

For the Coma Cluster of galaxies, the velocity dispersion (ie the statistical dispersion in radial velocity) is 977 km s^{-1}.

(a) Calculate the typical Doppler shift observed for the H alpha line (wavelength 656.28 nm) from galaxies within this cluster, using the simple formula for a small Doppler shift $f_{obs} = f_{em}(1 - \frac{v}{c})$ where v is the radial velocity of the emitting galaxy.

(b) How would the combined light from many galaxies in the cluster affect the shape of the observed H alpha spectral line?

Question 10 (10 marks)

The discovery of radiation from the cosmic microwave background (CMB) is considered a key observation supporting a big bang model for the Universe. Discuss the nature of the CMB and the importance of measuring how its intensity varies across the sky on different angular scales.

Question 11 (10 marks)

Huge cosmic ray showers are occasionally caused by the arrival in our atmosphere of protons with energy up to 10 joules. Describe some of the interactions that such a proton may encounter on its path to us through part of the Universe.

Question 12 (10 marks)

(a) Discuss the difference between the effects causing a Doppler redshift and an expansion redshift.

(b) How may the cause of an observed redshift be determined?

(c) For what circumstances would each of these effects produce a blue shift?

Question 13 (10 marks)

The space–time diagram in Figure 1 has been calculated for a big bang model universe with parameters $\Omega_M = 0.3$; $\Omega_\Lambda = 0.7$.

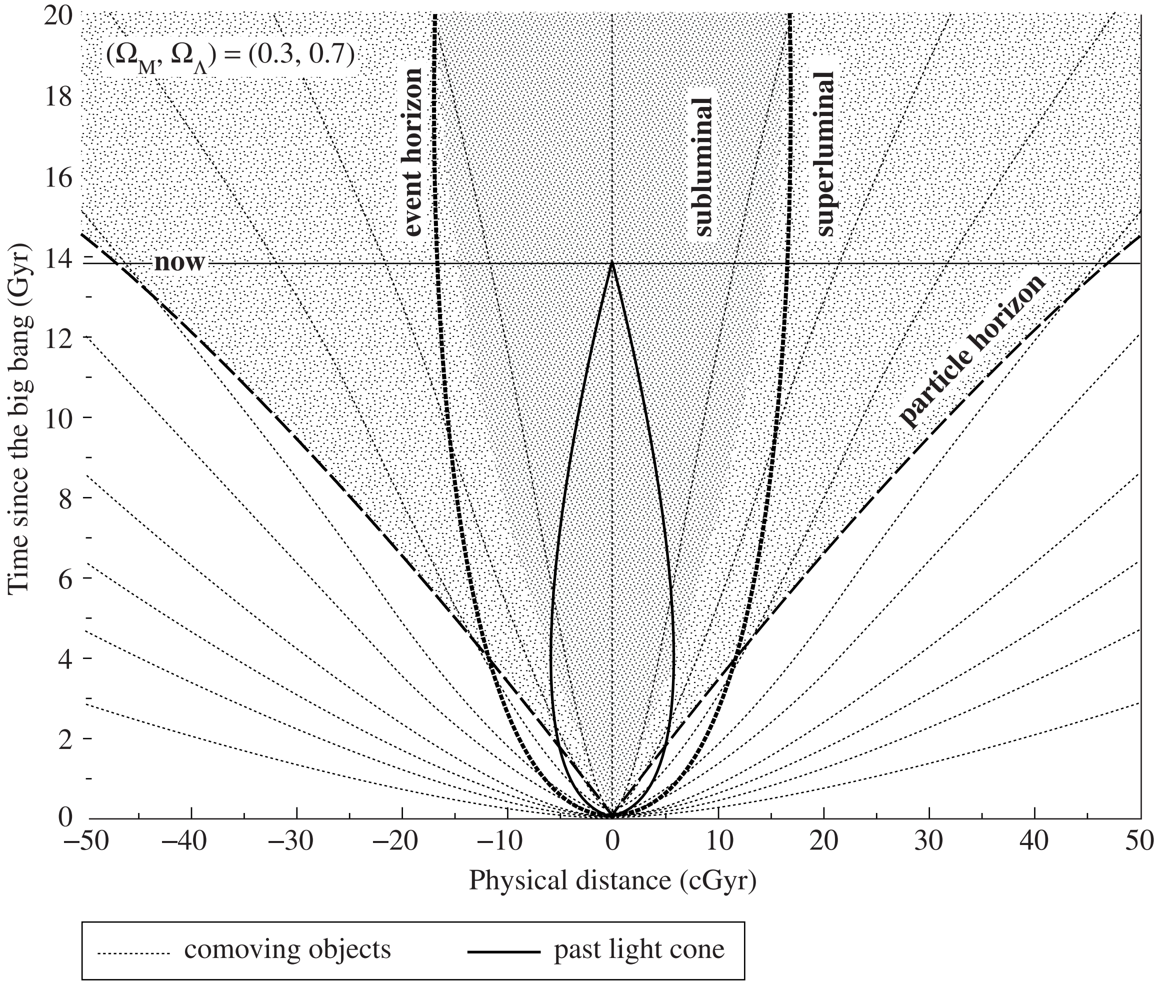

Figure 1

Referring to this figure:

(a) State the coordinates of our Earth now.

(b) What are the time and place of the event called the Big Bang?

(c) Sketch the part of the diagram showing the locus of events across the universe that can be seen from Earth right now.

(d) Explain briefly the difference between the particle horizon and the event horizon.

Please turn over

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)

During the evolution of the present Universe, it is believed that the creation of the chemical elements occurred by several processes and under greatly differing conditions for different parts of the periodic table.

Describe the conditions and the processes that produced the following groups of elements:

- hydrogen;
- helium and lithium;
- carbon and oxygen;
- iodine and uranium.

Question 15 (30 marks)

The Steady State Theory of the Universe is a model based on the Perfect Cosmological Principle. State the basic assumptions of the model, and explain how it conforms to this principle.

Discuss how it is possible to have a steady state in which stars are born, burn hydrogen and die.

Outline the observational evidence that has led to the rejection of steady state models by most cosmologists.

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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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