QUEEN'S UNIVERSITY BELFAST

PHY2003
Exam Time Table
Code PHY2003

Any calculator, except one with pre-programmable memory, may be used in this examination

Section A, B and C answer books

Level 2 Examination

PHY2003
Astrophysics I

Wednesday, 12th December 2018 10:00 AM - 12:00 PM

Examiners: Prof P Browning
Dr P van der Burgt
and the Internal Examiners

Answer ALL QUESTIONS in Section A
Answer ONE QUESTION in Section B
Answer ONE QUESTION in Section C

Use a separate answer book for each Section
Follow the instructions on the front of the answer book
Enter your Anonymous Code and Seat Number but NOT your name

THE QUEEN'S UNIVERSITY OF BELFAST

DEPARTMENT OF PHYSICS AND ASTRONOMY

PHYSICAL CONSTANTS

Speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{ms^{-1}}$
Permeability of a vacuum	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{Hm^{-1}}$ $\approx 1.26 \times 10^{-6}\ \mathrm{Hm^{-1}}$
Permittivity of a vacuum	$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{Fm^{-1}}$
Elementary charge	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
Electron charge	$= -1.60 \times 10^{-19}\ \mathrm{C}$
Planck Constant	$h = 6.63 \times 10^{-34}\ \mathrm{Js}$
Reduced Planck Constant	$\hbar = 1.05 \times 10^{-34}\ \mathrm{Js}$
Rydberg Constant for hydrogen	$R_\infty = 1.097 \times 10^{7}\ \mathrm{m^{-1}}$
Unified atomic mass unit	$1u = 1.66 \times 10^{-27}\ \mathrm{kg}$ $1u = 931\ \mathrm{MeV}$
1 electron volt (eV)	$= 1.60 \times 10^{-19}\ \mathrm{J}$
Mass of electron	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
Mass of proton	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
Mass of neutron	$m_n = 1.67 \times 10^{-27}\ \mathrm{kg}$
Molar gas constant	$R = 8.31\ \mathrm{JK^{-1}mol^{-1}}$
Boltzmann constant	$k = 1.38 \times 10^{-23}\ \mathrm{JK^{-1}}$
Avogadro constant	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
Gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{Nm^2kg^{-2}}$
Acceleration of free fall on the Earth's surface	$g = 9.81\ \mathrm{ms^{-2}}$

Level 2 Astronomy Data Sheet for PHY2003

Astronomical Constants

Mass of Sun	$M_{Sun} = 1.99 \times 10^{30}$ kg
Radius of Sun	$R_{Sun} = 6.96 \times 10^{8}$ m
Luminosity of Sun	$L_{Sun} = 3.90 \times 10^{26}$ W
Effective temperature of Sun	$T_{Sun} = 5770$ K
Mass of Earth	$M_{\oplus} = 5.98 \times 10^{24}$ kg
Radius of Earth	$R_{\oplus} = 6.38 \times 10^{6}$ m
Astronomical Unit	1 AU $= 1.496 \times 10^{11}$ m
Parsec	1 pc $= 3.08 \times 10^{16}$ m
Megaparsec	1Mpc $= 10^{6}$ pc
Hubble Constant	$H_0 = 71$ km/sec/Mpc

Solar System Data

Planet	**a (AU)**	**e**	**i (°)**	**($M/M_{\oplus}$)**	**$R/R_{\oplus}$**	**Albedo**
Mercury	0.387	0.206	7.00	0.056	0.38	0.06
Venus	0.723	0.007	3.39	0.815	0.95	0.76
Earth	1.000	0.017	0.00	1.000	1.00	0.40
Mars	1.524	0.093	1.85	0.107	0.53	0.16
Jupiter	5.203	0.048	1.31	318	11.19	0.51
Saturn	9.540	0.056	2.49	95	9.41	0.50
Uranus	19.18	0.047	0.77	14.5	4.01	0.66
Neptune	30.06	0.009	1.77	17.2	3.89	0.62
Dwarf Planet	**a (AU)**	**e**	**i (°)**	**($M/M_{\oplus}$)**	**$R/R_{\oplus}$**	**Albedo**
Ceres	2.77	0.080	10.59	1.6×10^{-4}	0.15	0.37
Pluto	39.44	0.249	17.15	2.0×10^{-3}	0.18	0.50
Eris	67.67	0.442	44.19	2.8×10^{-3}	0.18	0.96
Satellite	**a (km)**	**e**	**i (°)**	**($M/M_{\oplus}$)**	**$R/R_{\oplus}$**	**Albedo**
Moon	384,400	0.055	5.15	0.012	0.27	0.08

SECTION A

Use a section A answer book

Answer all questions in this section

(All questions are worth 10 marks)

1. Explain what is meant by signal-to-noise for an optical telescope on Earth, and how it defines the ability to detect an object. If that telescope detects 1 photon per second from a star, and it simultaneously receives 10 photons per second from the foreground sky, how long will the camera need to be exposed before there is sufficient signal-to-noise for a detection?

2. Describe how the Moon produces a tidal force on the Earth, and what effects this causes on the evolution of the Earth-Moon system.

3. Outline the spectral classification of stars, including approximate temperature ranges for each classification and a brief description of the dominant spectral features.

4. Show, mathematically, that in a uniformly expanding universe, the redshift z is related to the distance d of an object via the Hubble law

$$cz = H_0 d$$

where H_0 is the Hubble constant. What evidence is there that the Universe is not undergoing uniform expansion?

SECTION B

Use a Section B answer book

Answer <u>ONE</u> question from this section

5 (a) By considering the forces acting on a parcel of gas within the atmosphere of a star, derive the equation of hydrostatic equilibrium shown below, clearly explaining each step.

$$\frac{dP}{dr} = -\frac{Gm(<r)\rho(r)}{r^2}$$

[10]

(b) Hence approximating the density $\rho(r)$ by the average density within a star $\bar{\rho}$, show that the central pressure of a star P_C is approximately

$$P_C \approx \frac{2}{3}\pi G R\ \bar{\rho}^2$$

[6]

(c) By using the expression above and assuming that the star is dominated by ionized hydrogen obeying the ideal gas law, calculate the central pressure and temperature of the Sun.

[7]

(d) Briefly describe *two* pieces of evidence that shows astronomers' theoretical calculation of the physical state of the interior of the Sun is correct.

[7]

SECTION B

6 (a) Clearly explain what is meant by the apparent V magnitude of an object. If the flux at Earth in the V filter from the star Vega is 3.2×10^{-8} J/m^2/sec, show that the apparent V magnitude of an object is given by

$$m_V = -2.5 \log_{10} f - 18.69$$

[10]

(b) The apparent V magnitude of the planet Mars when it is closest to Earth is -2.8. Calculate the V-band flux arriving at Earth, the distance of Mars at this time, and therefore the effective luminosity of Mars.

[8]

(c) A telescope of diameter D is used to observe an object at a distance d. If the luminosity of that object at a wavelength is L, show that the number of photons collected per second is given by

$$n_\lambda = \frac{L_\lambda D^2}{16 d^2}$$

[6]

(d) Considering a solar system object of albedo A_λ and cross-section area C at a distance R_h from the Sun, show the equivalent equation for a planetary body is given by

$$n_\lambda = \frac{A_\lambda C L_\lambda D^2}{64 \pi R_h^2 d^2}$$

[6]

SECTION C

Use a Section C answer book

Answer ONE question from this section

7 (a) Sketch and annotate a Hertzsprung-Russell diagram, carefully labelling the axes and positions of the following categories of stars: main-sequence stars, giants, supergiants, white dwarfs, and brown dwarfs. **[10]**

(b) On your diagram, clearly indicate the positions of the following stars:

(i) The Sun.

(ii) An unresolved binary star of two identical Sun-like stars (explain your reasoning).

(iii) The red dwarf Proxima Centauri, which has (B-V) = 1.90 and M_V = 15.49.

(iv) The red giant Aldebaran, which has (B-V) = 1.54 and M_V = -0.63.

(v) The white dwarf Sirius B, which has a luminosity of 3 x 10^{-3} L_{Sun} and a temperature of 25,000K. **[10]**

(c) By comparison with the evolution of the Sun, carefully explain whether any of the last three stars (Proxima Centauri, Aldebaran, and Sirius B) may have been, or will become a solar-like star. **[6]**

(d) The stars Proxima Centauri and Aldebaran lie at distances of 1.30 pc and 20.0 pc, respectively. Calculate if either star can be seen by the naked eye, stating any assumptions clearly. **[4]**

SECTION C

8 (a) Briefly describe the following methods of measuring distance, including the approximate range of distances over which they may be used.

(i) RR Lyrae stars.

(ii) Cepheid variables

(iii) The Tully-Fisher relationship. **[10]**

(b) A supernova is observed in the outskirts of a large elliptical galaxy. The apparent magnitude of the peak brightness of the supernova is m_V = +15.1. The redshift of the galaxy is z = 0.0219.

(i) Without any other information, explain how you could be sure that the supernova was a Type Ia, and not a Type II? **[3]**

(ii) Spectroscopy confirms that it was a Type Ia supernova. Describe the spectral features that can be used to distinguish between Type Ia and Type II supernova, and carefully explain why these features arise. **[3]**

(iii) The absolute magnitude of the peak brightness of a Type Ia supernova is M_V = -19.6. From the information you know about this event and the host galaxy, calculate the age of the Universe assuming a constant expansion rate. **[4]**

(iv) Calculate the wavelength at which you would expect Hα (rest wavelength 6562.8Å) to be detected in this galaxy. **[3]**

(v) By how much has the Universe expanded since this radiation was emitted? **[2]**

(c) Explain 3 possible sources of error that might arise when using Type Ia supernovae to calculate the distance to galaxies. **[5]**

END OF EXAMINATION