PHY2003
Exam Time Table
Code PHY2003

Use lined, single-sided A4 paper
with a black or blue pen.
Write your student number
at the top of every page.

Any non-graphical calculator, except those with pre-programmable memory, may be used in this examination

LEVEL 2
Examination contributing to the Degrees of Bachelor of Science (BSc) and Master in Science (MSci)

PHY2003 - EXAM
Astrophysics I
Wednesday, 5th August 2020, 09.30 - 12.30

Examiners: Prof S Matthews, Dr P van der Burgt
and the Internal Examiners
Dr J Greenwood (j.greenwood@qub.ac.uk)

Answer ALL FOUR questions in Section A for 10 marks each.
Answer ONE questions in Section B for 30 marks each.
Answer ONE questions in Section C for 30 marks each.
You have THREE hours to complete and upload this paper.

Contact the module coordinator if you have queries/problems at a.fitzsimmons@qub.ac.uk and copy to mpts@qub.ac.uk

By submitting the work, you are declaring that:
1. The submission is your own original work and no part of it has been submitted for any other assignments;
2. You understand that collusion and plagiarism in an exam are major academic offences, for which a range of penalties may be imposed, as outlined in the Procedures for Dealing with Academic Offences.

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 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	$R = 8.31\ \mathrm{JK}^{-1}\mathrm{mol}^{-1}$
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	$G = 6.67 \times 10^{-11}\ \mathrm{Nm}^{2}\mathrm{kg}^{-2}$
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	$M_{Sun} = 1.99 \times 10^{30}\,\text{kg}$
Radius of Sun	$R_{Sun} = 6.96 \times 10^{8}\,\text{m}$
Luminosity of Sun	$L_{Sun} = 3.90 \times 10^{26}\,\text{W}$
Effective temperature of Sun	$T_{Sun} = 5770\,\text{K}$
Mass of Earth	$M_{\oplus} = 5.98 \times 10^{24}\,\text{kg}$
Radius of Earth	$R_{\oplus} = 6.38 \times 10^{6}\,\text{m}$
Astronomical Unit	$1\ \text{au} = 1.496 \times 10^{11}\,\text{m}$
Parsec	$1\ \text{pc} = 3.08 \times 10^{16}\ \text{m}$
Megaparsec	$1\text{Mpc} = 10^{6}\ \text{pc}$
Hubble Constant	$H_0 = 71\ \text{km/sec/Mpc}$

Solar System Data

Planet	**a (au)**	**e**	**i (°)**	**(M/M⊕)**	**R/R⊕**	**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⊕)**	**R/R⊕**	**Albedo**
Ceres	2.77	0.080	10.59	$1.6\text{x}10^{-4}$	0.15	0.37
Pluto	39.44	0.249	17.15	$2.0\text{x}10^{-3}$	0.18	0.50
Eris	67.67	0.442	44.19	$2.8\text{x}10^{-3}$	0.18	0.96
Satellite	**a (km)**	**e**	**i (°)**	**(M/M⊕)**	**R/R⊕**	**Albedo**
Moon	384,400	0.055	5.15	0.012	0.27	0.08

SECTION A

Answer all questions in this section

1. Explain how two exoplanet detection methods can be combined to calculate the average density of an exoplanet. Include the relevant equations in your explanation. **[10]**

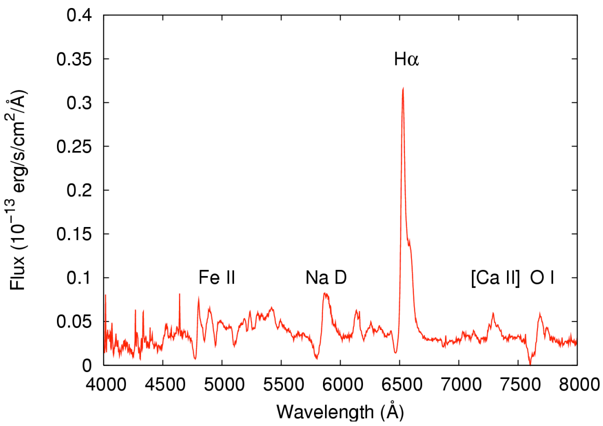
2. **(a)** Show that the escape velocity of a rocket orbiting at a distance d from the Sun is given by: **[5]**

$$v_{esc} = \sqrt{\frac{2GM_{\odot}}{d}}$$

(b) Describe what the Solar neutrino problem is and what its solution tells us about neutrinos and the Sun. **[5]**

3. Describe how observations of open clusters and globular clusters are used to show that our Sun resides in a spiral galaxy, including diagrams where appropriate. Include in your answer the approximate position of the Sun in our galaxy. **[10]**

4. **(a)** The spectrum of a supernova in a distant galaxy is shown below, with emission line identifications marked. Explain whether this a Type I or Type II supernova, explain what type of star likely exploded, and what type of object might be left after the explosion. **[5]**



(b) The distance modulus to the galaxy is measured as DM=31.65 magnitudes, and the redshift of the supernova is z=0.005. Estimate a value for the Hubble Constant H_0 from these measurements. **[5]**

SECTION B

Answer ONE question from this section, each question is worth 30 marks

5. **(a)** The gravitational effects of the Moon raise tides on the Earth. The Sun also produces tides on Earth but at 46% the strength of Lunar tides. The Sun is much more massive than the Moon. Explain why the tidal bulge on the Earth produced by the gravitational forces of the Sun is so much smaller than the one generated by the Moon. Include any relevant relations or equations in your description. **[3]**

(b) An alien observer detects the brightness of the Sun changing when Neptune transits in front of the Sun. By what percentage does the alien see the Sun's light decrease? **[3]**

(c) Kepler-21 b is a transiting super Earth exoplanet that orbits an F-type star. Its mass is 5.08 times that of Earth's, and it has a radius of 0.764 of Jupiter's radius. The planet's orbit has a semimajor axes of 0.0427 au and an eccentricity of 0.02. F-type stars are typically 1.4 times larger in mass than the Sun.

(i) How often does Kepler-21b transit its host star? **[5]**

(ii) How would the time to the next planet transit change if Kepler-21b was a gas giant with a mass of 1.5 times that of Jupiter? **[2]**

(iii) During one orbit of Kepler-21 b, what is the shortest time it takes for a photon emitted from the host star to reach the planet? **[3]**

(d) The QUB Teaching Observatory houses a 14-inch (0.35m) diameter mirror telescope. With the telescope, James measures an apparent V magnitude of +6.7 for dwarf planet Ceres, when it is closest to Earth. Calculate the V-band flux arriving at Earth, the distance of Ceres at this time, the effective luminosity of Ceres, and how many photons per second are hitting the Observatory's mirror. Assume the Earth is on a circular orbit. At visual wavelengths one photon has an energy of 3.6×10^{-19}J and the apparent V-band magnitude of an object is given by

$$V = -2.5 log f - 18.74$$ **[9]**

Question 5 continued on next page

SECTION B

(e) Delta is a star with an apparent magnitude of +2.3 and an absolute magnitude of –1.1. Gamma is a star with an apparent magnitude of -3.7 and a surface temperature of 8000K. Is there enough information given to determine which star is closer to the Earth? Explain your reasoning with relevant equations. **[5]**

SECTION B

6. **(a)** Calculate the minimum diameter of spherical planetesimals/planets with the following properties:

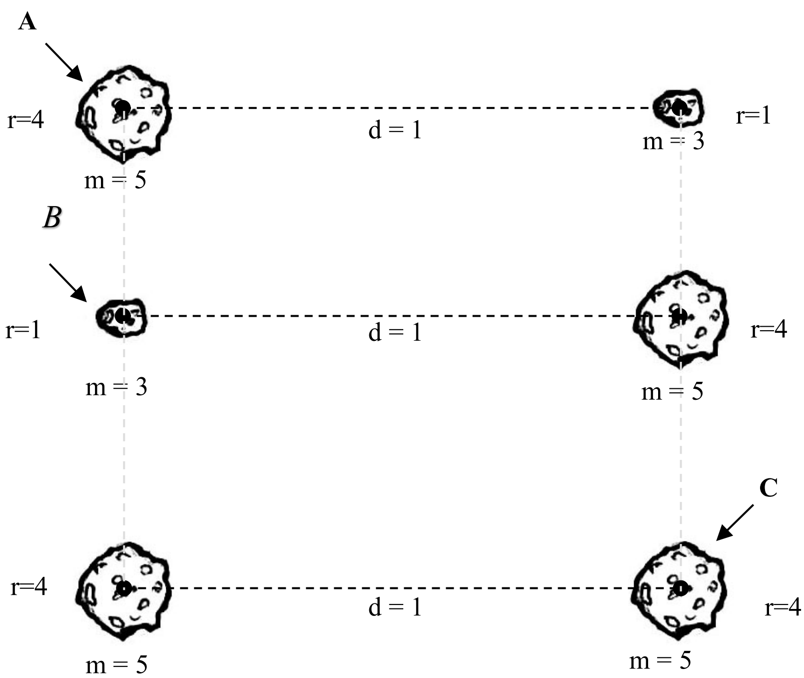
(i) Silicate with ρ = 3.5 g/cm^3 and $Y = 20{\times}10^9$ Pa **[2]**

(ii) Steel with ρ = 8.05 g/cm^3 and $Y = 200{\times}10^9$ Pa**.** **[2]**

(b) Explain why only one 1 dwarf planet is seen in the asteroid belt when at least 5 can be found in the Kuiper belt. **[3]**

(c) Give a brief description of one property commonly found in observed exo-planetary systems that is different from the architecture of our own Solar System. Explain which exoplanet discovery technique found this difference. **[4]**

(d) In the figure below, three pairs of two rocky asteroids are shown with masses (m), expressed in arbitrary units, radii (r) expressed in arbitrary units, and separated by a distance (d), also expressed in arbitrary units. Three of the asteroids are identified with the letters A, B, and C. Rank the accelerations of Asteroid A, B, and C due to gravity. Explain/justify your reasoning. **[3]**



Question 6 continued on next page

SECTION B

(e) Asteroid Eros has a perihelion and aphelion of 1.1084 au and 1.8078 au respectively. What is the eccentricity of Eros' orbit and what is the velocity of Eros when its distance from the Sun equals the semimajor axis of Mars's orbit? **[10]**

(f) Sally is an astronaut living on the surface of Mars. As part of an experiment, she measures the flux of solar neutrinos from the Sun each sol (day in Mars). How many more solar neutrinos does the Sally detect at the peak of solar neutrinos compared to the minimum value she records, as Mars completes one orbit of the Sun? **[6]**

SECTION C

Answer ONE question from this section, each question is worth 30 marks

7 **(a)** Explain with diagrams what is meant by the terms *visual binary, spectroscopic binary* and *eclipsing binary*, highlighting the physical quantities that may be measured for each. **[14]**

(b) A spectroscopic binary star is composed of two B5V stars that have an orbital period of 20.0 hours. Assuming both B5V stars have the same mass of 6.0 solar masses and the orbit is circular, calculate:

(i) The separation of the stars. **[4]**

(ii) The orbital velocity of each of the stars. **[3]**

(iii) The maximum velocity shift between the two stars is measured as 510.0 km/s. Calculate the inclination of the binary orbit to the line of sight. **[3]**

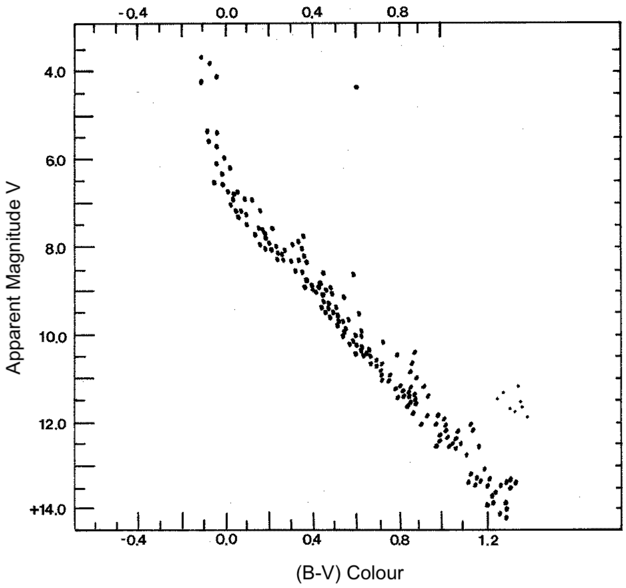
(iv) The normal radius of a B5V star is 3.9 solar radii. By comparing this with your calculated size of orbit, explain which of the three physical types of binary star this system may be classified as**.** **[4]**

(v) The system is subsequently discovered to be an eclipsing binary star. Making the simplifying assumption that the mutual orbit of the system is edge-on to the line of sight, draw a labelled sketch what the lightcurve of the binary star would look like. **[2]**

SECTION C

8 **(a)** Fully describe the evolution of a 1 solar mass star from lying on the main sequence to its final end state. Include in your description a labelled Hertzsprung-Russell diagram illustrating the path of the star during this evolution. **[15]**

(b) The diagram below shows the observed H-R diagram of a star cluster.



(i) Explain whether this star cluster is likely to be an open cluster or a globular cluster. **[3]**

(ii) What is the approximate apparent V-band magnitude of Solar-type stars in this cluster to an accuracy of 0.5 magnitudes, assuming there is no interstellar extinction in the direction of the cluster? **[2]**

(iii) Estimate the distance of this cluster from the Sun, assuming there is no interstellar extinction in the direction of the cluster. **[3]**

(iv) What is the likely spectral and luminosity classification of the star in the diagram with V=4.5, (B-V)=0.6, assuming it belongs to the cluster? Explain your reasoning. **[3]**

(v) Further spectroscopic observations show that Solar-type stars in this cluster have a value of (B-V) = 0.68. Calculate the true distance to this cluster. **[4]**

[M_V(sun) = 4.83, Solar (B-V) = 0.64]

END OF EXAMINATION