PHYSICS

DATE: 4 June 2009

DURATION OF EXAMINATION :
3 hours (180 minutes)

MATERIAL ALLOWED :
Calculator (not programmable and not graphic)

PARTICULAR REMARKS :

- Choose 4 questions from the 6 given questions.
- Indicate your choice of questions by placing a cross in each appropriate box on the supplied form.
- Use a different examination sheet for each question.

Question 1

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Gliese 581 is a red dwarf star situated in the constellation of Libra, at a distance of approximately 20 light years from our solar system.

Currently, three exoplanets (planets outside our solar system) have been detected orbiting round Gliese 581. They are called Gliese 581 b, c and d. Their orbits are approximately circular.

The table below lists the data concerning the three exoplanets. In the case of each exoplanet, its mass m is given as a multiple of the mass of the earth m_T, its period of revolution T is given in days (d) and the radius of its orbit R is given in astronomical units (AU).

Exoplanet	m / m_T	T / d	R / AU
Gliese 581 b	15.6	5.37	0.041
Gliese 581 c	5.1	12.9	0.073
Gliese 581 d	7.6	83.6	0.25

a) **i.** Check that $\frac{T^2}{R^3}$ has approximately the same value for the three exoplanets. — 3 marks

ii. Show that for any planet in a circular orbit of radius R and period T round a star of mass M, the following relationship holds : — 4 marks

$$\frac{T^2}{R^3} = \frac{4\pi^2}{GM}$$

iii. Calculate the mass of the star Gliese 581 using the data given in the table for the exoplanet Gliese 581 d. — 2 marks

Question 1

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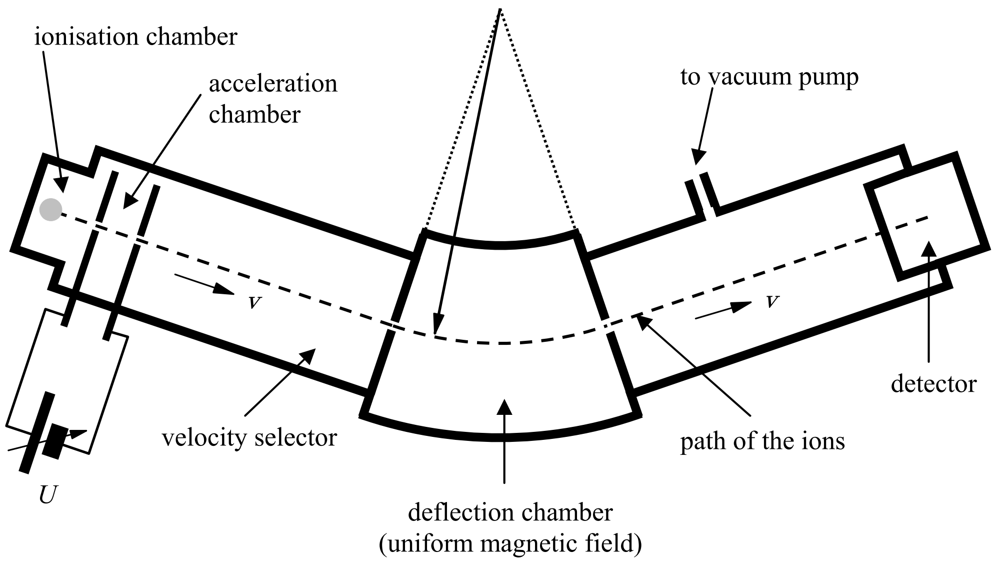
b) The exoplanet Gliese 581 c was discovered on the 4th April 2007 by a team of French, Portuguese and Swiss astronomers. Its radius is 1.5 times that of the Earth. The distance separating it from its star is such that its average temperature could be between 0 ºC and 40 ºC, which would allow for the presence of liquid water on its surface. At the present time, it is the exoplanet that most resembles our Earth.		
i. Calculate the gravitational field strength (acceleration due to gravity) at the surface of Gliese 581 c.		4 marks
ii. 1. Derive the formula for the escape velocity from the surface of a planet.		3 marks
2. Calculate the escape velocity from the surface of Gliese 581 c.		1 mark
iii. Imagine that this exoplanet is inhabited and that its inhabitants decide to put a 400 kg satellite in circular orbit at an altitude of 900 km above its surface.		
1. Calculate the period of such a satellite.		3 marks
2. Calculate the force of gravitation between the planet and the satellite at this altitude.		2 marks
3. Calculate the mechanical energy of the satellite in orbit.		3 marks
<u>Given</u>:		
universal gravitational constant .... $G = 6.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$;		
mass of the Earth .... $m_T = 5.97 \times 10^{24}$ kg;		
radius of the Earth .... $R_T = 6.37 \times 10^6$ m;		
astronomical unit .... $1\ AU = 1.50 \times 10^{11}$ m;		
1 day .... $1\ d = 8.64 \times 10^4$ s.		

Question 2		
	Page 1/2	Mark

In this question gravitational forces may be considered negligible.
A mass spectrometer consists of five parts, as shown in the diagram:

- ionisation chamber
- acceleration chamber
- velocity selector
- deflection chamber
- detector.



a) Positive ions are emitted from the ionisation chamber and enter the accelerating chamber with negligible speed, where they are accelerated by the electric field $\vec{E}$ between two parallel plates (see figure). The potential difference U between the plates is adjustable.

i. State the direction of the electric field $\vec{E}$ in the accelerating chamber. Justify your answer. — 2 marks

ii. Ions of mass m and charge q leave the accelerating chamber with speed v. Derive an expression for U as a function of m, q and v. — 3 marks

iii. Calculate the accelerating potential difference U so that He^+ ions leave the accelerating chamber with a speed of $v = 2.40 \times 10^5$ m s^{-1}. — 2 marks

Question 2		
	Page 2/2	Mark

b) Positive ions enter the deflection chamber in which there is a uniform magnetic field $\vec{B}$. The field $\vec{B}$ is perpendicular to the plane of the paper.

i. State the direction of the magnetic field $\vec{B}$ so that the ions will be deviated as shown in the diagram. Justify your answer. — 2 marks

ii. Show that the motion of the ions in the deflection chamber is uniform circular. — 4 marks

iii. Hence derive the equation for B as a function of m, q, v and r (the radius of the path). — 2 marks

iv. Calculate the value of B such that He^+ ions with the speed $v = 2.40 \times 10^5$ m s^{-1} follow a circular path of radius $r = 30.0$ cm in the deflection chamber. — 2 marks

c) The mass spectrometer described above is used to identify the gases contained in a meteorite. Gases are extracted from the rock and their atoms are ionised, acquiring a charge of $q = +e$. When $U = 1\,000$ V in the accelerating chamber and $B = 0.174$ T in the deflection chamber, ions of one of the elements follow a circular path of radius $r = 30.0$ cm in the deflection chamber and finally enter the detector.

i. For ions of mass m crossing the deflection chamber, derive the following relationship: — 5 marks

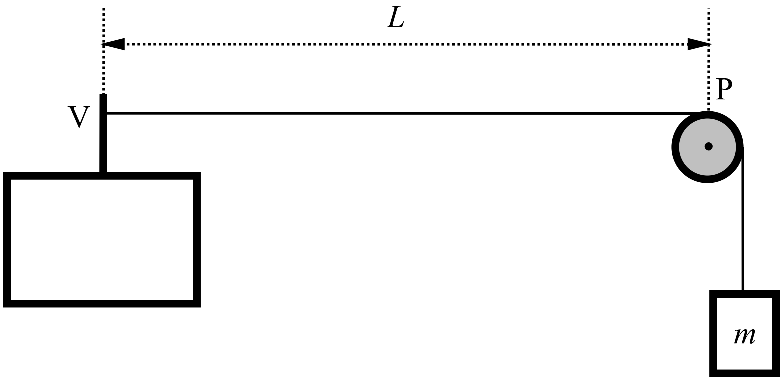
$$m = \frac{r^2 e B^2}{2U}$$

ii. Identify the gas which was contained in the meteorite. — 3 marks

Given:

Element	Helium	Neon	Argon	Krypton	Xenon
Atomic mass/u	4.00	20.2	39.9	83.8	131

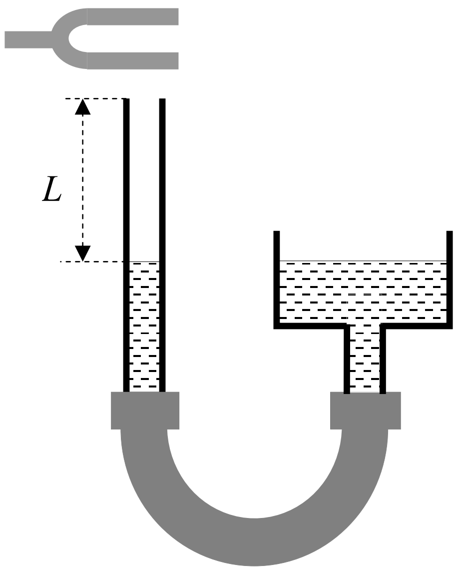
atomic mass unit ……………………...1 u $= 1.66 \times 10^{-27}$ kg;
elementary charge……………………..e $= 1.60 \times 10^{-19}$ C.

Question 3		
	Page 1/2	Mark
a) One end V of an elastic string is fixed to a vibrating system. The other end of the string is passed over a pulley wheel and is attached to a mass m, which exerts a tension F on the string. The part of the string between V and the point P at the top of the pulley has length L. P and V may be considered as nodes of vibration. The string is found to resonate at certain frequencies. 		
i. Show that the mass m is related to a resonance frequency f by the relationship $m = \frac{4L^2\mu}{n^2 g} f^2$ where n is the number of antinodes between V and P, and μ is the linear density (mass per unit length).		5 marks
ii. In an experiment L = 1.20 m and the mass of the string between V and P is 1.92 g. With a frequency of f = 120 Hz four antinodes are observed.		
1. Calculate the mass m required to obtain this resonance.		2 marks
2. Calculate the speed of the wave in the string.		4 marks
3. Calculate the fundamental resonance frequency of the string.		2 marks
4. When the mass m = 1.00 kg, explain whether or not resonance will occur at f = 120 Hz.		3 marks

Question 3

	Page 2/2	Mark

b) A tuning fork of frequency 1.00 kHz is held over a tube containing water. The level of water in the tube can be changed by moving the reservoir on the right vertically (see figure below).
A student observes resonance in the air column when its length L is:
8.5 cm, 25.8 cm, 43.0 cm and 77.5 cm.



	Mark
i. The student missed one of the positions at which resonance occurs. Calculate a value for the length that is missing between the measured lengths.	3 marks
ii. Calculate the speed of sound in air.	3 marks
iii. Draw a diagram to show the displacement nodes and antinodes of the stationary wave produced when $L = 43.0$ cm.	3 marks

<u>Given</u>:

acceleration due to gravity.......................... $g = 9.81 \text{ m s}^{-2}$;
speed of propagation v of a wave along a stretched string

$$v = \sqrt{\frac{F}{\mu}} \,,$$

where F is the tension and μ is the linear density (mass per unit length).

Question 4		
	Page 1/2	Mark

a) Monochromatic light of wavelength λ is incident on a double slit. The centres of the slits are separated by distance d. An interference pattern is observed on a screen at a distance L from the double slit.

i. 1. Derive the relationship $d \sin\theta_n = n\lambda$ using a labelled diagram. — 4 marks

2. Using the above relationship, derive the formula

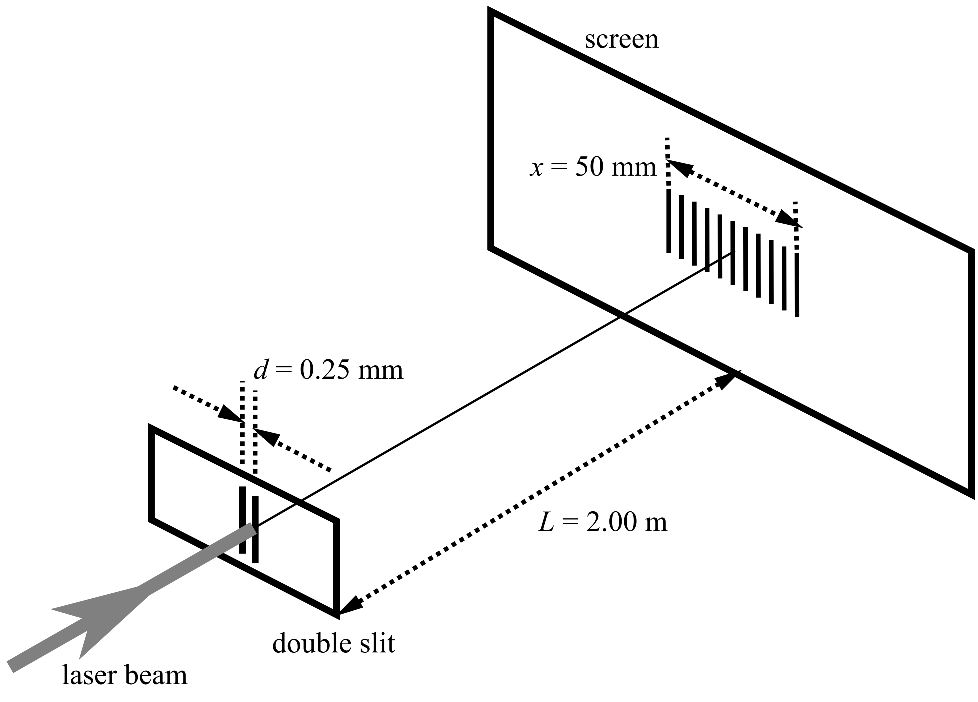
$$x_n = n\lambda \frac{L}{d} ,$$

where x_n is the distance from the central maximum to the maximum of order n.
Explain the approximation used. — 3 marks

3. Show that the distance Δx between two consecutive maxima is given by

$$\Delta x = \lambda \frac{L}{d} .$$

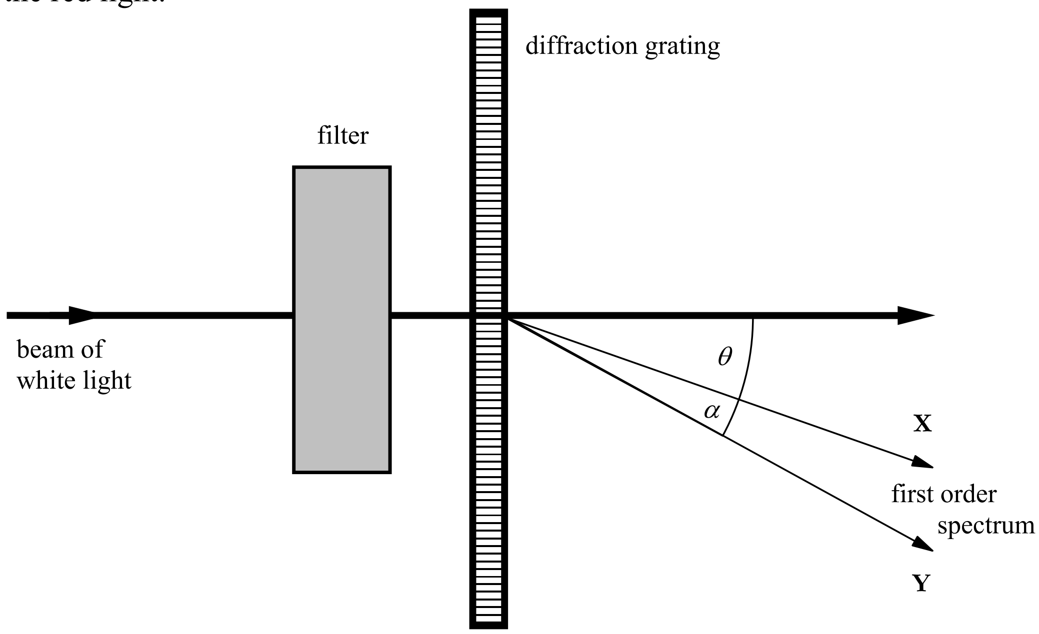
— 2 marks



ii. A laser beam is directed on a double slit of slit separation 0.25 mm. An interference pattern is observed on a screen at a distance of 2.00 m from the double slit. On the diagram 11 maxima are shown. The distance between the outermost maxima shown on the diagram is 50 mm.
Calculate the wavelength of the laser light used. — 3 marks

iii. The double slit is replaced by a double slit with a smaller slit separation.
What effect does this have on the interference pattern? Explain your answer. — 2 marks

Question 4		
	Page 2/2	Mark
b) A student sets up the apparatus shown below using a diffraction grating of 600 lines per millimetre to produce a spectrum of sunlight. The filter absorbs part of the red light.		



i. The wavelength of the light at the end X of the first order spectrum is 410 nm. Calculate the value of the angle θ.		3 marks
ii. The angle α in the above diagram is 9°. Calculate the wavelength at the end Y of the spectrum.		2 marks
iii. How many complete spectra of the filtered light could be observed with this filter and grating?		3 marks
iv. Do the first and second order spectra overlap? Justify your answer.		3 marks

Question 5

	Page 1/1	Mark
a) In 1905 Einstein established an equation explaining the photoelectric effect. This equation can be written in the form $eU_{stop} = hf - W_0$.		
i. State what is meant by the photoelectric effect, and state the condition necessary for this effect to occur.		3 marks
ii. Explain the above equation.		4 marks
b) A photocell contains a potassium coated cathode. Photoemission from this cathode occurs only for light of wavelength shorter than 700 nm.		
i. Calculate the work function for potassium.		2 marks
ii. What is the maximum speed of the photoelectrons emitted when the surface is illuminated with light of wavelength 500 nm?		2 marks
iii. Calculate the wavelength of the incident light when the stopping potential is 0.60 V.		2 marks
c) The following data on wavelength λ and stopping potentials U_{stop} were obtained from an experiment using a different photocell.		

λ / nm	366	405	436	492	546
U_{stop} / V	1.48	1.15	0.93	0.62	0.36

	Mark
i. Plot a graph of U_{stop} as function of the frequency *f*.	4 marks
ii. 1. From the graph determine the threshold frequency.	1 mark
2. Does light of wavelength 670 nm cause the photoelectric effect to occur? Justify your answer.	2 marks
iii. Determine the work function in eV.	2 marks
iv. Determine a value for Planck's constant from the graph.	3 marks

<u>Given</u>:
speed of light in a vacuum .... c $= 3.00 \times 10^{8}$ m s^{-1};
the Planck constant .... h $= 6.63 \times 10^{-34}$ J s ;
elementary charge ....e $= 1.60 \times 10^{-19}$ C;
mass of the electron.............................m_e $= 9.11 \times 10^{-31}$ kg.

Question 6

	Page 1/1	Mark
a) In the upper atmosphere a $^{14}_{6}C$ nucleus is formed as a result of a collision between a neutron and a $^{14}_{7}N$ nucleus. Write down the equation describing the formation of $^{14}_{6}C$.		3 marks
b) $^{14}_{6}C$ is radioactive and disintegrates to $^{14}_{7}N$. **i.** Write down the decay equation. **ii.** Calculate the energy released in this process. Give the answer in MeV and J.		2 marks 4 marks
c) The number N of radioactive nuclei remaining in an initial sample of N_0 radioactive nuclei after time t is given by the equation $N = N_0\, e^{-\lambda t}$ where λ is the decay constant of the radioactive isotope in the sample. **i.** Define the term half-life $T_{½}$ of a radioactive isotope. **ii.** Show that $\lambda T_{½} = \ln 2$. **iii.** The half-life of $^{14}_{6}C$ is $T_{½} = 5.73 \times 10^3$ years. Calculate the decay constant λ for $^{14}_{6}C$.		2 marks 3 marks 1 mark
d) It is known that the activity of 1.00 g of carbon in any living organism is 15.3 disintegrations per minute. This radioactivity is due to the presence of $^{14}_{6}C$ and after death the quantity of $^{14}_{6}C$ decreases. The activity of 1.00 g of carbon in a piece of fossilised wood is 8.1 disintegrations per minute. Calculate the age of the piece of wood.		5 marks
e) Calculate the percentage of carbon-14 remaining in carbon from a 40 000 years old piece of fossilised wood.		5 marks
<u>Given</u>: atomic mass of $^{14}_{6}C$ .... 14.003 242 u ; atomic mass of $^{14}_{7}N$ .... 14.003 074 u ; mass of the electron................................ $m_e = 9.11 \times 10^{-31}$ kg; speed of light in vacuum .... $c = 3.00 \times 10^{8}$ m·s^{-1}; elementary charge .... $e = 1.60 \times 10^{-19}$ C ; atomic mass unit .... 1 u = 1.66×10^{-27} kg = 931 MeV/c^2 .		