UNIVERSITY OF DUBLIN

TRINITY COLLEGE

FACULTY OF ENGINEERING, MATHEMATICS & SCIENCE

SCHOOL OF PHYSICS

Junior Freshman — Trinity Term 2015

Annual Examination

Physics, Paper 1

(Science (Physics), Nanoscience Physics and Chemistry of Advanced Materials, Chemistry with Molecular Modelling and Theoretical Physics)

Friday 1st May 2015 — RDS — 14:00 – 17.00

Professors M. Ferreira, L. Bradley, J. Lunney and T. Ray.

ALL QUESTIONS CARRY EQUAL MARKS.

USE SEPARATE ANSWER BOOKS FOR EACH SECTION

Log tables (Booklet of Formulae and Tables) are available from the invigilator for all students who require them. Graph paper is also available.

Non-programmable calculators are permitted for this examination – please indicate the make and model of your calculator on each answer book used.

Science (Physics), Chemistry with Molecular Modelling, Nanoscience Physics and Chemistry of Advanced Materials Students

Answer *SIX* questions, AT LEAST TWO from Section A, AT LEAST TWO from Section B, AT LEAST ONE from Section C AND ONE OTHER from these Sections in 3 hours.

Theoretical Physics Students

Answer *SIX* questions, AT LEAST TWO from Section B, AT LEAST ONE from Section C, AT LEAST TWO from Section D AND ONE OTHER from these Sections in 3 hours.

Physics Paper 1

SECTION A

1. A small hand granade is thrown with an initial speed V_0 forming an angle ɵ with the horizontal ground.

(a) Specify the maximum height H reached by the granade and the distance between the launching and landing points (assuming that it does not explode)

[4 Marks]

(b) Assume that at its highest point the granade explodes and is split into two identical parts. Knowing that one of the parts travels down along the same path followed by the granade from launching to explosion, determine the distance between the landing points of both parts.

[3 Marks]

(c) Calculate how much energy was released in the explosion.

[3 Marks]

2. A block is released from a height H and slides down a frictionless curved surface (see figure). When reaching the bottom of the curved path, it moves on to a horizontal rough surface whose friction coefficient $\mu(x) = a\,x$. The quantity x represents the position along the rough surface and measures the distance to the bottom of the curved path whereas the coefficient a is a constant that makes the friction coefficient dimensionless.

(a) Obtain the value Xmax where the block will stop

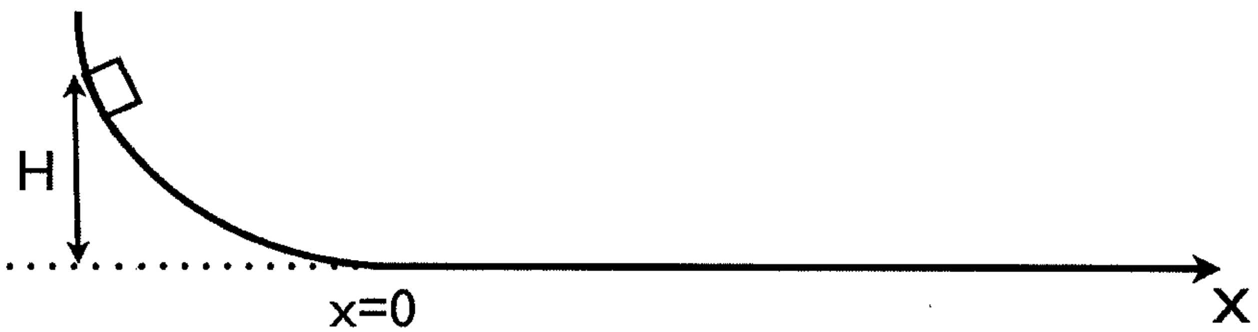
[4 Marks]

(b) Find the value of Xmax when an initial velocity V_0 is given to the block at the start

[3 Marks]

(c) How would answers (a) and (b) change if this experiment is carried out on a planet with a gravitational acceleration that is a third of the gravity on Earth?

[3 Marks]



3. Two blocks of mass M1 and M2 moving along a 1-dimensional straight line with velocities V1 and V2, respectively, collide elastically. After the collision they move with respective velocities U1 and U2.

(a) What quantities are conserved in a collision of this type?

[3 Marks]

(b) What happens when M1>>M2 (M1 much larger than M2) and V2=0?

[3 Marks]

(c) What is the ratio M1/M2 if the velocities are to be interchanged, ie, U1=V2 and U2=V1?

[4 Marks]

4. A non-homogeneous ladder has its centre of mass located at 1/3 of its length from the bottom. The ladder leans against a vertical wall which has friction coefficient μv and supported by the horizontal ground which has a friction coefficient μh. The ladder forms an angle ϴ with the horizontal ground.

(a) Calculate the maximum angle ϴ that the ladder can have before it slips when μh ≠0 and μv=0?

[4 Marks]

(b) Calculate the maximum angle ϴ that the ladder can have before it slips when μh =0 and μv ≠0?

[3 Marks]

(c) Calculate the maximum angle ϴ that the ladder can have before it slips when μh ≠ 0 and μv≠0 ?

[3 Marks]

SECTION B

5. (a) In Young's double slit experiment a monochromatic light source is used to form an interference pattern on a distance screen. Derive an expression for the distance from the central bright fringe (m=0) to the m^{th} bright fringe.

[3 Marks]

(b) How does the fringe spacing change if the separation between the slits is halved and the slit width is also halved? Explain your reasoning clearly.

[2 Marks]

(c) Light from a red laser with λ=700 nm illuminates two slits. At the same time light of a different wavelength also passes through the two slits. The interference pattern that can be seen on a far viewing screen is a mixture of the two colours. However, the centre of the third bright fringe (m=3) of the red light is pure red, with none of the second colour present. What are the possible wavelengths for the second colour of light?

[5 Marks]

6. (a) Derive Malus's Law. For linearly polarized incident light sketch the percentage of light transmitted through a polarizer as a function of the angle between the polarizing axis and the direction of polarization of the incident light.

[4 Marks]

(b) Unpolarized light is incident on a stack of two polarizers, which have an angle of 30^0 between their polarizing axes. Determine the percentage of light transmitted through the stack.

[3 Marks]

(c) By placing a third polarizing sheet between the two polarizers in part (b) the intensity of transmitted light can be increased. Determine an angle between the polarizing axes of the new polarizer and the polarizing axes of the first polarizer in the stack that will maximize the intensity of transmitted light?

[3 Marks]

7. (a)

i. A travelling wave on a string is described by the equation $ACos(kx - \omega t)$. If the end of the string is fixed, write the corresponding equation for the reflected wave.

ii. Derive the expression for the standing wave that will result from the superposition of an incident wave and the wave reflected at the fixed end of the string. Determine an expression for the positions of the nodes as a function of wavelength.

[5 Marks]

(b) A string fixed at both ends is oscillating in its fourth harmonic. The ampliftude of the standing wave is 4.00 mm. The string with mass m = 2.500 g, and length L= 0.800 m is under a tension of 325.0 N.

i. Sketch the standing wave pattern.

ii. Determine the wavelength and frequency of the transverse waves producing the standing wave pattern.

iii. Determine the maximum magnitude of the transverse velocity of the element oscillating at x=0.180 m.

iv. At what point during this element's oscillation is the transverse velocity maximum?

[5 Marks]

8.

(a) In a system under simple harmonic motion the period of oscillation is given by $T = 2\pi\sqrt{\frac{m}{k}}$. Derive this equation.

[4 Marks]

(b) A 23.5 N force stretches a vertical spring 0.5 m. Determine what mass must be suspended from the spring so that the system will oscillate with a frequency of 0.5 Hz.

[2 Marks]

(c) For the system described in part (b), plot on the same graph the potential energy, the kinetic energy and the total energy of the harmonic oscillator, for this spring with x = 2.0 cm at t = 0. Plot over one period of oscillation.

[4 Marks]

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SECTION C

9.

(a) What is meant by the term stellar magnitude and give a mathematical expression for the magnitude difference between two stars

[4 Marks]

(b) Show that if the magnitude difference between two stars is exactly 5, that one is brighter than the other by a factor of 100

[1 Mark]

(c) The magnitude system requires a zero point of reference, what is it?

[1 Mark]

(d) Discuss the differences between globular clusters and open clusters

[2 Marks]

(e) Explain, in general terms how we can measure the ages of such clusters. You should illustrate your answer by reference to the Hertsprung Russell (HR) Diagram

[2 Marks]

10.

(a) Discuss how solar systems like ours form. In your answer explain the role of proto-planetary disks and jets.

[6 Marks]

(b) What is the source of a young star's energy before it joins the Main Sequence?

[2 Marks]

(c) The nearest stellar nurseries are approximately 150 parsecs away. Assuming a disk around a young star is 75 astronomical units (au) in diameter, what angle (in arcseconds) would such a disk subtend as seen from Earth with the Hubble Space Telescope?

[2 Marks]

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SECTION D

11.

(a) Briefly describe the Michelson-Morley experiment and how it relates to the special theory of relativity.

[4 Marks]

(b) Two spaceships A and B, each measuring 50 m in its own rest frame, pass each other going in opposite directions. As measured on A it is found that the front end of B takes 5×10^{-7} s to traverse the full length of A.

i. What is the relative velocity of A and B?

ii. A clock on the front end of B reads exactly 11 am as it passes the front end of A. What will it read when it passes the rear end of A?

[6 Marks]

$$x = \gamma(x' + vt'), y = y', z = z', t = \gamma\left(t' + {vx'}/{c^2}\right)$$

12.

(a) A flash of light is emitted at the origin and absorbed at x = 100 m in a frame S. As measured in a frame S′ moving with velocity v = 0.5 c along the x-axis, what is (i) the separation between the points of emission and absorption, and (ii) the time interval between the emission and absorption?

[5 Marks]

(b) A photon of wavelength 0.2 m has a head-on collision with an electron moving with velocity v, as measured in the laboratory. Calculate the value v must have if the collision results in a photon recoiling directly backwards with the same wavelength as the incident photon.

[5 Marks]

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13.

(a) A source of electromagnetic radiation emits at frequency, ν, in its own rest frame. Derive an expression for the frequency, ν', measured by an observer if the source moves away from the observer at speed v.

[7 Marks]

(a) An interstellar gas cloud which is receding from Earth at 0.2*c* contains atomic hydrogen which emits electromagnetic radiation at 1420 MHz. What is the frequency of this radiation when it is detected on Earth?

[3 Marks]

14.

(a) An electron (rest mass = 0.51 MeV) is accelerated from rest through a voltage of 10^6 V, and then travels through a field-free region. How long will it take, as measured in the laboratory frame, for the electron to travel a distance of 10 m in the field-free region?

[5 Marks]

(b) Find the minimum energy γ-ray photon for which electron-positron pair production can occur, and show that the process cannot occur in free space.

[5 Marks]

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Electron rest mass	m_e	9.11×10^{-31} kg
Proton rest mass	M_p	1.67×10^{-27} kg
Electronic charge	e	1.60×10^{-19} C
Speed of light in free space	c	3.00×10^{8} m s^{-1}
Planck's constant	h	6.63×10^{-34} J s
	$h/2\pi = \hbar$	1.05×10^{-34} J s
Boltzmann's constant	k	1.38×10^{-23} J K^{-1}
Molar gas constant	R	8.31×10^{3} JK^{-1}kmol^{-1}
Avogadro's number	N_A	6.02×10^{26} kmol^{-1}
		$= 6.02 \times 10^{23}$ mol^{-1}
Standard molar volume		22.4×10^{-3} m^3
Bohr magneton	μ_B	9.27×10^{-24} A m^2 OR J T^{-1}
Nuclear magneton	μ_N	5.05×10^{-27} A m^2 OR J T^{-1}
Bohr radius	a_o	5.29×10^{-11} m
Fine structure constant		
	$e^2/(4\pi\varepsilon_o\hbar c) = \alpha$	$(137)^{-1}$
Rydberg's constant	R_∞	1.10×10^{7} m^{-1}
Stefan's constant	σ	5.67×10^{-8} W m^{-2} K^{-4}
Gravitational constant	G	6.67×10^{-11} N m^2 kg^2
Proton magnetic moment	μ_p	$2.79\ \mu_N$
Neutron magnetic moment	μ_n	$-1.91\ \mu_N$
Permeability of free space	μ_o	$4\pi \times 10^{7}$ H m^{-1}
Permittivity of free space	ε_o	8.85×10^{-12} F m^{-1}
1 electron volteV	1.60×10^{-19} J	

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1 unified atomic mass unit (^{12}C scale)		1.66×10^{-27} kg = 931 MeV/c^2
Wavelength of 1 eV photon		1.24×10^{-6} m
1 atmosphere	1.01×10^{5} N m^{-2}	
Standard acceleration due to gravity		10 m s^{-2}
Free space impedance	Z_0	377 Ω
Astronomical unit	au	1.50×10^{11} m
Parsec	pc	3.09×10^{16} m
Solar radius	$R_\odot$	6.96×10^{8} m
Solar mass	$M_\odot$	1.99×10^{30} kg
Solar luminosity	$L_\odot$	3.85×10^{26} W
Earth mass	$M_\oplus$	5.97×10^{24} kg
Earth radius (equatorial)	$R_\oplus$	6378 km