Coláiste na Tríonóide, Baile Átha Cliath
Trinity College Dublin
Ollscoil Átha Cliath | The University of Dublin

FACULTY OF ENGINEERING, MATHEMATICS & SCIENCE

SCHOOL OF PHYSICS

Junior Freshman — Trinity Term 2016

Annual Examination

Physics, Paper 1

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

Wednesday 11 May 2016 — RDS — 09:30 – 12.30

Professors M. Ferreira, L. Bradley, P. Gallagher and J. Lunney.

ALL QUESTIONS CARRY EQUAL MARKS.

USE SEPARATE ANSWER BOOKS FOR EACH SECTION

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 hand grenade of mass M is thrown vertically up in the air with an initial velocity V_0. It explodes into two equal parts at a time $T=V_0/g$ after it was launched, where g is the gravitational acceleration. Knowing that the two parts do not move horizontally but only along the vertical direction throughout their motion, you may ignore air resistance to answer the following questions:

(a) What velocity did the grenade have at the time of the explosion? How high from the ground was the grenade when it exploded ?

[2 marks]

(b) Draw a graph indicating how the velocity of the grenade varies with time. Use one line to represent the motion of the grenade prior to the explosion and two lines to represent the two separate halves after the explosion. Assume that the explosion is instantaneous and that it releases $E = M\,(V_0)^2$ in the form of kinetic energy to the system.

[4 marks]

(c) What is the time interval between the grenade halves hitting the ground?

[4 marks]

2. A block of mass M is pushed on a horizontal table and released with an initial velocity V_0. The friction coefficient between block and table is constant and given by μ.

(a) Draw a free-body diagram indicating all forces acting on the block after it has been released. How far does the block travel and how long does it take between the time it is released until it stops?

[3 marks]

(b) What is the work done by the friction force during this time? What is the power with which the energy is being dissipated?

[3 marks]

(c) Imagine that the table has now been tilted by an angle ß and that the block slides down with a constant velocity V. Determine the value of ß needed to make the block slide down with a constant speed. How much power is being dissipated by friction in this case?

[4 marks]

3. A child is right on the middle point of a ladder of length L that leans against a frictionless vertical wall. The ladder forms an angle ß with the horizontal floor and its mass is negligible compared to the child's.

(a) In the case of a constant friction coefficient μ between ladder and floor, what is the minimum leaning angle ß that the ladder can have without collapsing to ground?

[3 marks]

(b) Imagine that the ladder (with the child on its midpoint) is at rest at $ß = \pi/4$. By releasing oil on to the floor, the friction coefficient now varies with time and is given by $\mu(t) = 1/(t+1)$, where t is the time expressed in seconds. Find the time instant t' when the ladder will fall to ground?

[3 marks]

(c) Imagine that the child is initially at the midpoint of the ladder and that $ß = \pi/4$. Assuming the same time-dependent friction coefficient μ(t) of part (b), what is the height the child should keep to prevent the ladder from collapsing when time $t > t'$?

[4 marks]

SECTION B

4.

(a) A double slit pattern is observed on a screen 1.0 m behind two slits spaced 0.30 mm apart. Ten bright fringes span a distance of 1.7 cm. Determine the wavelength of the light. Derive any equations used.

[3 marks]

(b) Sketch the following (i) an ideal two slit interference pattern with no diffraction from the slits considered and (ii) a two slit interference pattern with diffraction.

[2 marks]

(c) The figure below shows single slit diffraction patterns. The distance between the slit and the viewing screen is the same in both cases. The slit width is labelled *a*. Which of the follow statements is true (there may be more than one)?

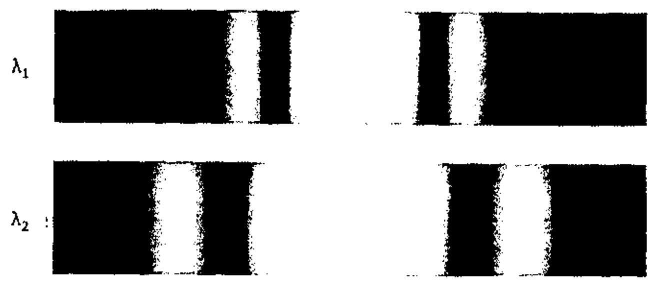
i) The slits are the same for both and $\lambda_1 > \lambda_2$

ii) The slits are the same for both and $\lambda_2 > \lambda_1$

iii) The wavelengths are the same for both and $a_1 > a_2$

iv) The wavelengths are the same for both and $a_2 > a_1$

Clearly justify your answer . [2 marks]



Question **4(d)** continued on next page

(d) Determine the width of the central bright fringe on a screen 1.0 m away from the slit if the light has a wavelength $\lambda = 633$ nm and the slit width is 0.25 mm.

[3 marks]

5.

(a) A 2.00 m long string, fixed at both ends, vibrates as a 100 Hz standing wave with nodes at 1.00 m and 1.50 m from one end of the string and at no points in between these two.

i) Sketch the standing wave pattern produced and determine which harmonic of the string has been described.

ii) Determine the string's fundamental frequency.

iii) The standing wave occurs due to the superposition of two traveling waves. Determine the speed at which theses waves travel on the string.

iv) Sketch the new standing wave pattern that will be produced if the tension of the string is quadrupled while the frequency and length of the string remain unchanged.

[5 marks]

(b) State Fermat's principle of least time and demonstrate that Snell's Law can be derived from this principle.

[5 marks]

6.

(a) A sound wave travelling through air can be described by the displacement of the air

$$s(x,t) = s_{\max}\cos(kx - \omega t)$$

or as a variation in pressure

$$\Delta P(x,t) = Bks_{\max}\sin(kx - \omega t).$$

Demonstrate that the intensity of the sound wave is given by $I = \frac{1}{2}k\omega(s_{\max})^2 B$, where B is the bulk modulus, and all other symbols have their usual meaning.

[4 marks]

(b) The intensity of a sound wave at a distance of 8.00 m from a speaker vibrating at 2.00 kHz is 70.0 dB.

i) Determine the intensity in W/m^2.

ii) The amplitude of the displacement of the sound wave.

iii) Calculate the sound power incident on the eardrum. The area of a typical eardrum is approximately 5.00 x 10^{-5} m^2.

[The speed of sound is air is 344 m/s and the bulk modulus is 1.42 x 10^5 Pa.]

[6 marks]

SECTION C

7.

(a) Describe early models of the Solar System, making particular reference to geocentric and heliocentric views.

[2 marks]

(b) State and describe Kepler's Laws of Planetary Motion, using diagrams to illustrate your answer.

[3 marks]

(c) Using Newton's Law of Gravity, show that the period (*P*) of a planetary orbit can be written

$$P^2 = \frac{4\pi^2}{GM_s} r^3$$

where r is the radius, M_s is the mass of the Sun, and G is the gravitational constant. Clearly explain your assumptions and steps.

[3 marks]

(d) The asteroid Ceres orbits the Sun every 4.6 years. Calculate its semi-major axis in Astronomical Units.

[2 marks]

8.

(a) Describe the main properties of the planets of our Solar System. Why is Pluto not currently defined as a planet?

[2 marks]

(b) Calculate the densities of Earth and Jupiter. What do the densities imply about the composition of these planets? Note: R_E = 6,371 km and m_E = 5.972 x 10^{24} kg and R_J = 69,911 km and m_J = 1.898 x 10^{27} kg.

[2 marks]

(c) Exoplanets are notoriously challenging to detect due to their low brightness relative to their host star. Describe the main techniques currently used to detect exoplanets.

[3 marks]

(d) The star Rho Cancri is 57 light-years from Earth and has a mass 0.85 times that of our Sun (1.989 x 10^{30} kg). A planet has been detected in a circular orbit around Rho Cancri with an orbital radius equal to 0.11 AU (1 AU = 149 x 10^6 km). What are (i) the orbital speed and (ii) the orbital period of the planet of Rho Cancri?

[3 marks]

SECTION D

9. An astronomer O observes two supernova events E_1 and E_2 occurring at the same time but at different positions on an *x*-axis

(a) Explain why another inertial observer O′ moving at $v = 4c/5$ along the x-axis relative to O will not observe the two events to be simultaneous.

[3 marks]

(b) If O′ measures a time interval of 3 s between E_1 and E_2, what is the separation of the two events along the *x*-axis as measured by O?

[4marks]

(c) What is the spatial separation of the two events as measured by O′?

[3 marks]

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

10.

(a) Briefly describe how the definitions of energy and momentum are modified in going from non-relativistic to relativistic mechanics.

[2 marks]

(b) An electron is accelerated from rest to v = 0.9*c*.

i. How much energy must be applied to the electron to reach this speed?

[2 marks]

ii. Find the total energy, kinetic energy and momentum of the electron at 0.9 *c*.

[2 marks]

iii. Find the velocity and kinetic energy of the electron in a frame which is moving at 0.5 *c* in the opposite direction to the electron.

[4 marks

11.

(a) Briefly describe the Compton effect and show that

$$1/_{Q} - 1/_{Q_0} = 1/_{m_0 c^2}\,(1 - \cos\theta),$$

where Q_0 is the energy of the input photon, Q is the energy of the scattered photon, m_0 is the rest mass of the electron and θ is the angle through which the photon is scattered.

[7 marks]

(b) A stream of very high energy photons (>>10 MeV) is fired at a block of material. Show that energy, Q, of the photons scattered directly backwards is nearly independent of the energy of the incident photons. What is the value of Q?

[3 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 μ_N
Neutron magnetic moment	μ_n	-1.91 μ_N
Permeability of free space	μ_o	$4\pi \times 10^{7}$ H m^{-1}

Physics Paper 1

Permittivity of free space	ε_o	8.85×10^{-12} F m^{-1}
1 electron volteV	1.60×10^{-19} J	
1 unified atomic mass unit (^{12}C scale) MeV/c^2		1.66×10^{-27} kg = 931
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