XPY1P101

UNIVERSITY OF DUBLIN

TRINITY COLLEGE

FACULTY OF ENGINEERING, MATHEMATICS & SCIENCE

SCHOOL OF PHYSICS

Junior Freshman — Trinity Term 2013

Annual Examination

Physics, Paper 1

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

Friday 10th May 2013 — RDS — 09:30 – 12.30

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

ALL QUESTIONS CARRY EQUAL MARKS.

USE SEPARATE ANSWER BOOKS FOR EACH SECTION

Both old log tables (Mathematics Tables) and new 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.

SECTION A

1. A projectile is launched with initial speed V_0 at an angle θ above the horizontal ground. Disregard the effect of air resistance to answer the following questions:

(a) Write an equation for the trajectory of the projectile in terms of V_0, θ and the gravitational acceleration g

[4 marks]

(b) Determine the launching angle θ for the case in which the horizontal range of the trajectory is $4\sqrt{3}$ times its maximum height

[4 marks]

(c) Assuming the value of θ derived in item (b), obtain the value of V_0, knowing that τ was the time interval between launching and landing.

[2 marks]

2. A box is sliding along a straight line with a speed V on a horizontal surface when, at point P, it enters a rough section. On the rough section, the coefficient of friction μ is not constant, but starts from zero at P and increases linearly with distance past P, reaching a value of μ_{max} at a distance L away from P.

(a) Use the work-energy theorem to find how far this box slides before stopping;

[4 marks]

(b) What is the friction coefficient at the stopping point ?

[3 marks]

(c) How far would the box have slid if the friction coefficient did not increase, but instead had the constant value of $\mu_{max}/5$?

[3 marks]

3. Knowing that the coefficient of restitution α for a head-on collision is defined as the ratio between the relative speed after the collision to the relative speed before the collision, answer the following questions.

(a) What are the values of α for a completely inelastic and for a perfectly elastic collision?

[3 marks]

(b) A properly inflated basketball should have a coefficient of restitution 0.85. When dropped from a height of 1.2 m on a solid floor, to what height should the basketball bounce?

[3 marks]

(c) A ball with coefficient of restitution α is released from an initial height H and left to bounce repeatedly on a solid floor. Derive a general expression for the height reached by the ball after it bounces n times.

[4 marks]

4. A small object lies at rest on top of a hemispherical rock of radius R (see figure below). After being hit by a horizontal force, the object acquires an initial speed v_0.

(a) What must be its minimum initial speed v_{min} if the ball is never to hit the rock ?

[4 marks]

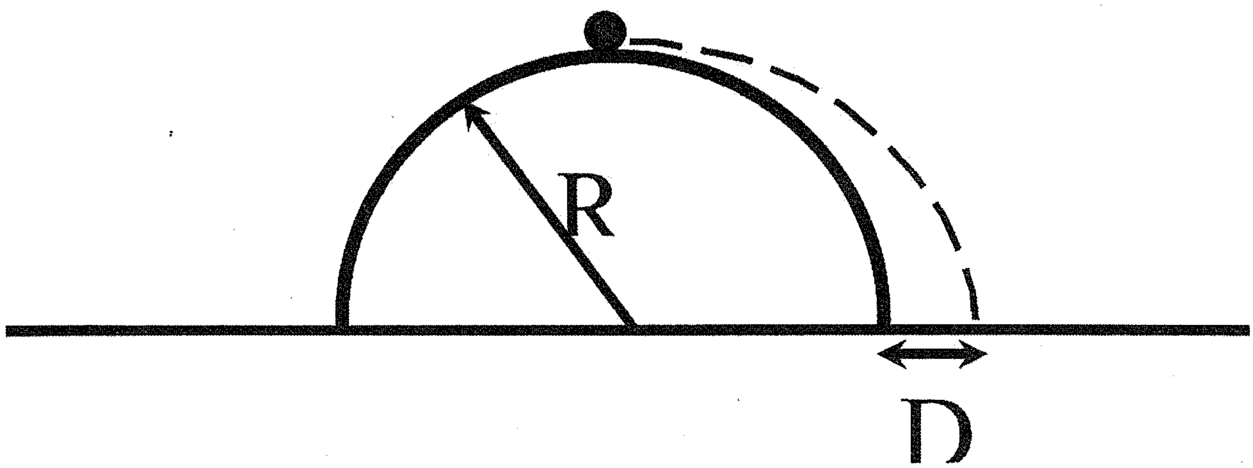
(b) With this initial speed (v_{min}), calculate the distance D between the rock and the landing spot.

[3 marks]

(c) With the same initial speed (v_{min}), calculate the velocity with which the object hits the ground.

[3 marks]

Note: Figure on next page


R
D

SECTION B

5. (a) A wave described by $y(x,t) = (6.00cm)\cos[(30.0m^{-1})x - (4.00s^{-1})t]$ is propagating along a string. Determine the wavelength, frequency, speed and direction of propagation of the wave.

[3 marks]

(b) The wave is subsequently reflected from a fixed end, x = 0. Derive the expression for the standing wave that is formed due to the superposition of the incident and reflected waves. Find the amplitude of the simple harmonic motion at the position x = 8.00 cm.

[3 marks]

(c) Determine the positions of the first three nodes with x>0, where one end of the string is at x = 0. Demonstrate whether the nodes get closer together or further apart as the tension of the string is increased.

[4 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) Determine the amplitude of the displacement for a sound with an intensity of 120 dB, which corresponds to the threshold of pain for the human ear. The sound has a frequency of 1 kHz. The bulk modulus of air is 1.42 x 10^5 Pa and the speed of sound in air is 340 m/s.

[4 marks]

(c) By what factor does the intensity change if the listener doubles their distance from the source?

[2 marks]

7. (a) A whistle with a frequency of 3.00 kHz is emitted from a train travelling at 72.0 km/hour. If this is heard by a listener on a train approaching from the opposite direction at a speed of 93.6 km/hr, determine the frequency that the listener would hear. The speed of sound in air is 340 m/s Derive any expression used.

[6 marks]

(b) Derive Malus' Law for linearly polarised light transmitted through a linear polariser. Plot the dependence of the transmitted intensity as a function of the angle between the plane of polarization and the polarising axis of the polariser.

[4 marks]

8. (a) In a double slit interference experiment the slit separation is 2.20 μm, the light wavelength is 600 nm and the distance to the viewing screening from the slits is 3.00 m. Determine the angle between the centre of the pattern and the second bright fringe

[3 marks]

(b) For a light source of a different wavelength, λ_2, the first bright fringe overlaps with the second bright fringe for λ_1 = 600 nm. Determine λ_2.

[2 marks]

(c) Sketch the intensity as a function of θ for (i) an ideal two slit interference pattern with no diffraction from the slits considered and (ii) a two slit interference pattern with diffraction. In the case of (ii) explain how the fringe pattern will change if (a) the separation between the slits is reduced and (b) the slit width is reduced.

[5 marks]

SECTION C

9. (a) We now know of the existence of hundreds of planets outside our own solar system. Describe how astronomers have been able to find them. In your answer explain why it is so difficult to image even a large planet like Jupiter around a nearby star

[7 marks]

(b) The absorption lines of a star with the same mass as the Sun are found to oscillate sinusoidally with a period of 1 year and an amplitude of 15 ms^{-1}. Assuming these variations are caused by a single planet, what is the planet's mass? You can take it that the planet's orbit is circular and in a plane with a small angle of inclination to our line of sight.

Hint: Use the fact that the planet must be moving at the same speed as the Earth.

[3 marks]

10. (a) The discovery that galaxies like Andromeda are "island Universes" relied on measuring their distances using cepheids. Explain how we can determine distances in Astronomy using cepheids

[5 marks]

(b) What important cosmological discovery did this lead to?

[3 marks]

(c) A star is found to make a small circle in the sky during the year with a radius of 0.3 arcseconds. How far is it away?

[2 marks]

SECTION D

11. (a) Explain the meaning of the terms "proper time" and "time dilation". Briefly describe a physical phenomenon where time dilation is observed.

[3 marks]

(b) A spaceship flies close by the Earth at $v = 0.1c$ and continues on a straight line until it passes close to Pluto 2 hours later, as observed by space scientists on Earth.

(i) How long does the trip take according to the clocks on the spaceship?

[4 marks]

(ii) What distance has the spaceship travelled according the space scientists on Earth?

[1 marks]

(iii) How do the astronauts account for the fact that, according to their clocks, the time for the Earth-Pluto trip is not equal to 2 hours?

[2 marks]

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

12. (a) Show that when a particle of rest mass, m_0, moving in the x-direction is subject to a force, F, which acts only in the x-direction, that the acceleration of the particle is given by: $a = {}^{F}/_{\gamma^3 m_0}$.

[4 marks]

(b) Thence show that as $t \to \infty$, the speed of the particle approaches c.
[Note: a useful integral is: $\int (1-x^2)^{-3/2}\,dx = {}^{x}/_{\sqrt{1-x^2}}$]

[3 marks]

(c) Also find an expression for kinetic energy of the particle in terms of m_0, c and γ.

[3 marks]

13. (a) Write down the non-relativistic and relativistic equations for the kinetic energy of a particle and show that the relativistic equation reduces to the non-relativistic equation when the speed is much less that c.

[3 marks]

(b) A particle of rest mass 6×10^{-30} kg which is at rest emits a gamma-ray photon of energy 1 MeV. Calculate the kinetic energy (in MeV), velocity and rest mass (in MeV) of the recoiling particle.

[7 marks]

14. (a) Explain why the fusion of nuclei light elements leads to the release of energy.

[4 marks]

(b) Calculate the kinetic energy released by the fusion of one deuterium $({}^{2}_{1}H)$ and one tritium $({}^{3}_{1}H)$ nuclei and calculate the number of fusions per second required for a 400 MW power plant.

[4 marks]

(c) Assuming that the helium nuclei and neutrons travel at non-relativistic speeds calculate the fraction of the released kinetic energy which is carried by the neutrons. Ignore the initial kinetic energy and momentum of the deuterium and tritium nuclei.

[2 marks]

Atomic masses: M$({}^{2}_{1}H)$ = 2.01410 amu, M$({}^{3}_{1}H)$ = 3.01605 amu, M$({}^{4}_{1}He)$ = 4.00260 amu, M$({}^{1}_{0}n)$ =1.00866 amu. 1 amu = 1.6605×10^{-27} kg.

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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}
Permittivity of free space	ε_o	8.85×10^{-12} F m^{-1}
1 electron volt	eV	1.60×10^{-19} J
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_o		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