UNIVERSITY OF DUBLIN

TRINITY COLLEGE

FACULTY OF ENGINEERING, MATHEMATICS & SCIENCE

SCHOOL OF PHYSICS

Junior Freshman Trinity Term 2014

Annual Examination

Physics, Paper 1

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

Date 9th May 2014 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

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) Consider a projectile launched with a speed v from the ground in a direction that forms an angle θ with the horizontal ground. You may neglect the effect of air resistance to answer the following questions:

a) Determine the maximum vertical height (H) reached by the projectile as well as the horizontal distance (D) separating the landing and launching points. All these quantities must be expressed in terms of the launching angle θ and the initial speed v.

[3 marks]

b) Derive an equation that describes the trajectory of the projectile.

[3 marks]

c) Assuming that θ_m is the launching angle that makes H = m D, find an expression for θ_m.

[4 marks]

2) A circular turntable of radius R has its surface completely covered with little coins.

a) What is the minimum friction coefficient needed to prevent any coin from sliding off the turntable?

[3 marks]

b) Assuming that the friction coefficient between the coins and the turntable surface is μ=1/2 and uniform across the entire surface, determine the radius of the turntable that remains covered with coins when it spins with a constant angular speed ω.

[3 ½ marks]

c) What is the radius of the turntable that remains covered by coins when the angular speed ω is increased by 50%?

[3 ½ marks]

3) Two blocks of masses M_a and M_b connected by a very thin cord slide down the incline shown in the figure below. μ_a and μ_b are the respective dynamic friction coefficients between the blocks a and b and the surface of the incline. Describe the motion of the blocks:

a) if $\mu_a < \mu_b$

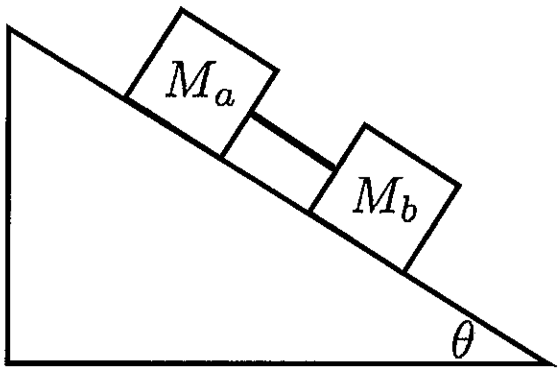
[3 marks]

b) if $\mu_a > \mu_b$

[3 marks]

c) Derive a formula for the acceleration of each block in terms of the relevant quantities.

[4 marks]



4) A block mass M=0.200 kg is pushed against a horizontal spring of negligible mass and elastic constant k=250 N/m until the spring is compressed by a distance x = 6.00 cm (see figure over). When it is released, the block travels along a horizontal surface to point B, the bottom of a vertical circular track of radius R=1.0 m, and continues to move up the track. Note that the figure is not to scale. Assume all surfaces are frictionless and answer the following questions:

a) Calculate the maximum height reached by the block;

[4 marks]

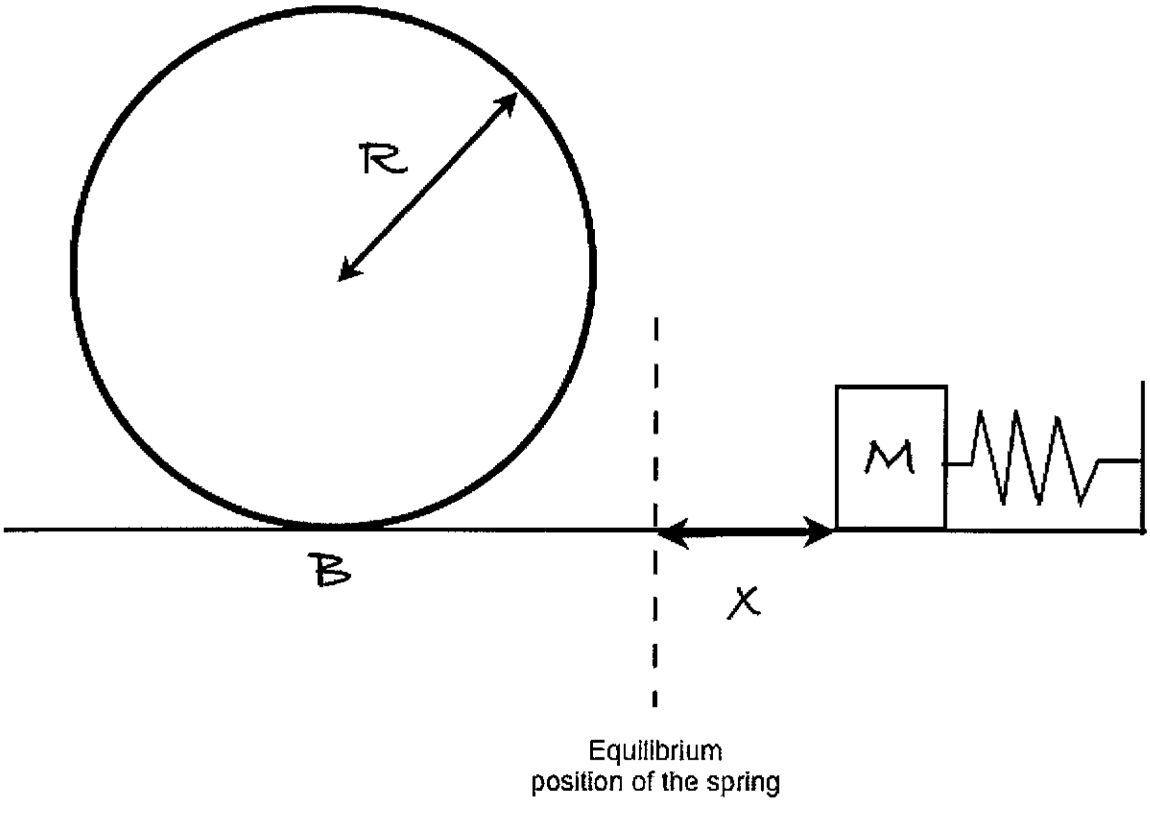
b) Find the minimum compression x_{min} above which the block is certain to complete the loop without losing contact with the track;

NOTE: Question 4 continued on next page

[4 marks]

c) What other combination of mass M, radius R and elastic constant k would give exactly the same value for the minimum compression x_{min} as the one found in part b)?

[2 marks]



SECTION B

5)

a) Derive this expression for the kinetic energy in one wavelength for a sinusoidal wave on a string

$$E_{K\lambda} = \frac{1}{4}\mu\omega^2 A^2 \lambda$$

where A is the amplitude, μ is the mass per unit length, ω is the angular frequency and λ is the wavelength of the wave.

[5 marks]

b) Use the expression from part (a) to show that the rate of energy transferred by a sinusoidal wave on a string is given by $P = \frac{1}{2}\mu\omega^2 A^2 v$. It can be assumed that the kinetic energy in one wavelength equals the potential energy in one wavelength.

[1 mark]

c) A taut rope has a mass of 0.180 kg and a length of 3.60 m.

i) What power is transmitted along the rope if it is carrying sinusoidal waves having amplitude of 0.100 m, a wavelength of 0.500 m and travelling at a speed of 30.0 m/s?

ii) How is the power transmitted affected if the mass per unit length of the rope is doubled assuming the tension is constant? The source of the wave continues to oscillate with the same frequency and amplitude.

[4 marks]

6)

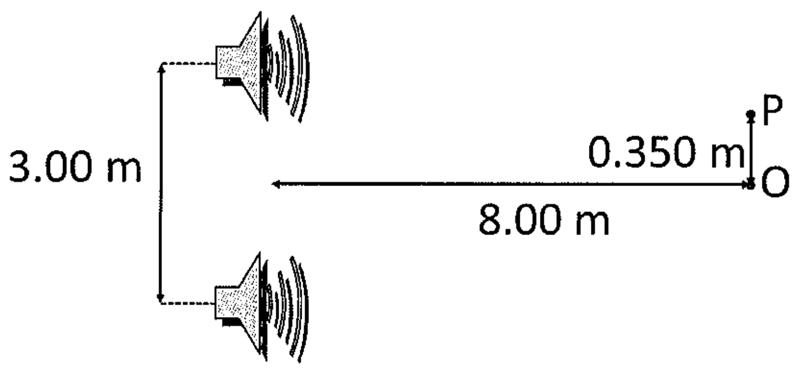
a) Define the principle of superposition. Sketch two graphs to show

i) the superposition of the identical waves which are exactly in phase and

ii) the superposition of two identical waves which are exactly out of phase. The axes on each graph should be labelled as displacement and time.

[2 marks]

b) Two speakers placed 3.00 m apart are driven in phase by the same oscillator. A listener is originally at a point O, located 8.00 m along the centre line. The listener then moves to point P, which is a perpendicular distance of 0.350 m from point O. The listener hears the first minimum in sound intensity at point P. Determine the frequency of the oscillator. [Speed of sound in air is 343 m/s]

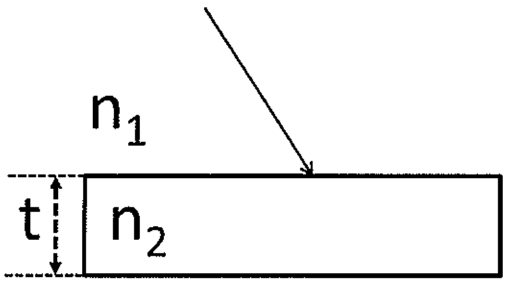


c) A driver travels on a motorway at a speed of 25.0 m/s. A police car, travelling in the opposite direction at a speed of 40.0 m/s, approaches with its siren producing a sound at a frequency of 2500 Hz. What frequency does the driver detect after the police car passes him? [Speed of sound in air is 343 m/s]

[3 marks]

7)

a) A slab of material (medium B) with refractive index n_2 is surrounded by another medium (medium A) with refractive index n_1, see the diagram below. A beam of light passes from medium A into medium B and then emerges on the other side of the slab. Show that the emerging beam is parallel to the incident beam.

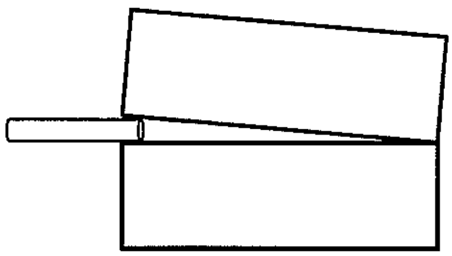


[2 marks]

b) If the thickness t of the slab is doubled does the lateral displacement also double? Provide proof of your answer.

[4 marks]

c) An air wedge is formed between two glass plates separated at one end by a very fine wire. When the wedge is illuminated from above by 600 nm light, and viewed from above, 30 dark fringes are observed. Calculate the radius of the wire.



[4 marks]

8)

a) The intensity in the single slit diffraction pattern is given by

$$I = I_0 \left[\frac{\sin\left(\beta/2\right)}{\beta/2} \right]^2$$

Use the phasor addition method to derive this expression for the intensity in the single slit pattern. Illustrate with clear diagrams and define all parameters in the expression.

[5 marks]

b) Laser light with a wavelength of 580 nm is incident on a single slit. The slit has a width of 0.300 mm. The observing screen is 2.00 m from the slit. Determine (i) the positions of the first dark fringes and (ii) the width of the central bright fringe.

[3 marks]

c) Describe what happens to the diffraction pattern in part (b) if the slit width is increased by an order of magnitude to 3.00 mm. Compare the size of the central bright fringe to the slit width and comment.

[2 marks]

SECTION C

9)

a) It is often stated that the Sun is a run-of-the-mill star, similar to many millions of others in the Milky Way. Explain this statement in the context of the Hertzsprung Russell (HR) diagram, and, using a HR diagram, describe how a star like the Sun evolves from birth to death.

[7 marks]

b) Victorian astronomers pondered on whether the release of gravitational energy by the Sun could provide its power. If this were the case, show that the Sun would last at most a few million years before shrinking considerably.

[3 marks]

10)

a) Explain where we think long-period comets come from and the evidence to support the theory.

[3 marks]

b) The presence of the Edgeworth-Kuiper Belt has changed our ideas of how planets form around stars and led to the demotion of Pluto as a planet. What is the Edgeworth-Kuiper Belt, how has its presence changed our ideas, and explain the current status of Pluto?

[4 marks]

c) *Makemake* is an Edgeworth-Kuiper Belt object similar in size to Pluto. If *Makemake's* distance from the Sun is assumed to be constant at 45 au, what is its approximate orbital period?

[3 marks]

SECTION D

11)

a) As a metre stick, moving along its length, flies past you at high speed, you simultaneously measure the positions of the two ends and conclude that the length L < 1m. For an observer in the rest frame of the stick, S′, did you make your measurements simultaneously, and if not, which end did you measure first?

[5 marks]

b) In an experiment an electron is fired to the right with a speed of 0.9c and a proton is fired to the left with a speed of 0.9c. What is the speed of the electron relative to the proton?

[5 marks]

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

12)

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*.

[6 marks]

b) An interstellar gas cloud which is receding from Earth at 0.3*c* contains atomic hydrogen which emits electromagnetic radiation at 1420 MHz. What is the frequency of this radiation when it is detected on Earth?

[4 marks]

13) Briefly discuss how the concepts of energy and momentum are modified when going from Newtonian to relativistic mechanics.

[3 marks]

An electron is released with very low energy in a region of uniform electric field of 10^6 V m^{-1}. It then travels a distance of 2 m in the field before striking an obstacle.

a) What are the kinetic energy and the total energy of the electron just before it strikes the obstacle?

[2 marks]

b) What is the momentum of the electron just before it strikes the obstacle?

[2 marks]

c) How long does it take for the electron to travel from the point of release to the obstacle?

[3 marks]

(Rest mass energy of electron = 0.51 MeV)

14)

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

[2 marks]

b) Calculate the kinetic energy released by the fusion of one deuterium $({}^2_1H)$ and one tritium $({}^3_1H)$ nuclei. Also calculate the number of fusions per second required for a 400 MW power plant.

[4 marks]

NOTE: Question 14 continued on next page

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.

[4 marks]

Atomic masses: M(^2_1H) = 2.01410 amu, M(^3_1H) = 3.01605 amu, M(^4_2He) = 4.00260 amu, M(^1_0n) =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	$2.79\ \mu_N$
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 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_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