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 2017

Annual Examination

X-PY1P10-1

Physics, Paper 1

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

Tuesday 16 May 2017 — Sports Centre — 14:00 – 17:00

Professors M. Ferreira, L. Bradley, M. Moebuis and J. Lunney

ALL QUESTIONS CARRY EQUAL MARKS.

USE SEPARATE ANSWER BOOKS FOR EACH SECTION

Booklets 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.

Two inclined planes have a common vertex and a massless string passing over a smooth pulley at the vertex is attached to two equal blocks at rest, one on each plane. Assume that one plane is smooth, i.e., frictionless, and the other is rough. See figure below.

(a) Identify all the forces acting on each one of the blocks.

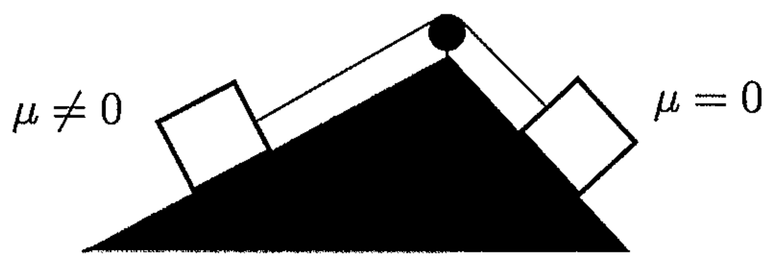
[2 marks]

(b) Find the relation between the angles of inclination of the two planes if the weight on the smooth plane is on the verge of sliding down.

[5 marks]

(c) Describe the motion of each block separately if the string attaching them is cut.

[3 marks]



2. A particle of mass M_1 and initial velocity V_1 strikes a stationary particle of mass M_2. The collision is perfectly elastic. It is observed that after the collision the particles have equal and opposite velocities.

(a) What is the ratio M_2/M_1 ?

[2.5 marks]

(b) What is velocity of the centre of mass before and after the collision?

[2.5 marks]

(c) The final kinetic energy of the particle with mass M_1 ?

[2.5 marks]

(d) How much kinetic energy was transferred to the particle of mass M_2 ?

[2.5 marks]

3. A hand grenade is launched vertically from the ground with a velocity V_0. You may ignore air resistance when carrying out the following tasks:

(a) Draw position-time, and velocity-time graphs for the motion of the grenade, assuming that it does not explode. Draw another graph that relates the magnitude of the velocity with the vertical position of the grenade.

[3 marks]

(b) Imagine that in its descending motion, at a certain height H, the grenade explodes in two identical halves landing simultaneously a distance D apart. Assuming that the kinetic energy released in the explosion is eight times the mechanical energy of the grenade prior to the explosion, obtain the distance D as a function of the height H.

[4 marks]

(c) Now, imagine that the grenade explodes at the highest point of its trajectory but instead of landing apart, both halves land exactly on the spot where the grenade was launched from. Calculate the time difference between the landing of the first and second halves.

[3 marks]

SECTION B

4.

(a) Derive the frequency of sound heard by i) a listener moving at v_L speed toward a stationary source emitting at frequency f_s and ii) a stationary listener when a source of sound emitting at frequency f_s is moving toward them at speed v_s. Illustrate both cases with clear diagrams and highlight the differences between the two cases. The speed of sound in air is v.

[4 marks]

(b) While moving along a straight road, as you approach a stationary car you hear the horn at a frequency of 853 Hz. After passing the car you hear a frequency of 741 Hz. Determine the frequency of sound emitted by the car horn and your own speed. Use the value of 330 m/s for the speed of sound in air.

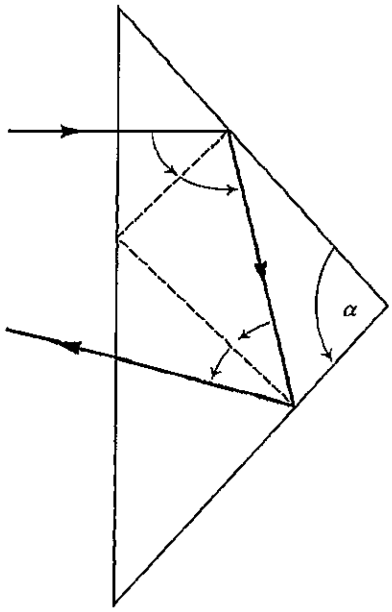
[4 marks]

(c) Determine the frequency that would be heard by the approaching listener if the car had initially been moving toward them with a speed of 30 m/s.

[2 marks]

5.

(a) Light is incident normally on the long face of a symmetric prism. What is the range of values of α that will permit total internal reflection from both rear faces for glass of n = 1.55?



[5 marks]

(b) A travelling wave along a string is described by

$$y(x,t) = 3.27\ mm\ \cos\left[\left(72.1 rad \cdot m^{-1}\right)x + \left(2.72 rad.s^{-1}\right)t\right]$$

i. Derive the expression $y(x,t) = A\cos[kx + \omega t]$ for a travelling wave.

ii. Determine the velocity, direction of propagation, wavelength and frequency of the wave.

iii. Sketch the displacement as a function of time for an element of the string.

iv. Determine the transverse velocity and transverse acceleration at x = 22.5 cm and t = 18.9 s.

[5 marks]

6.

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

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

where all parameters have their usual meaning. Define each parameter. Use the phasor addition method to derive this expression for the intensity in the single slit pattern. Illustrate with clearly labelled diagrams.

[5 marks]

(b)

i. Sketch the intensity as a function of the position on a viewing screening far from the single slit.

ii. Sketch the intensity as a function of position for two of these slits.

iii. Sketch clearly how the intensity pattern in part (ii) will change as the slit width increases, assuming the distance between slits remains unchanged.

[3 marks]

(c) A student finds a diffraction grating but does not know the spacing of the ruled lines. She shines light from a laser with λ =680 nm through the grating and examines the maxima on a screen 265 cm away. If the distance between the 10th maximum on either side of the central peak is 14.3 cm, what is the rule spacing of the grating?

[2 marks]

SECTION C

7.

(a) Given two independent variables V and r, with associated uncertainties ΔV and Δr, state the general error propagation formula that yields the uncertainty of a function f(V,r).

[2 marks]

(b) The charge to mass ratio of an electron, e/m, can be obtained by measuring the radius r of the circular trajectory of an electron in a magnetic field of strength B that has been accelerated through a potential difference V.

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

Assuming that the error in B is negligible ($i.e. \Delta B = 0$), derive the *fractional* error in $\frac{e}{m}$ using the error propagation formula.

[6 marks]

(c) Calculate e/m and its error for the following measurement: $V = (90.0 \pm 0.1)\ Volts$ $r = (5.3 \pm 0.3) cm$ and $B = 0.61\ m\,T$.

[2 marks]

8. A particular medicine works on 60% of the patients. A new formulation of this medicine is tested to increase the fraction of patients that benefit from it. The test involves 600 patients.

(a) State the null hypothesis and calculate the mean and standard deviation according to this hypothesis.

[3 marks]

(b) The new formulation has been successful in 390 patients. How many standard deviations is that result away from the mean calculated in (a)?

[2 marks]

(c) Write down the Gaussian approximation of the distribution governing your null hypothesis.

[2 marks]

(d) Based on the success rate of the test, can you conclude that the improvement is statistically significant at a 1% significance level? Use the tabulated values of the error function $\mathrm{erf}(t) = \frac{1}{\sqrt{2\pi}}\int_{-t}^{t} e^{-z^2/2}dz$ below to answer this question.

[3 marks]

t	0	0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.5	3.0	3.5	4.0
Prob (%)	0	20	38	55	68	79	87	92	95.4	98.8	99.7	99.95	99.99

SECTION D

9. Explain the meaning of the terms “proper time” and “time dilation”. Briefly describe an example of a physical phenomenon where time dilation is observed.

[5 marks]

An astronaut travels from Earth to a planet 4.5 light years away at a speed of 0.9c. Assume that the time needed to accelerate and decelerate is negligible.
(A light year is the distance travelled by light in 1 year)

(a) How long does the journey take according to Mission Control on Earth?

[1 mark]

(b) How long does the journey take according to the astronaut?

[2 marks]

(c) How much time elapses between the launch and the arrival of a radio signal sent by the astronaut when he arrives at planet?

[2 marks

10.

(a) Explain why the fusion of nuclei 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, 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.

[4 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.

11.

(a) Briefly describe the Compton effect and show that

$$\frac{1}{Q}-\frac{1}{Q_o}=\frac{(1-\cos\theta)}{m_0c^2},$$

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
	$\hbar = h/2\pi$	1.05×10^{-34} J s
Boltzmann's constant	k	1.38×10^{-23} J K^{-1}
Molar gas constant	R	8.31 J K^{-1}mol^{-1}
Avogadro's number	N_A	6.02×10^{23} mol^{-1}
Standard molar volume		22.4×10^{-3} m^3
Bohr magneton	μ_B	9.27×10^{-24} A m^2 <u>OR</u> J T^{-1}
Nuclear magneton	μ_N	5.05×10^{-27} A m^2 <u>OR</u> J T^{-1}
Bohr radius	a_o	5.29×10^{-11} m
Fine structure constant	$e^2/(4\pi\varepsilon_o\hbar c)$	$(137)^{-1}$
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 (1 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}
Acceleration due to gravity	g	9.8 m s^{-2}
Free space impedance	Z_0	377 Ω

Physics Paper 1

Astronomical unit (1 au)		1.50×10^{11} m
Parsec (1 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)	$R_\oplus$	6.378×10^{6} m