OLLSCOIL NA hÉIREANN GAILLIMH

NATIONAL UNIVERSITY OF IRELAND GALWAY

AUTUMN EXAMINATION 2001

FIRST SCIENCE EXAMINATION

Experimental Physics

Dr J.M. Woolsey
Prof. R.M. Redfern

Time allowed: THREE hours.

Answer Question 1 (30 marks) and FOUR questions from the remainder (10 marks each). The total marks for the paper are 70.

Use a separate answer book for Question 1.

Numerical values of the required physical constants and relevant data are given at the end of the paper.

Q.1 Answer **all** parts. [1 mark per question]

(a) Which of the following quantities are vectors and which are scalars? : mass, momentum, force, energy, electric charge, electric field intensity?

(b) Express a speed of 25 m s^{-1} in kilometres per hour, and a volume of 25 cm^3 in cubic metres

(c) A rubber ball is dropped onto the ground from a height of 10 m. It rebounds to a maximum height of 5 m. Sketch on a graph how the velocity varies with time from the instant that the ball is dropped until it attains its maximum height of 5 m after the first bounce.

(d) A uniform metre stick hangs in a horizontally when suspended from the 25 cm mark, if a 250 g mass is suspended from the 5 cm mark. What is the mass of the metre stick?

(e) What is the weight of a 10 kg mass at the surface of the Earth?

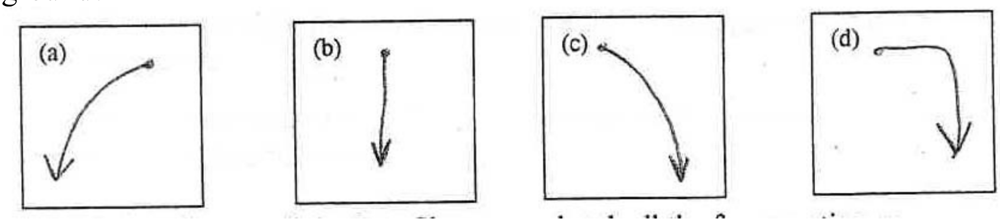
(f) A force of 40 N is applied to a lead sphere of mass 2 kg. What is the acceleration of the sphere?

(g) What is the temperature on the Fahrenheit scale when the temperature on the Celsius scale reads 25 ^{o}C?

(h) A brass rail is exactly 100 m in length when the temperature is 15 °C. What will be its length if the temperature rises to 35 °C?

(i) A spaceship travels in a straight line from Earth to the Moon. The gravitational forces of the Earth and Moon on the spaceship cancel when the space craft has travelled 74% of the distance to the Moon.
What is the ratio of the masses of the Moon to the Earth?

(j) A heavy mass is dropped from an aircraft which is travelling from left to right in the diagram. Neglecting air resistance, which of the diagrams a-d best represents the subsequent path of the mass as seen by an observer on the ground?



(k) A body is in orbit around the Sun. Show on a sketch all the forces acting on the body, and the acceleration of the body – neglect forces due to all bodies other than the Sun.

(l) What is the frequency in air at 15 °C of a sound wave of wavelength 0.1 m? Is this within the audible range?

(m) A Garda "radar speed gun" operates at a frequency of 10^{10} Hz. What is the frequency shift observed in a signal reflected from a car travelling at the legal speed limit of 26.7 m s^{-1} directly towards the gun?

(n) What is the end-to-end resistance of a 2.5 cm nichrome film on glass, which is 1 μm thick and 1.5 mm wide?

(o) What is the equivalent capacity of a series combination of 5 μF, 15 μF, and 50 μF capacitors?

(p) What is the acceleration of a proton in an electric field of 150 V m^{-1}?

(q) Four 100 Ω resistors are joined together to form a square. What is the equivalent resistance of the network across one side of the square?

(r) An electron is moving from right to left at a velocity of 15 x 10^4 ms^{-1} in a magnetic field of 0.6 T directed perpendicularly into the page. Calculate the magnitude and direction of the force on the electron.

(s) 2.5 x 10^{-6} J of work is done in transferring 0.5 nC of charge between two points. What is the potential difference between the points?

(t) What is the time constant of a circuit consisting of a 3 μF capacitor in series with a 680 Ω resistor?

(u) At what distance from a concave mirror of 25 cm focal length should an object be placed to produce an image magnified by 2 and inverted ? Sketch the ray diagram.

(v) Light is incident, at an angle of 45° to the normal, on the surface of a glass block. Calculate the angle of refraction of the light within the block.

(w) An object is placed 50 cm from a diverging lens of focal length 100 cm. Where is the image formed? Is it real or virtual?

(x) When the light from a He-Ne laser (λ = 633 nm) is incident normally on a diffraction grating, the second order maximum is observed at an angle of 49.4 degrees from the straight through direction. Calculate the separation of the slits in the grating.

(y) How does the mass number (A) of a nucleus change with the emission of (i) an α-particle, (ii) a β-particle, and (ii) a γ ray. ?

(z) What is the energy in eV of a photon of green light of wavelength 500 nm.

(A) How many carbon atoms are there in 10 g of ^{12}C ?

(B) An X-ray machine produces X-rays with minimum wavelength of 2.1×10^{-11} m. What is the voltage of the X-ray machine?

(C) Starting with 1.6 moles of a radioactive material, the half life of which is 2.6 years, how long does it take for 1.2 moles of the material to decay?

(D) Draw a ray diagram showing the image formation in a simple magnifying glass.

Q.2 State clearly the principle of conservation of linear momentum. Make clear under what conditions the law applies. [3 marks]

A truck of mass 10,000 kg travelling at a speed of 20 m s^{-1} collides with a car of mass 1,000 kg travelling at a speed of 10 m s^{-1} in the same direction. If the two vehicles lock together on collision, calculate the initial velocity of the two-vehicle composite. [4 marks]
How much energy is lost? [2 marks]
Where has this energy gone? [1 mark]

Q.3 Write down the laws governing linear motion under constant acceleration, carefully defining the meaning of the symbols used [3 marks]

A small boy stands at the edge of a well and drops a stone into it. He hears it splash after 2 seconds. At what depth below the ground is the surface of the water? (ignore the speed of sound) [3 marks]

(Q.3 continued)

This same small boy now tosses a stone vertically upwards with a velocity of 7 m s^{-1} and it eventually falls back in the well. What is the time interval between the release of the stone and when it splashes into the water in the well? [4 marks]

Q.4 Write down the Ideal Gas formula, clearly explaining what each term means. [2 marks]

Show how this contains both Boyle's law and Charles' law for gases.[2 marks]

What is the volume of a mole of ideal gas at standard temperature and pressure? [1 mark]

A bubble consisting of 0.02 g of nitrogen gas (N_2) is released from a tank that is 20 m below the surface of a pool of water. What fraction of a mole of nitrogen gas is contained in this bubble? [2 marks]

Calculate the total pressure on the bubble at this depth. [2 marks]

By what factor has the volume of the bubble increased just before it reached the surface of the water? [1 mark]

(mass of nitrogen molecule = 28 amu)

Q.5 Write down Coulomb's Law in electrostatics, carefully explaining the meanings of the all the terms used [2 marks]

Explain what is meant by the following terms, define the units for each term, and state whether each is a vector or scalar:

electric field intensity, electrical potential, and capacitance. [3 marks]

Two charges are placed on the x-axis: a +20 μC charge at x = 50 cm and a –30 μC charge at x = 80 cm.

At what position on the x-axis is the electric field **E** = 0? [4 marks]

Why is there only one position on the x axis for which this is true. [1 mark]

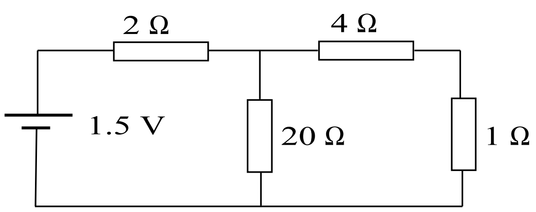
Q.6 State Ohm's Law and Kirchhoff's two circuit rules for the analysis of electrical circuits carefully explaining the terms used. [2 marks]

Derive an expression for the equivalent resistance of three resistors R1, R2, and R3 connected in series. [2 marks]

What is the total current drawn by the battery in the circuit shown? [2 marks]

Calculate also the voltage across the 1 Ω resistor [2 marks]

and the power dissipated by the 4 Ω resistor. [2 marks]



Q.7 In relation to light waves, explain briefly what is meant by polarisation, diffraction, and interference. [3 marks]
Indicate two methods used to produce a polarised light beam. [2 marks]

Two slits 0.50 mm apart are illuminated coherently with monochromatic light. Fringes separated by 0.44 mm are observed on a screen 40 cm from the slits. What is the wavelength of the light used ? [5 marks]

Q.8 Give an account of the origin of α, β, and γ emissions from atomic nuclei and describe their interaction with matter. [3 marks]
In the case of absorption of γ radiation by matter, explain what is meant by the absorption coefficient and the half-thickness and write down the relationship between these quantities. [2 marks]

Describe an experimental approach which could be used to measure the absorption coefficient of a material for γ radiation. [2 marks]
A Geiger counter shows a reading of 4000 counts in a 5 minute period when placed in front of a Cs^{137} source emitting γ radiation. Calculate the new count rate expected if a 1.2 cm thick steel plate is placed between the source and detector. [3 marks]
Linear absorption coefficient of Cs^{137} γ rays in steel = 0.43 cm^{-1}.

Q.9 Write detailed notes (1-2 pages at most) on *one* of the following topics: [10 marks]

(1) Hubbles' Law.
Include a discussion of the physical effects that Hubble used to establish his Law, and explain why Hubbles' Law **does not** mean that we are at the centre of the Universe.

(2) The importance of chaos in our daily life.

(3) Our ionizing radiation environment.
Topics should include: the percentage contributions from different sources, the radon problem, cosmic rays, internal radioactivity, medical applications and nuclear discharges.

(4) Radiocommunication.

PHYSICAL CONSTANTS and DATA

Absolute zero of temperature, 0 K		=	–273 ºC
Acceleration due to gravity, g		=	$9.81\ m\ s^{-2}$
Atomic mass unit, 1 u		=	1.6606×10^{-27} kg
Atomic mass of copper		=	63.54 kg $kmol^{-1}$
Avogadro's number, N_A		=	$6.02 \times 10^{26}\ kmol^{-1}$, $6.02 \times 10^{23}\ mol^{-1}$
Boiling point of nitrogen		=	77 K
Boltzmann's constant, k		=	$1.38 \times 10^{-23}\ J\ K^{-1}$
Coefficients of linear thermal expansion of	brass	=	$18 \times 10^{-6}\ K^{-1}$
	steel	=	$12 \times 10^{-6}\ K^{-1}$
Density of air at STP (0 ºC, 1 atm)		=	$1.28\ kg\ m^{-3}$
Densities of	copper	=	$8960\ kg\ m^{-3}$
	lead	=	$11350\ kg\ m^{-3}$
	mercury	=	$13600\ kg\ m^{-3}$
	steel	=	$7800\ kg\ m^{-3}$
	water	=	$1000\ kg\ m^{-3}$
Distance (mean) Earth to Sun		=	1.5×10^{11} m
Distance (mean) Earth to Moon		=	3.84×10^{8} m
Electron volt, 1 eV		=	1.60×10^{-19} J
Electronic charge, e		=	1.60×10^{-19} C
Gas constant, R		=	$8314\ J\ K^{-1}\ kmol^{-1}$, $8.314\ J\ K^{-1}\ mol^{-1}$
Gravitational constant, G		=	$6.67 \times 10^{-11}\ N\ m^2\ kg^{-2}$
Mass of the electron, m_e		=	9.1×10^{-31} kg
Mass of the neutron, m_n		=	1.6749×10^{-27} kg
Mass of the proton, m_p		=	1.6726×10^{-27} kg
Mass of the Earth		=	5.98×10^{24} kg
Mass of the Moon		=	7.35×10^{22} kg
Mass of the Sun		=	2.0×10^{30} kg
Melting points of	lead	=	328 ^{O}C
	mercury	=	–39 ^{O}C
Permeability of vacuum, μ_o		=	$4\pi \times 10^{-7}\ H\ m^{-1}$
Permittivity of vacuum, ε_o		=	$8.85 \times 10^{-12}\ F\ m^{-1}$
$k = 1/(4\pi\varepsilon_o)$		=	$9 \times 10^{9}\ N\ m^2\ C^{-2}$
Planck's constant, h		=	6.63×10^{-34} J s
Radius of the Earth		=	6.4×10^{6} m
Radius of the Moon		=	1.74×10^{6} m
Radius of the Sun		=	7×10^{8} m
Refractive indices of	glass	=	1.50
	water	=	1.33
Resistivity of nichrome		=	$1.0 \times 10^{-6}\ \Omega$ m
Specific heat capacity of	copper	=	$389\ J\ kg^{-1}\ K^{-1}$
	lead	=	$125\ J\ kg^{-1}\ K^{-1}$
	mercury	=	$140\ J\ kg^{-1}\ K^{-1}$
	water	=	$4180\ J\ kg^{-1}\ K^{-1}$
	ice	=	$2092\ J\ kg^{-1}\ K^{-1}$
Specific latent heats of fusion of	lead	=	$21 \times 10^{3}\ J\ kg^{-1}$
	water	=	$335 \times 10^{3}\ J\ kg^{-1}$
Specific latent heats of evaporation of	nitrogen	=	$2 \times 10^{5}\ J\ kg^{-1}$
	water	=	$2.26 \times 10^{6}\ J\ kg^{-1}$
Speed of light in vacuum, c		=	$3 \times 10^{8}\ m\ s^{-1}$
Speed of sound in air (15 ºC)		=	$340\ m\ s^{-1}$
Standard atmospheric pressure		=	1.01×10^{5} Pa
Thermal conductivities of	glass	=	$0.9\ W\ m^{-1}\ K^{-1}$
	copper	=	$398\ W\ m^{-1}\ K^{-1}$
Young's modulus for steel		=	$2.1 \times 10^{11}\ N\ m^{-2}$