OLLSCOIL NA hÉIREANN
GAILLIMH

NATIONAL UNIVERSITY OF IRELAND
GALWAY

SEMESTER II (SUMMER) EXAMINATIONS 2002

FIRST SCIENCE EXAMINATION

Experimental Physics

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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 (each part carries 1½ marks)

(a) What are the SI units of density, specific heat capacity, power ?

(b) Calculate, in kg, the mass of air at temperature 0 ^{o}C in a room of width 6 m, length 8 m, and height 4 m.

(c) A piece of lead, when suspended by a thread from a calibrated spring balance, is found to have a mass of 200 g. What is the reading on the balance when the lead mass is immersed in water while still suspended from the balance ?

(d) An 20 kg object is hauled, at constant velocity, a distance of 10 m up a frictionless slope inclined at 30^{o} to the horizontal. Calculate the work done on the object.

(e) When a 1 kg mass is attached to the end of a spring its stretches by 2.5 cm. The mass is pulled beyond its equilibrium point and released. Determine the frequency of oscillation.

(f) The temperature and pressure of the air in a balloon change from 22°C and 1 atm to 345 K and 5×10^{5} Pa. What is the ratio of the final to the initial volume?

(g) A 2 kW heater is submerged in 1 kg of water at 20 ^{o}C. How long does it take for the water to reach 100 ^{o}C ?

(h) A 2 μF capacitor is charged so that a potential difference of 5.0 V is developed across it. Calculate the energy stored in the capacitor.

(i) An electric kettle which operates from a 220 V mains supply delivers 1MJ of heat energy in 15 minutes. Calculate the current flowing in the heating element during this time.

(j) Three resistors with resistances of 2 Ω, 3 Ω and 6 Ω are arranged in parallel. Calculate the net resistance of the combination.

(k) During a certain electrical storm a flash of lightning was seen 5 s before the clap of thunder was heard. Calculate how far the lightning was from the observer.

(l) Calculate the magnetic force on a proton which is travelling with a speed of 20 m s^{-1} at right angles to a uniform magnetic field of 3.0 mT.

(m) Calculate the resistance of a piece of nichrome wire which has a length of 3.0 m and a cross-sectional area of 1.5 mm^2.

(n) An object is placed 5.0 cm in front of a concave mirror of focal length 20.0 cm. Calculate the position of the image of the object and draw a ray diagram showing where this image is formed.

(o) The wavelength of light from a He-Ne laser is 633 nm in a vacuum. What is its wavelength in water?

(p) An aging person can no longer focus on the print in a book unless it is held at arm's length at 60 cm from their eyes. Calculate the power in dioptres of a spectacle lens that would allow the person to read the book if it was held at a normal near point of 25 cm from the eyes.

(q) A double slit is illuminated by light of wavelength 589 nm. This produces interference fringes separated by 0.500 mm on a screen 2.00 m from the slits. Calculate the separation of the slits.

(r) How much mass must be totally converted to energy to release 3.50 MJ of energy?

(s) Identify the unknown particle *X* in the following nuclear reaction

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + X$$

(t) A teacher purchases a cobalt-60 radioactive source. Ten years later, the activity of the source has decreased to 25% of its activity when it was purchased. Calculate the half-life of source.

Q.2 Answer **either** (a) **or** (b)

(a) Sketch the general form of the speed-time graph for motion with uniform acceleration in a straight line. Hence, or otherwise, derive the three formulae connecting initial speed, final speed, distance travelled, acceleration, and time. [4 marks]

Sketch the distance-time graph in the special case where the initial speed is zero. [1 mark]

As it prepares for takeoff, an airplane (of mass $8x10^4$ kg) is initially moving down the runway at 4.5 m s^{-1}. The pilot pulls the throttle, giving the plane a constant acceleration of 1.8 m s^{-2}. The plane then travels a distance of 1700 m down the runway before lifting off. Calculate the speed of the plane when it lifts off and the time taken from initial acceleration until it becomes airborne. [4 marks]
Calculate the increase in the kinetic energy of the plane during the acceleration phase. What is the source of this additional energy ? [1 mark]

(b) Define the terms *Young's modulus of rigidity, coefficient of linear expansion, specific heat capacity , latent heat of vaporisation.* [4 marks]

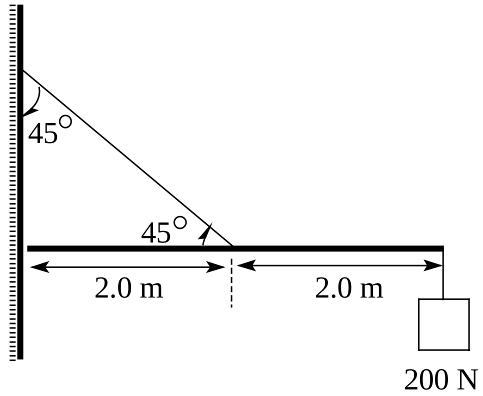
Describe briefly an experiment to measure the latent heat of vaporisation of water [2 marks]
Calculate the increase in length of a steel rod, 3 m long at 0 ^oC, due to a rise in temperature of 50 ^oC. If the rod has a diameter of 1.5 mm diameter, what tensile force must be applied to the ends in order to cause the same increase in length ? [4 marks]

Q. 3 Answer **<u>either</u>** (a) **<u>or</u>** (b).

(a) Define the terms weight, torque, principle of moments. [3 marks]
State the conditions for a solid object to be in static equilibrium. [2 marks]
Explain how the principle of moments can be used to find the weight of a metre stick without using a balance. [1 mark]

A beam is supported as shown by a cable attached to the midpoint of the beam and to the wall. Find the vertical and horizontal components of the force exerted by the wall on the beam. The weight of the beam is 300 N.

[4 marks]



(b) Explain what is meant by : conservation of energy, conservation of momentum, impulse, inelastic collision. [4 marks]

A railway carriage, of mass 1000 kg and travelling at 8 m s^{-1}, collides with a second carriage of mass 800 kg, which is travelling at 2 m s^{-1} in the same direction. After the collision, the carriages are coupled together. Calculate the velocity of this combined unit after the collision. [4 marks]

Calculate also the total mechanical energy before and after the collision, and account for any difference. [2 marks]

Q.4 State Coulomb's law of electrostatics and write down an expression for the electrostatic force between two point charges. [1 mark]

Calculate the electrostatic force between two charges, 2.0 pC and -3.0 pC, which are separated by a distance of 4.0 mm. Draw a sketch to show the direction of the force.
[2 marks]

Define the terms electric field strength and equipotential surface. Write down an expression for the electric field strength at a distance r from a point charge, Q. Draw a sketch which shows the electric field lines and equipotential surfaces about a positive point charge.
[4 marks]

A certain air-spaced, parallel-plate capacitor is charged so that a potential difference of 10 V exists between the plates which are separated by a distance of 1.0 cm. Calculate the electric field strength in the region between the plates. Calculate the acceleration experienced by an electron which is placed in the space between the plates. [3 marks]

Q.5 Answer **either** (a) **or** (b).

(a) Write down an expression for the magnetic field at a distance d from a long straight wire, carrying a current I. Sketch the magnetic field lines about the wire, paying particular attention to the direction of the field. If this wire is bent into the shape of a circular loop, sketch the resultant magnetic field lines. [3 marks]

State Faraday's law of Electromagnetic Induction. Show how Lenz's law can be used to obtain the direction of the induced current. [2 marks]

A certain coil is made from N = 200 turns of wire and has a cross-sectional area A = 50 mm^2. It is mounted so that its axis of rotation is at right angles to a uniform magnetic field B = 0.5 T. If the coil rotates at 50 revolutions per second, derive an expression for the e.m.f. induced in the coil. Calculate the values of the peak voltage and root-mean-square voltage induced in the coil. [5 marks]

(b) Define the terms transverse and longitudinal waves and give an example for each type. [2 marks]

Define (with the aid of sketches) the terms wavelength λ, periodic time T, and frequency f. With reference to the sketches, derive a relationship between λ, f and the speed of the wave. [3 marks]

Sketch two of the possible standing wave patterns for sound in a pipe which is closed at one end and open at the other. If the length of the pipe is L, derive an expression for the allowed frequencies which can form standing waves in the pipe. [3 marks]

Two such pipes with lengths of 16 cm and 16.1 cm emit sounds at their fundamental frequencies. Calculate the beat frequency which will be heard when both pipes sound simultaneously. [2 marks]

Q.6 Explain clearly what are meant by the terms critical angle and total internal reflection. [3 marks]

Light travelling through a material of refractive index n_1 reaches the interface of this material with a material of refractive index n_2. Derive an expression for the critical angle in terms of n_1 and n_2. [3 marks]

An optical fibre with a refractive index 1.67 is surrounded by a cladding material with a refractive index 1.45. Calculate the critical angle for this interface and then calculate the maximum angle at which light can enter the fibre from air and still be transmitted effectively down the fibre. Assume that the end face of the fibre is perpendicular to the fibre axis. [4 marks]

Q.7 Draw a labelled diagram of a modern X-ray tube. [2 marks]

Draw a sketch of the spectrum of X-rays produced by a tube containing a target such as molybdenum. Explain clearly how the two main components of the spectrum arise. [5 marks]

The shortest wavelength of X-rays produced by a particular x-ray tube is 0.026 nm. Calculate the operating voltage of the tube and also calculate the speed of electrons in the tube just before they hit the target where the X-rays are produced. [3 marks]

Q.8 Write detailed notes (1-2 pages at most) on ***one*** of the following topics:

[10 marks]

(a) Measuring the distance to the stars.

(b) Alternative energy sources in the 21^{st} Century.

(c) Ionising radiation: what is it and what are the origins and doses received by an average Irish citizen?

(d) Radiocommunication for the 21^{st} Century.

PHYSICAL CONSTANTS and DATA

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