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NATIONAL UNIVERSITY OF IRELAND
GALWAY

SUMMER EXAMINATIONS 1999

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.

(a) Indicate which of the following quantities are scalars and which are vectors: mass, electrical potential, force, electric charge.

(b) A mass of 5.0 kg is thrown vertically upwards from the ground with a kinetic energy of 30.0 J. Calculate the maximum height reached by the stone.

(c) The driver of a certain car, travelling with a speed of 20 m s^{-1} in a straight line, suddenly applies the brakes and comes to rest while decelerating uniformly for a distance of 40 m. Calculate the time taken for the car to come to rest.

(d) A person tries to swim directly across a certain river with a speed of 1.0 m s^{-1} relative to the water. If the river flows with a speed of 2.0 m s^{-1} calculate the speed and direction of the swimmer relative to the river bank.

(e) Calculate how much work must be done to push a 20 kg box 30 m across a horizontal surface if the coefficient of friction between the box and surface is 0.65.

(f) A 200 kg object, moving in a straight line with a speed of 10 m s^{-1}, collides with and sticks to a stationary object with a mass of 300 kg. Calculate the speed and direction of the objects after the collision.

(g) Calculate the force necessary to keep a 4.0 kg object moving with a constant speed of 3.0 m s^{-1} in a circle of radius 2.0 m.

(h) Calculate the gravitational force experienced by a 200 kg satellite which orbits the earth at a height of 300 km.

(i) Calculate the period of oscillation of a simple pendulum of length 0.50 m.

(j) Calculate the rate of heat loss through a 1.0 m^2 pane of window glass which is 5.0 mm thick on a cold night if the outside temperature of the glass is + 5.0 °C while the inside temperature is + 10 °C.

(k) Calculate how much heat is required to convert 100 g of water at an initial temperature of 20 °C to steam at 100 °C.

(l) A piece of steel wire with a length of 2.0 m and a cross sectional area of 3.0 mm^2 is used to suspend a mass of 20 kg from a ceiling. Calculate the increase in length which will occur in the wire when the mass is suspended from it.

(m) Calculate the wavelength in air (at 15 °C) of a sound wave with a frequency of 600 Hz.

(n) The sound intensity from a certain loudspeaker is increased by a factor of 4. Calculate the increase in dB of the intensity level.

(o) A person with a mass of 100 kg stands on one foot. If the area of the person's shoe which comes into contact with the ground is 18 cm^2, calculate the pressure exerted on the ground by the foot.

(p) Calculate the magnitude of the repulsive force between two charges, each of 1.0 μC, separated by 1.0 cm.

(q) To move a charged particle through an electric potential difference of 10^{-3} V requires 2 x 10^{-6} J of work. What is the magnitude of the charge ?

(r) When you press one of the buttons on a pocket calculator, the battery provides a current of 300 μA for 10 ms. (a) How much charge flows during that time and (b) how many electrons flow in that time.

(s) A piece of nichrome wire has a cross-sectional area of 40 mm^2 and a length of 2 m. What is the potential difference across the wire when it carries a current of 10.0 A ?

(t) A 10 Ω resistor is connected in series with the parallel combination of a 47 Ω resistor and a 23 Ω resistor. What is the equivalent resistance of this total combination ?

(u) A straight wire with a length of 0.25 m carries a constant current and is arranged at right angles to a uniform magnetic field of 100 T. If the wire experiences a total force from the field of 9.81 N, what is the value of the current ?

(v) The flux at right angles to the plane of a single-loop coil of area 37 cm^2 steadily changes from 6.5 × 10^{-3} T to 9.3 × 10^{-3} T in 0.5 s. What emf is induced in the coil ?

(w) How long does it take for light to travel from the sun to the earth ?

(x) What is the apparent depth of a swimming pool full of water which is 1.5 m deep ?

(y) A coin with a diameter of 2.0 cm is held 100 cm from a concave spherical mirror of R = 30.0 cm. Calculate the position and diameter of the image of the coin.

(z) A spectacle lens has a power of +5.00 dioptres. What is the focal length of the lens ?

(A) Light from a laser with a wavelength of $\lambda = 633$ nm is passed through a dense flint glass with a refractive index of 1.65. What is the velocity and wavelength of the laser light in the glass ?

(B) At what rate is mass converted into energy in a nuclear reactor operating at a power of 2000 MW ?

(C) A certain radioactive isotope has a half-life of 7.0 years. What will be the activity of a 100 MBq sample of the isotope after 14.0 years ?

(D) A gamma-ray from the nuclear decay of Cs-137 has an energy of 661 keV. What is its wavelength ?

Q.2 Write down the equations of motion which describe the motion of a object in a straight line due to a constant acceleration.

Use a graphical means to derive any two of these equations.

A car accelerates uniformly from rest to a speed of 5.0 m s^{-1} in a time of 3.0 s. It then travels with a constant speed of 5.0 m s^{-1} for 4.0 s and then decelerates uniformly to rest in a time of 6.0 s. Draw a velocity-time graph for the motion and **from the graph** calculate the total distance travelled by the car and also its acceleration during the three periods. (Note: no marks will be awarded for using the equations of motion to solve this problem.)

A stone is thrown horizontally out to sea from the top of a 100 m high vertical cliff with a speed of 5.0 m s^{-1}. How far will the stone travel from the cliff face before it hits the sea ? How long will the motion last ? Draw a rough sketch of the path followed by the stone. (Note: you may use the equations of motion to solve this problem.)

Q.3 State the laws of conservation of energy and conservation of linear momentum.

Describe **briefly** four forms of energy which you have encountered in your physics course and mention a practical example in each case.

Why is linear momentum an important quantity in physics ?

A block of wood with a mass M = 200 g hangs from a light rope which has a length of 100 cm. A bullet of mass m = 5.0 g, fired horizontally from a rifle with a speed of 300 m s^{-1}, strikes the wooden block and remains embedded in it. Calculate the speed of the block with the embedded bullet just after collision and the amount of energy lost during the impact. Calculate the maximum height reached by the block and also the time taken to react this height. Suggest a reason why this value for the time may not be exact.

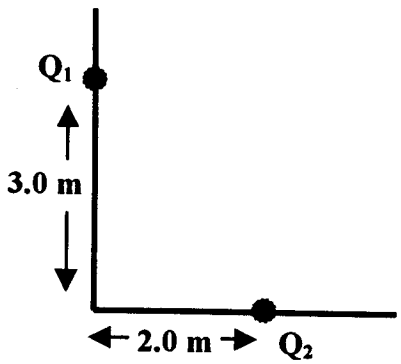
Q.4 Define the following terms: specific heat capacity; latent heat of fusion; thermal conductivity.

Describe the three mechanisms by which heat may be transported from place to place and give an everyday example in each case. Which method is, in your opinion, most essential for the maintenance of life on the Earth ? Explain **briefly** why.

A well-lagged copper can (mass = 100 g) contains 200 g of ice and 400 g of water at a temperature of 0 °C. The can is connected to a heat source by a copper bar with a cross-sectional area of 3.0 cm^2 and a length of 40 cm. The bar is thermally insulated so that heat can flow from the source to the can without loss to the surroundings. If the heat source is maintained at a temperature of 160 °C, calculate the rate of heat flow along the bar. How long will it take for all the ice in the can to melt ? Draw a sketch of the long-term temperature profile (i.e., temperature vs. time) of the copper can.

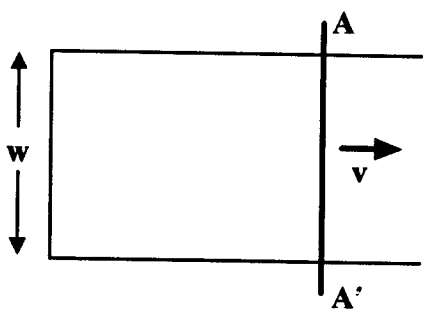
Q.5 State Coulomb's Law in words and describe it mathematically. Define the quantities electric field strength, E, electrical potential at a point, V, and electrical potential difference, V_{ab}.

Two charges, Q_1 = + 2.0 μC and Q_2 = - 4.0 μC are arranged on the x- and y-axis as illustrated. Calculate the net electric field and the electrical potential at the origin due to Q_1 and Q_2. A third charge, Q_3 = + 1.0 μC is now located at the origin. Find the net force on Q_3 due to Q_1 and Q_2. How much work is done in moving Q_3 from the origin to any point very far away from the origin ?



Q.6 State Faraday's Law of electromagnetic induction and explain Lenz's Law.

A piece of wire with negligible resistance is bent into a U-shape and laid on the page as in the figure. The width of the shape is w. A conducting rod A-A′ is placed on the U-shape as indicated and is pulled to the right with a constant speed v. The resulting coil is placed in a uniform magnetic field B which points directly into the page. Calculate the magnetic force on charge carriers in the moving rod and use this result to explain the origin of the induced emf in the circuit. If the resistance of the current-carrying rod is R, calculate the current flowing in the loop.



A rectangular coil with 50 turns and cross-sectional area A = 100 cm^2 rotates at a constant rate ω = 4.0 rad s^{-1} about a symmetry axis in the plane of the coil which is at right angles to a uniform magnetic field B = 30 × 10^{-3} T. Derive an expression for the emf induced in the coil. Calculate the peak and root mean square values of this voltage.

Q.7 Compare the arrangements of the lenses in a refracting astronomical telescope with the mirrors in (a) a Newtonian, and (b) a Cassegrain reflecting telescope.

What are the advantages and disadvantages of the reflecting telescope compared to the refracting telescope ?

What are the limitations to the useful magnification of an astronomical telescope and how may these be overcome in practice ?

An astronomer uses a telescope with a mirror diameter of 25 cm. What is the smallest feature which she can just resolve on the moon, assuming that the wavelength of light used is 600 nm.

Q.8 In the context of nuclear radiation physics, define the terms disintegration constant, and half-life, and the units of the becquerel, the gray, and the sievert.

Calculate the activity of 3 μg of pure iodine - 131 given that it has a half-life of 8 days.

If the daily treatment of a patient undergoing radiotherapy with gamma-rays from Co-60, which has a half-life of 5.2 years, is 5 minutes, how long would the treatment need to be in order to give the same dose with the same source in 10 months time ?