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NATIONAL UNIVERSITY OF IRELAND
GALWAY

SUMMER EXAMINATIONS 2000

FIRST SCIENCE EXAMINATION
Repeat Students

Experimental Physics EP101

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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) Which of the following quantities are vectors and which are scalars: electrical potential difference, momentum, mass, force?

(b) A person walks 4 km northwards and then turns and walks a further 3 km in an easterly direction. Calculate how far the person is from her starting point. In what direction would she have had to travel in order to reach this point by walking in a single straight line from the starting point ?

(c) A certain object has a weight of 5.0 kg wt. in air. Its apparent weight when immersed in water is found to be 4.6 kg wt. What is the relative density of the object ?

(d) A person with a mass of 70 kg stands on the ground on one leg. If the area of the person's foot in contact with the ground is 40 cm^2 calculate the pressure exerted by the person on the ground.

(e) Calculate the time it takes for light to travel from the Sun to the Earth.

(f) Calculate the period of a simple pendulum with a length of 2.0 m.

(g) Calculate the total pressure at the bottom of a lake of fresh water with a depth of 30 m.

(h) By what factor does the capacitance of a parallel plate capacitor change if the separation of the plates of the capacitor is halved and the area is increased by a factor of four ?

(i) If a unit of electricity (kWh) costs 8 pence, how much does it cost to run a 1500 W heater for four hours per day for a period of one week ?

(j) If the activity of Cobalt-60 (half life 5.3 years) is 4.0×10^{10} Bq, what will the activity be 10.6 years from now ?

(k) A car travelling with an initial speed of 30 m s^{-1} experiences a uniform deceleration and comes to rest after travelling a distance of 100 m. Calculate the deceleration of the car.

(l) A stone is thrown vertically upwards with an initial speed of 5.0 m s^{-1}. Calculate the maximum height reached by the stone.

(m) Calculate the gravitational force exerted on the Earth by the Sun.

(n) A spring with a spring constant $k = 2.0$ N m^{-1} is stretched by a length of 4.0 cm from its equilibrium position. Calculate the potential energy stored in the spring.

(o) A uniform metre stick (mass = 200 g) has a 50 g mass suspended from one of its ends and is found to be in horizontal equilibrium when balanced on a knife edge. How far is the knife edge from the end of the metre stick?

(p) An ideal gas is heated from 300 K to 400 K while its volume is held constant. Calculate the fractional increase in the gas pressure.

(q) Calculate the wavelength in air of a sound with a frequency of 600 Hz.

(r) A certain sound intensity is increased by a factor of 4. Calculate the dB increase in the intensity level.

(s) Calculate the electrostatic force of attraction between a proton and an electron which are separated by a distance of 10 nm.

(t) Calculate the current in a 100 Ω resistor which has a potential difference of 2 V across it ?

(u) Calculate the energy stored in a 5.0 μF capacitor when it is charged to a potential difference of 2.0 V.

(v) What is the average e.m.f. induced in a circuit when the flux linkage is increased from 1.0 Wb to 3.0 Wb in 10 s?

(w) Calculate the peak voltage in a household mains circuit which has an r.m.s value of 220 V.

(x) A ray of light is found with an angle of refraction of 30° when it enters a piece of glass from air at an angle of 49° to the normal. Calculate the refractive index of the glass.

(y) A certain concave mirror forms an image of the moon at a distance of 15 cm from its pole. What is the radius of curvature of the mirror?

(z) Identify the product nucleus, X, in the nuclear reaction depicted below:

$$^{147}_{62}\mathrm{Sm} \rightarrow {}^{143}_{60}\mathrm{Nd} + \mathrm{X}$$

(A) How much energy is released when 1 μg of matter disappears in a certain mass-energy conversion process?

(B) What is the energy of a photon of light with a wavelength of 500 nm?

(C) Calculate the final velocity of a proton which is accelerated from rest through a potential difference of 10 kV.

(D) Calculate the angle of the first-order diffraction maximum for a HeNe laser beam (λ = 633 nm) when it passes through a 600 lines/mm diffraction grating.

Q.2 Write down the laws governing linear motion under constant acceleration.

A person standing on a ledge 50 m above the ground fires a projectile vertically upwards with an initial velocity of 10 m s^{-1}. On its return downward, the projectile just misses the ledge and falls to the ground. What is the velocity of the projectile just before it hits the ground ?

If, instead of firing the projectile vertically upwards, the projectile is fired horizontally outwards at the same initial velocity of 10 m s^{-1}, what is the velocity of the projectile just before it hits the ground ?

Comment on the calculated answers for the final velocities in the two cases above.

Q.3 Define the Young's Modulus (E) for a solid material which obeys Hooke's law. What are the SI units of E?

Define the coefficient of linear thermal expansion of a solid, giving its SI units.

A bar of steel 5 m in length and 10 cm^2 in cross-section is heated from 10 °C to 50 °C. By how much will the length expand if the bar is free to expand? If the rod is fixed into supports so that it cannot expand, what compressive force is exerted by the supports on the ends of the rod? How much energy is stored in the rod?

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

Derive an expression relating the density of a gas to its temperature and pressure.

A tank of volume 10 m^3 contains N_2 gas at a temperature of 300 K and a pressure of 1 atmosphere. What is the mass of gas in the tank? What is the RMS velocity of the molecules ?

The temperature of the gas is raised to 500 K, but a leak develops so that the pressure stays at 1 atmosphere. What mass of gas has leaked from the tank?

(The mass number of a nitrogen atom is 14)

Q.5 State Coulomb's law of electrostatics paying particular attention to the direction of the forces experienced by the charges.

Calculate the electric field strength at a distance of 10 μm from a proton. Sketch the direction of the electric field lines in this case. Now sketch the electric field lines surrounding two positive charges each of charge q and also the field lines due to a long line of equally spaced charges q. Extend this treatment to explain the electric field that exists between the plates of a charged parallel plate capacitor.

How much work is done when a proton is moved through a distance of 1.0 cm against a uniform electric field strength, E = 1000 V m^{-1}? Give the answer in joules and also in electron-volts. What force does the proton experience in this field?

Q.6 Define the following terms: current; potential difference; resistivity.

Use these definitions to derive expressions for the heat generated in a resistor, R, which carries a current, I, when a potential difference, V, is applied across it.

A 2 kW electric heater is connected to a 220 V household mains circuit. Calculate the current drawn by the heater and also the resistance of the heating element.

Additionally, this mains circuit is used to power a 1 kW kettle, a 700 W microwave oven, 500 W iron and a 100 W table lamp. Calculate whether the 20 A fuse in the circuit will blow. If not, how much more current can the circuit supply ?

Would you expect to get 100 W of visible light power from the table lamp bulb? Explain your reasoning.

Q 7 (a) Write down the thin lens formula. Define all the terms in the equation.

(b) Is the focal length of a convex lens positive or negative ?

(c) Draw a ray diagram for an object of height L placed a distance u from a thin convex lens of focal length f, where $u > f$. Show the position of the image.

(i) Is the image real or virtual ?

(ii) Use this diagram to prove the thin lens equation.

(d) A convex lens with $f = 60$ mm is used in a slide projector.

(i) How far from the lens must a slide be placed in order to form a clear image on a screen 5 m away ?

(ii) The image on the slide is 36 mm wide. How wide is the image on the screen ?

Q.8 (a) What are the three main types of radioactive decay ?

(b) Describe briefly, with the aid of a diagram, how a smoke detector using $^{241}_{91}$Am works.

(c) The half-life of bismuth ($^{212}_{83}$Bi) is 60.6 minutes. What is:

(i) its decay constant ?

(ii) the activity of 2 g of $^{212}_{83}$Bi ?

(d) Describe briefly how radioisotopes are used as tracers in medicine. What is the most commonly used radiotracer ?

PHYSICAL CONSTANTS and DATA

Absolute zero of temperature, 0 K		=	−273 °C
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		=	6.02×10^{26} $kmol^{-1}$, 6.02×10^{23} mol^{-1}
Boiling point of nitrogen		=	77 K
Boltzmann's constant, k		=	1.38×10^{-23} J K^{-1}
Coefficients of linear thermal expansion of	brass	=	18×10^{-6} K^{-1}
	steel	=	12×10^{-6} K^{-1}
Density of air at STP (0 °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		=	1.5×10^{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		=	6.67×10^{-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 °C
	mercury	=	−39 °C
Permeability of vacuum, μ_o		=	$4\pi \times 10^{-7}$ H m^{-1}
Permittivity of vacuum, ε_o		=	8.85×10^{-12} F m^{-1}
$k = 1/(4\pi\varepsilon_o)$		=	9×10^{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		=	1.0×10^{-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	=	21×10^{3} J kg^{-1}
	water	=	335×10^{3} J kg^{-1}
Specific latent heats of evaporation of	nitrogen	=	2×10^{5} J kg^{-1}
	water	=	2.26×10^{6} J kg^{-1}
Speed of light in vacuum, c		=	3×10^{8} m s^{-1}
Speed of sound in air (15 °C)		=	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		=	2.1×10^{11} N m^{-2}