Ollscoil na hÉireann, Gaillimh
National University of Ireland, Galway

GX 908

Semester II Examinations, 2002/2003

Exam Code(s)	2BS1, 2EL1, 2ER1, 2PT1
Exam(s)	Second Science (Undenominated) Second Science (Denominated Physics) Second Science (Earth Science) Second Science (Physics & Astronomy)
Module Code(s)	2BS1-EP213, 2EL1-EP213, 2ER1-EP213, 2PT1-EP213 2BS1-EP214, 2EL1-EP214, 2ER1-EP214, 2PT1-EP214
Module(s)	EP213 Modern Physics EP214 Thermodynamics
Paper No.	
Repeat Paper	Special Paper
External Examiner(s)	Prof. E.T. Kennedy
Internal Examiner(s)	Prof. S.G. Jennings Dr. R. Butler Dr. G. Gillanders

Instructions:

Answer FIVE questions, at least TWO from each section.

Use separate answer books for each section.

Values of physical constants are given at the end of sections.

Duration	3 hrs
No. of Answer books	2

Requirements:

Handout	
MCQ	
Statistical Tables	X Log tables
Graph Paper	
Log Graph Paper	
Other Material	

No. of Pages	5
Department(s)	Experimental Physics

SECTION A - EP213 MODERN PHYSICS

Q.1 Distinguish between Fresnel diffraction and Fraunhofer diffraction.[1 mark]

Using phasors, show that the Fraunhofer Diffraction pattern from a single slit is described by the expressions

$$I = I_0\left(\frac{\sin\alpha}{\alpha}\right)^2 , \quad \alpha = \frac{\pi a}{\lambda}\sin\theta$$

where a is the width of the slit and λ and θ have their usual meanings. [7 marks]

Helium-neon laser light of wavelength 633 nm, normally incident on a narrow slit, produces a diffraction pattern on a screen 1.50 m from the slit. If the central maximum of the diffraction pattern has a width of 3.00 mm, what is the width of the slit?

[2 marks]

Q.2 In Bohr's semi-classical model of the hydrogen atom, E_n, the energy of the nth allowed orbit in a hydrogenic atom, is given by

$$E_n = \frac{-Z^2 e^4 m_e}{8\varepsilon_0^2 h^2 n^2}$$

where the various symbols have their usual meanings.

(a) Describe how the Bohr model may be used to explain the line spectra of hydrogenic atoms. Show that the wavelengths of the spectral lines are given by the Rydberg formula, *i.e.*

$$\frac{1}{\lambda} = \frac{Z^2 e^4 m_e}{8\varepsilon_0^2 h^3 c}\left(\frac{1}{m^2} - \frac{1}{n^2}\right) = Z^2 R\left(\frac{1}{m^2} - \frac{1}{n^2}\right)$$

where R is the Rydberg constant, $m = 1, 2, 3$ ... and $n = m+1, m+2$ ... [5 marks]

(b) Calculate the wavelength of the longest-wavelength line in the Balmer series of He^+.

[1½ marks]

(c) Describe very briefly the origin of the K_α line in the x-ray spectrum of a Coolidge tube. State, and explain, any modification you would have to make to the Rydberg formula to use it to obtain the wavelength of the K_α line. [2 marks]

(d) Calculate the wavelength of the K_α x-rays in a Coolidge tube containing a molybdenum ($Z = 42$) target.

[1½ marks]

Q.3 Write down an expression for the relativistic momentum of a particle in terms of the mass of the particle and the velocity of the particle. [1 mark]

Show that the relationship between the total energy, E, and the momentum, p, of a relativistic particle is described by the equation

$$E^2 = p^2c^2 + m^2c^4$$

where m is the rest mass of the particle and c is the speed of light in a vacuum. [3 marks]

A charged pion (rest mass = $2.50\text{x}10^{-28}$ kg ≡ 140 MeV/c^2, proper lifetime = 26.0 ns) with a total energy of 180 MeV is produced in an accelerator experiment.

(i) Calculate the momentum of this pion. [2 marks]
(ii) Calculate its kinetic energy. [1 mark]
(iii) Calculate its lifetime in the accelerator's frame of reference. [1 mark]
(iv) Calculate its speed. [2 marks]

Q.4 (a) Explain clearly what are meant by alpha decay and beta decay. [2 marks]

(b) Derive an expression for the kinetic energy of an alpha particle in terms of the mass number of the parent nucleus and the total energy liberated in the decay process. [3½ marks]

(c) Explain why alpha particles produced in the decay of heavy nuclides have definite characteristic energies while electrons emitted in the beta decay of similar nuclides have a spectrum of energies. [2½ marks]

(d) $^{137}_{55}Cs$ decays spontaneously via a form of beta decay. Identify the type of beta decay occurring, giving the reason for your answer and showing the particles produced in this decay. (Note: Relevant atomic masses are: $^{137}_{55}Cs$ = 136.90707 u, $^{137}_{56}Ba$ = 136.90582 u, $^{137}_{54}Xe$ = 136.91173 u) [2 marks]

Physical Constants

Mass of electron, m_e	=	9.11×10^{-31} kg (≡ 511 keV/c^2)
Electronic charge, e	=	1.60×10^{-19} C
Planck's constant, h	=	6.63×10^{-34} J s
Velocity of light, c	=	3.00×10^{8} m s^{-1}
Permittivity of free space, ε_0	=	8.85×10^{-12} F m^{-1}
$e^4 m_e / (8\, \varepsilon_0^2\, h^2)$	=	13.6 eV (= 2.17×10^{-18} J)

SECTION B - EP214 THERMODYNAMICS

Q.5 Explain clearly the thermodynamic difference between: (i) closed systems *and* isolated systems; (ii) heat transferred from a system *and* work performed by a system. [2 marks]

At what temperature is the numerical value the same on

(i) both the Celsius and Fahrenheit scales? [1 mark]

(ii) both the Kelvin and Fahrenheit scales? [1 mark]

State Newton's law of cooling, and show that $\Delta T = \Delta T_0 e^{-At}$, where ΔT and ΔT_0 are the temperature differences between an object and its surroundings at time t and at time $t = 0$ respectively. [3 marks]

At 25°C, a hole in an aluminium plate has a diameter of 2.140 cm, and a steel ball has a diameter of 2.150 cm. What is the lowest temperature at which the ball will just fit through the hole? [3 marks]

Q. 6 Explain what are meant by the following terms: (i) molar heat capacity; (ii) equipartition principle. [2 marks]

Explain the differences between isothermal, isometric, and isobaric processes, and sketch a Pressure-Volume (P-V) diagram for each of these processes. [3 marks]

Show that the following relationship

$$W = \frac{1}{\gamma - 1}\left(P_i V_i - P_f V_f\right)$$

represents the work done in an adiabatic process for an ideal gas, where P is the pressure, V is the volume, γ is the ratio of molar specific heats at constant pressure and at constant volume, and the subscripts i and f denote the initial and final states respectively. [2 marks]

20.9 J of heat is added to a particular ideal gas. As a result, its volume changes from 63.0 cm^3 to 113 cm^3, while the pressure remains constant at 1.0 atmosphere.

(i) By how much did the internal energy of the gas change? [1 mark]

(ii) If the quantity of gas present is 2.00×10^{-3} moles, find the molar heat capacity at constant pressure. [1 mark]

(iii) Find the molar heat capacity at constant volume. [1 mark]

Q. 7 Explain the Second Law of Thermodynamics, with reference to two of the different statements of this Law. [2 marks]

Describe the operating cycle of a typical refrigerator. [3 marks]

Obtain an expression for the coefficient of performance of a refrigerator. [2 marks]

To make some ice, a freezer extracts 185 kJ of heat at −12°C. The freezer has a coefficient of performance of 5.70. The temperature of the room containing the freezer is 26°C.

(i) How much heat is delivered to the room? [1½ marks]

(ii) How much work is required to run the freezer? [1½ marks]

Q. 8 Explain the following terms used to describe properties of solid matter: (i) Bulk modulus; (ii) modulus of rigidity; (iii) elastic limit. [3 marks]

Explain clearly the differences between each of the following: (i) saturated air; (ii) unsaturated air; (iii) supersaturated air. Sketch each of them on a graph of vapour pressure versus temperature. [3 marks]

Show that the bulk modulus B for an adiabatic process involving an ideal gas can be given by $B = P\gamma$, where P is the pressure of the gas and γ is the ratio of its molar specific heats at constant pressure and constant volume. [2 marks]

Given the formula $P = P_0 e^{-0.1172\,(km^{-1})y}$ for the variation of pressure in the atmosphere, at what altitude does atmospheric pressure fall to 10% of its mean sea level value? [2 marks]

Physical Constants

Coefficient of linear expansion of aluminium	=	$23 \times 10^{-6}\ K^{-1}$
Coefficient of linear expansion of steel	=	$11 \times 10^{-6}\ K^{-1}$
Standard atmospheric pressure	=	$1.0125 \times 10^{5}\ N\,m^{-2}$
Universal gas constant	=	$8.314\ J\,mol^{-1}\,K^{-1}$