LANCASTER UNIVERSITY

2000 EXAMINATIONS

Part I

PHYSICS - Paper PH1.2

- *Candidates should attempt all those sections identified with the modules for which they are registered.*
- *The time allocated is 60 minutes per section.*
- *An indication of mark weighting (30 marks per section) is given by the numbers in square brackets following each part.*
- *In each section attempted, candidates should answer question 1 (10 marks) and either question 2 or question 3 (20 marks).*
- *Use a separate answer book for each section.*

PHYSICAL CONSTANTS

Planck's constant	h	=	6.63×10^{-34} J s
	$\hbar$	=	1.05×10^{-34} J s
Boltzmann's constant	k_B	=	1.38×10^{-23} J K^{-1}
Mass of electron	m_e	=	9.11×10^{-31} kg
Mass of proton	m_p	=	1.67×10^{-27} kg
Electronic charge	e	=	1.60×10^{-19} C
Speed of light	c	=	3.00×10^{8} m s^{-1}
Avogadro's number	N_A	=	6.02×10^{23} mol^{-1}
Permittivity of the vacuum	ϵ_0	=	8.85×10^{-12} F m^{-1}
Permeability of the vacuum	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
Gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
Bohr magneton	μ_B	=	9.27×10^{-24} J T^{-1} (or A m^{2})
Bohr radius	α_0	=	5.29×10^{-11} m
Gas constant	R	=	8.31 J K^{-1} mol^{-1}
Acceleration due to gravity	g	=	9.81 m s^{-2}
1 standard atmosphere		=	1.01×10^{5} N m^{-2}

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Section A: Module 103 - Thermal Properties of Matter

A1. (a) The molecular mass of nitrogen gas is $0.028\,\mathrm{kg\,mol^{-1}}$. Calculate the root mean square speed of a nitrogen molecule at room temperature (20°C). [2]

(b) The temperature of 2.00 moles of a monatomic ideal gas is changed from 400 K to 300 K by an unknown process. Calculate the change in the internal energy. [3]

(c) A domestic refrigerator has walls 2.0 cm thick and a total surface area of $3.0\,\mathrm{m^2}$. If the insulating material forming the walls has thermal conductivity $0.010\,\mathrm{W\,K^{-1}m^{-1}}$, calculate the power the refrigerator must be able to absorb in order to maintain a temperature of 4.0°C on a hot summer day (25.0°C). [2]

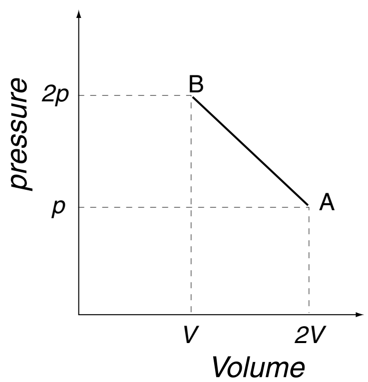
(d) An ideal heat engine operates between a hot reservoir at 30.0°C and a cold reservoir at 5.0°C. It absorbs 10.0 J from the hot reservoir per cycle. What is the energy rejected to the cold reservoir and how much work is done per cycle? [3]

A2. (a) State the 1st law of thermodynamics for an infinitesimal process. Define your sign convention. [2]

(b) State the work done in an infinitesimal volume change. [2]

(c) Describe what is (i) an isothermal process, (ii) an adiabatic process. On the same p-V diagram, sketch a possible path for each process which passes through the point (p_1, V_1). [5]

(d) One mole of a monatomic ideal gas undergoes a (non-isothermal, non-adiabatic) process such that the path from point A $(p, 2V)$ to point B $(2p, V)$ is a straight line on the pressure-volume diagram, as below.



(i) Give an expression for the temperature at A and determine the temperature at B relative to A. [2]

(ii) Calculate the change in the internal energy. [1]

(iii) Deduce an expression for the work done in the process in terms of p and V and show that this can be written as $W = -\frac{3}{4}RT$, [5]

(iv) and hence calculate the total heat flow during the process. What is the direction of this heat flow? [3]

A3. (a) Define:

(i) the specific heat capacity, [1]

(ii) the latent heats of fusion, vaporisation and sublimation. [3]

(b) Sketch the form of the p-V diagram for water. Discuss the major features of the diagram. [4]

(c) Heat is supplied at a constant rate to an initially solid sample so that it ultimately changes phase to a vapour. The pressure is maintained at a constant value. Explain, and sketch, how the temperature varies as a function of time for the three different possible sequences of phase changes. Indicate these paths on a p-V diagram. [5]

(d) A solid sample of 0.40 kg of ice at -20.0°C is in an open container of negligible heat capacity. Power is provided at a constant rate of 1.50 kW. Calculate:

(i) the heat required to empty the container, [4]

(ii) how long this takes. [1]

Determine the time required if the container were to have a heat capacity of 30.0 $\mathrm{J\,K^{-1}}$.

[2]

You may assume the following data:

Specific Heats ($\mathrm{J\,K^{-1}kg^{-1}}$)	Ice	2000
	Water	4190
Latent Heats ($\mathrm{J\,kg^{-1}}$)	Fusion	334×10^3
	Evaporation	2256×10^3

Section B: Module 104 - Mechanical Waves and Sound

B1. (a) What conditions are required for a system to undergo Simple Harmonic Motion (SHM)? [2]

(b) At what points in SHM are (i) the potential energy (ii) the kinetic energy separately a maximum? When are they equal? [2]

(c) Define the terms (i) longitudinal (ii) transverse as applied to mechanical wave motion. [2]

(d) Define frequency, wavelength and phase velocity for a mechanical wave. [2]

(e) State the principle of superposition as applied to mechanical waves. [2]

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B2. (a) Give expressions for the phase velocity of transverse v_T waves on a string, and longitudinal waves v_L in a rod. Define all symbols used. [4]

(b) Mechanical waves, one longitudinal and one transverse, propagate on the same rod. For the waves to have the same velocity show that the tensile stress in the rod must be numerically equal to Y, Young's Modulus. Why is it unlikely that such a stress could be set up? Explain why in practice, v_T is usually less than v_L. [4]

(c) A string of mass μ_1 per unit length extends from $x = -\infty$ to $x = 0$ where it is joined to a second string of mass μ_2 per unit length which extends from $x = 0$ to $x = +\infty$. A tension F is established in the strings.

(i) A pulse propagates from $x = -\infty$ in the positive x-direction along the string of mass μ_1 per unit length. Discuss what happens to this pulse at $x = 0$ in the three special cases

1) $\mu_1 = \mu_2$,

2) $\mu_2 = 0$, i.e. the end of the first string is essentially free

3) $\mu_2 = \infty$, i.e. the second string is effectively immovable. [4]

(ii) Consider now the case where $\mu_2 = 4\mu_1$. Describe, illustrating your answer with appropriate diagrams, the form of the displacement of the strings before, during and after the pulse arrives at $x = 0$. [4]

(iii) Sinusoidal waves of amplitude A are sent from $x = -\infty$ along the string in the positive x-direction. Describe the resultant wave motion seen on the strings when $\mu_2 = 4\mu_1$. [4]

B3. Define the terms *standing wave*, *node* and *anti-node* in the context of waves in a pipe containing a gas and closed at both ends. Give your definitions in terms of the displacement of the gas molecules. [4]

Such a pipe is able to maintain a series of standing waves. Sketch and explain the five lowest frequency modes. Derive a general expression for the possible frequencies. [4]

The displacement of the molecules causes pressure variations in the gas. Describe the same five modes in terms of pressure waves. Use pressure waves to derive a general expression for the possible standing wave frequencies in a pipe open at one end and closed at the other. [4]

Give an expression for the phase velocity of longitudinal waves in a gas in terms of its mechanical properties. Use this expression to show that for an ideal gas the wave velocity $v \propto \sqrt{T}$. [4]

Two identical tubes, closed at both ends, are filled with gas at the same pressure. One tube is maintained at a constant temperature T_1 and the other at a variable temperature T which is initially set at T_1. Each tube is excited at its fundamental frequency. Describe the nature of the combined sound which is heard as the temperature T is gradually raised. [4]

Section C: Module 105 - Electric and Magnetic Fields

C1. (a) Why do lightning conductors have sharp points on top? [2]

(b) An electric field is produced by two point charges, one of magnitude $+Q$ at $x = +a$ and the other of magnitude $-Q$ at $x = -a$. Find (i) the electric field at $x = 0$ and (ii) the potential at $x = 0$. [3]

(c) Explain from first principles why $C = C_1 + C_2$ is the correct formula for combining two capacitors in parallel. [2]

(d) Use Faraday's law and a sketch diagram to explain briefly how a coil rotating in a magnetic field can be arranged to generate an alternating voltage. [3]

C2. (a) Gauss's law relates the electric flux out of a closed surface to the charge inside the surface. Explain what is meant by *electric flux* out of a surface. [2]

(b) A thin spherical metal shell (shell A) of outer radius R carries a charge Q. Find the electric field E produced by the charge at any distance r from the centre of the sphere. You should consider the cases $r < R$ and $r > R$ separately. [5]

(c) A second thin spherical metal shell (shell B) of radius $2R$ and carrying charge $-2Q$ is now placed carefully around the first shell, without the spheres touching at any time. The two spheres are arranged to have the same centre. Giving your reasoning fully, find:

(i) the electric field $E(r)$ for the different regions of r, [4]

(ii) the charge distribution on the outer sphere, [3]

(iii) the potential difference $(V_A - V_B)$ between the two spheres (magnitude and sign). [6]

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C3. The Lorentz force law for a charged particle in electric and magnetic fields states that

$$F = q(\underline{E} + \underline{v} \times \underline{B})$$

where the symbols have their usual meanings. Use it to discuss the following.

(a) When an electron moves in a region of uniform magnetic field B, it does so (i) at constant speed (ii) in a helical (corkscrew) path. Explain these observations, and give a sketch. [6]

(b) A *velocity selector*, designed for a beam of electrons moving in the x-direction, can be arranged by having an electric field in the y-direction and a magnetic field in the z-direction.

(i) Explain how the device works, and give a formula for the velocity of electrons which continue undeviated in the x-direction. [4]

(ii) Make a sketch which shows clearly the polarity of the fields. Would the same arrangement work for protons of the same velocity? (Protons have opposite charge to electrons and are heavier.) [4]

(iii) The electron beam is produced by accelerating electrons from rest through an accelerating voltage of 2000 V. A magnetic field of 0.03 T is available, and the electric field in the selector is provided using plates which are 3 mm apart. Calculate the voltage which should be applied to these plates for the majority of the electrons to pass through. [6]