LANCASTER UNIVERSITY

2000 EXAMINATIONS

Part I

PHYSICS - Paper PH1.1

- *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 101 - Fundamental Mechanics

A1. (a) A particle starts from rest at the origin at time $t = 0$ and moves with a displacement given by: $s = 3t + 2t^2 + t^5$. Calculate its speed and acceleration after 2 seconds. [2]

(b) Find the resultant magnitude of the two forces $\underline{\boldsymbol{F}}_a = 2\underline{\boldsymbol{i}} + \underline{\boldsymbol{j}} + 3\underline{\boldsymbol{k}}$ and $\underline{\boldsymbol{F}}_b = \underline{\boldsymbol{i}} + 2\underline{\boldsymbol{j}} - \underline{\boldsymbol{k}}$ acting on a particle. [2]

(c) A non-constant force given by $F(x) = 18x^5 + 8x - 2$ moves a body along the x-axis, from $x = 0$ to $x = 1$. Calculate the work done by the force. [3]

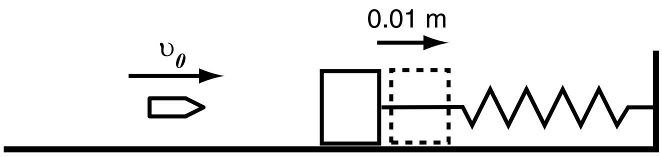
(d) The potential energy of a body is given by $U = x^2+3y^2-z^3$. If the magnitude of the acceleration of the body at (1, 1, 1) is determined to be $14.0\,\mathrm{ms}^{-2}$, calculate the mass of the body. [3]

A2. Explain what is meant by the terms *impulse, elastic collision*, and *inelastic collision.* [3]

Write down a general expression for the impulse J associated with a non-constant force F acting for a time interval from t_1 to t_2. [3]

With the aid of a diagram distinguish between the two cases of a 'hard' collision and a 'soft' collision. [2]

A block of mass 0.99 kg rests on a horizontal frictionless surface and is attached to a spring of spring constant $k = 200\,\mathrm{Nm}^{-1}$, as shown in the diagram below. A rifle bullet of mass 0.01 kg strikes and embeds itself in the block. The impact compresses the spring 0.010 m.



Find

(a) the magnitude of the velocity of the block and bullet just after impact, and

(b) the initial speed v_0 of the bullet. [6]

In another experiment, a 2.00 g bullet travelling horizontally with a speed of $500\,\mathrm{ms}^{-1}$ is fired into a wooden block of mass 1.00 kg, initially at rest on a level surface. The bullet passes through the block and emerges with its speed reduced to $100\,\mathrm{ms}^{-1}$. If the block slides a distance of 0.30 m along the surface from its original position, what is the coefficient of kinetic friction between the block and the surface? [6]

A3. Explain what is meant by *instantaneous velocity.*

How are instantaneous velocity and acceleration related to displacement? [4]

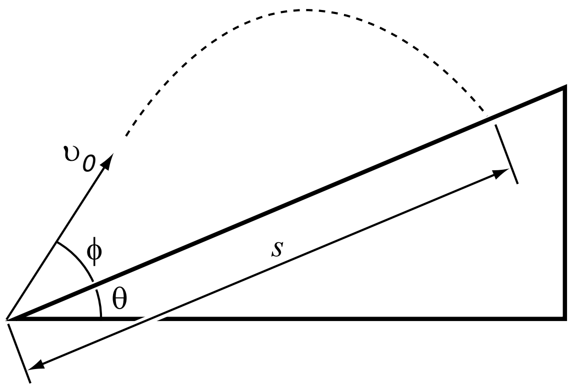
A book slides off a table top with a horizontal speed of $3.60\,\mathrm{ms}^{-2}$. It strikes the floor after $0.500\,\mathrm{s}$. Find

(a) The height of the table top above the floor.

(b) The horizontal distance from the edge of the table to the point where the book strikes the floor.

(c) The horizontal and vertical components of the book's velocity and the magnitude and direction of its velocity at the instant it reaches the floor. [6]

A projectile is given an initial velocity of magnitude v_0 at an angle of ϕ above the surface of an incline, which in turn is inclined at an angle θ above the horizontal.



Show that the distance s, measured along the incline from the launch point, to where the object strikes the incline is given by:

$$s = \frac{2v_0^2\cos^2(\phi+\theta)}{g\cos\theta}(\tan(\phi+\theta)-\tan\theta). \qquad [5]$$

Given that s can also be written as

$$s = \frac{2v_0^2\sin\phi}{g\cos\theta}(\cos\phi-\tan\theta\sin\phi),$$

find the angle ϕ which gives the maximum range along the incline. [5]

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Section B: Module 102 - Mechanics of Real Systems

B1. (a) Define Young's modulus. [2]

(b) A bone has a Young's modulus of $10^{10}\,\mathrm{Nm}^{-2}$. It fractures when the compressive strain exceeds 1%. What is the maximum load it can sustain if the bone has a cross-sectional area of $3\,\mathrm{cm}^2$. [3]

(c) If the ice cap covering the Antarctic landmass were to melt, global sea-level would rise. However, if the ice cap covering the Arctic Ocean were to melt, sea-level would not rise. Explain why this would happen. [3]

(d) Give Bernoulli's law, defining all the terms in the equation. [2]

B2. A spherical planet has uniform density, a mass M and a radius R. Using Newton's law of Gravity, derive an expression for the acceleration due to gravity at the planet's pole. [4]

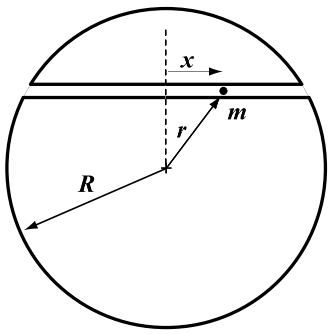
Given that the planet is of uniform density, show that the mass $M(r)$ contained within a radius r is given by $M(r) = Mr^3/R^3$. [2]

At a radius $r < R$ the gravitational potential energy is given by

$$V(r) = -\frac{GM(r)m}{r}.$$

(a) Give the relation between the force on a mass m and its potential energy, [2]

(b) and thereby obtain the acceleration due to gravity at a radius $r < R$. [3]



A tunnel (which does **not** pass through the centre of the planet) is made through the planet as shown in the figure above. A body is dropped down this tunnel.

(a) Indicate with a sketch the force acting on the body at the position shown in the diagram. [1]

(b) Express the acceleration of the body dropped down the tunnel as a function of the distance x from the centre of the tunnel, and [2]

(c) prove that the motion executed is simple harmonic in nature. [3]

(d) What is the period of the motion? [3]

B3. The angular displacement θ of a solid rotating body at time t is given by

$$\theta(t) = at + bt^2 - ct^4$$

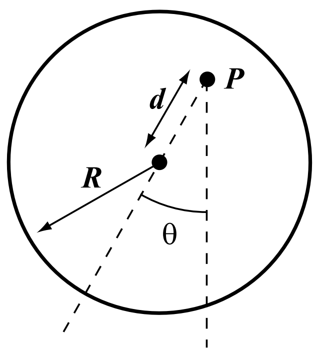
Define the instantaneous angular velocity and the instantaneous angular acceleration. Give their values at time t for the above angular displacement θ. [4]

Define the moment of inertia of a point mass m_i with respect to an axis. [2]

A disk mass M, radius R is free to turn about an axis through its centre and perpendicular to the disk.

(a) Show that the moment of inertia of the disk about the axis through its centre and perpendicular to the disk is $MR^2/2$. [4]

(b) What is the moment of inertia of the disk about an axis P parallel to the original axis but displaced a distance d from the centre? [4]



The disk is suspended vertically from the point P. It is then slightly displaced so that it swings with an angle θ to the vertical.

(a) Show that the angular motion is approximately Simple Harmonic. [4]

(b) Give the period for the motion in terms of d, M, R and g. [2]