The University of Nottingham

SCHOOL OF PHYSICS & ASTRONOMY

A LEVEL 1 MODULE, SPRING SEMESTER 2010-2011

FROM NEWTON TO EINSTEIN – PAPER 1

Time allowed TWO Hours

Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced.

Answer FOUR out of Six Questions

Only silent, self contained calculators with a Single-Line Display or Dual-Line Display are permitted in this examination.

Dictionaries are not allowed with one exception. Those whose first language is not English may use a standard translation dictionary to translate between that language and English provided that neither language is the subject of this examination. Subject specific translation dictionaries are not permitted.

No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.

*An indication is given of the approximate weighting of each part of a question by means of a bold figure enclosed by curly brackets, e.g. {**2**}, immediately following that part.*

DO NOT turn examination paper over until instructed to do so

ADDITIONAL MATERIAL : Moments of Inertia Formula Sheet

Speed of light in free space	c	$3.00\text{x}10^{8}$ m s^{-1}
Gravitational constant	G	$6.67\text{x}10^{-11}$ N m^{2} kg^{-2}
Planck's constant	h	$6.63\text{x}10^{-34}$ J s
	$\hbar$	$1.055\text{x}10^{-34}$ J s
Elementary charge	e	$1.60\text{x}10^{-19}$ C
Mass of electron	m_e	$9.11\text{x}10^{-31}$ kg
Mass of proton	m_p	$1.6726\text{x}10^{-27}$ kg
Mass of neutron	m_n	$1.6749\text{x}10^{-27}$ kg
Boltzmann's constant	k_B	$1.38\text{x}10^{-23}$ J K^{-1}
Gas constant	R	8.31 J K^{-1} mol^{-1}
Permittivity of free space	ε_0	$8.85\text{x}10^{-12}$ F m^{-1}
Permeability of free space	μ_0	$4\pi\text{x}10^{-7}$ H m^{-1}
Bohr magneton	μ_B	$9.27\text{x}10^{-24}$ J T^{-1}
Stefan-Boltzmann constant	σ	$5.67\text{x}10^{-8}$ W m^{-2} K^{-4}
Avogadro's number	N_A	$6.02\text{x}10^{23}$ mol^{-1}

Turn over

You must answer 4 out of 6 questions.
You should aim to spend about 30 minutes on each question.

1. (a) A ball starts its motion from the top of a frictionless incline of length l = 25 m. The initial velocity of the ball is v_0 = 0 ms^{-1}. The velocity of the ball at the bottom of the incline is v = 10 ms^{-1}. Find the angle θ of the incline. {**5**}

   (b) A typical Ferris wheel has a radius r = 10 m and rotates two times per minute. Find the magnitude of the acceleration experienced by a rider on the wheel and sketch the direction of the rider's velocity and acceleration. {**5**}

   (c) A ball rolls along the frictionless track shown in Fig. Q1. Each segment of the track is straight and the ball passes smoothly from one segment to the next without leaving the track. Draw three vertically stacked graphs showing acceleration (a_s) {**5**}, velocity (v_s) {**5**} and position (s) {**5**} versus time (t). Each graph should have the same time axis.

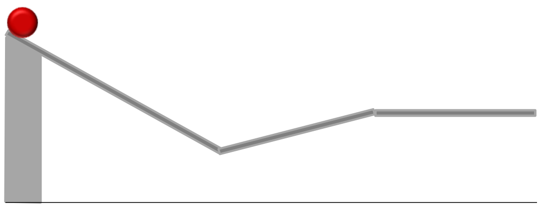

Fig. Q1

2. An ice skater of mass, M, is spinning about a vertical axis through the centre of his body at angular speed ω.

   (a) State equations which describe the angular momentum of a particle in terms of (i) linear and (ii) angular velocity. {**4**}

   (b) Calculate the new angular speed of rotation which results if the skater suddenly crouches. Assume that an ice skater can be approximated by a cylinder of radius *a* when standing and radius *2a* when crouching. {**6**}

   (c) Calculate the change in kinetic energy of the skater when he crouches. {**5**}

   (d) Two identical ice skaters skate towards each other with speed v on parallel paths such that their bodies are separated by a constant distance d. When they are level with each other they lock hands so that they spin in a circle of radius $d/2$. Show the angular speed of rotation of the skaters after they join hands is:

$$\omega = \frac{vd}{\left(a^2 + \frac{1}{2}d^2\right)} \qquad \{\mathbf{10}\}$$

3. (a) State Newton's 2nd and 3rd Laws, including mathematical equations. {**4**}

A block of mass 30 kg rests 12 m from the bottom of an inclined plane that is at an angle of 60^0 to the horizontal. It is connected by a rope of negligible mass via a frictionless pulley to a bucket of mass 5 kg of water, hanging vertically as shown in Fig. Q3. The static and dynamic coefficients of friction between the block and the plane are 0.7 and 0.4, respectively. Water leaks from the bucket at a constant rate of 20 g s^{-1}.

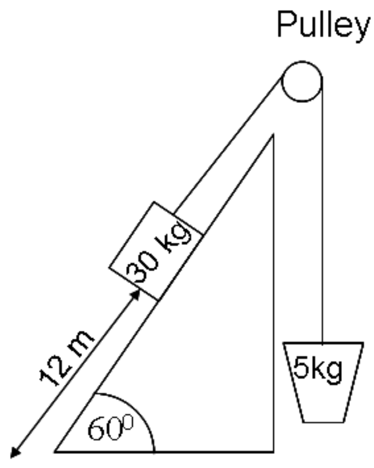

Fig. Q3

(b) Show that the block will not initially move up or down the incline {**10**}. Calculate the time for the block to begin to move. {**3**}

(c) Calculate the initial acceleration of block A. {**3**}

(d) Calculate the time taken by the block to reach the bottom of the incline, justify any assumptions. {**5**}

4. (a) A mass *M* on a spring oscillates with a period T of 0.8 s and an amplitude A of 0.02 m. At time t = 0 s, the object is 0.01 m to the left of the equilibrium position and is moving to the left.

i) Find the position of the mass *M* at t = 2.0 s. {**5**}
ii) Find the direction of motion at t = 2.0 s. {**2**}

(b) A rod of length L = 0.02 m swings on a hook with a period T of 0.9 s. Its centre of mass is at a distance l = 0.015 m from the hook. When the rigid body hangs from a spring of spring constant 360 Nm^{-1}, it stretches the spring by 0.003 m.

i) Write down the equation of motion for the swinging object in the approximation of small oscillations, and derive an expression for the angular frequency of these oscillations. {**10**}
ii) Find the mass, *M*, of the rod. {**4**}
iii) Find the moment of inertia, I, of the rod about the hook. {**4**}

Turn over

5. (a) State how the motion of a rigid body can be analysed on a flat, uniform plane, and derive the velocity of the centre of mass. {**5**}

A solid cylinder of mass M and radius R released from rest from the top of a ramp of length L and height h, rolls without slipping due to the frictional force f between the cylinder and the ramp.

(b) Find the speed of the centre of mass of the cylinder when it reaches the bottom of the ramp from conservation of energy. {**7**}

(c) Estimate the torque acting on the cylinder and hence show that the frictional force is given by:

$$f = \frac{1}{2} M a_{cm} \quad , \qquad \{\mathbf{8}\}$$

where a_{cm} is the acceleration of the centre of mass.

(d) Use your answer from (b) and force considerations to estimate the speed of the centre of mass of the cylinder when it reaches the bottom of the ramp. {**5**}

6. (a) A transverse wave on a stretched string is defined by the equation

$$y(x,t) = 0.2\cos[6\pi(x-t)],$$

where time t is measured in seconds, and x and y in metres. Find

i) the wavelength of the wave, {**2**}
ii) the angular frequency of the wave, and {**2**}
iii) the speed of the wave. {**2**}
iv) For time t = 0 s, sketch how y varies with x and indicate on the graph the direction of propagation of the wave for t > 0 s. {**4**}

(b) Find the two longest wavelengths and corresponding frequencies for standing sound waves in a tube of length 0.12 m that is:

i) open at both ends; {**5**}
ii) open at one end, closed at the other end. {**5**}
iii) Draw the fundamental mode for the pressure wave in the case of an open-closed and an open-open tube. {**5**}

[Assume a speed of sound v_s= 340 ms^{-1}]

End