NATIONAL UNIVERSITY OF SINGAPORE

DEPARTMENT OF PHYSICS

ADVANCED PLACEMENT TEST
(SAMPLE)

PC1431 PHYSICS IE

MMM-YYYY---Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES

1. This paper contains **six short** questions in Part I and **three long** questions in Part II. It comprises **9** printed pages including this one.

2. The total marks for Part I is 24 and that for Part II is 36.

3. This is a **CLOSED BOOK** test.

4. **Non-Programmable calculator** is allowed to be used.

5. Answer **ALL** questions.

6. Answers to the questions are to be written in the answer booklets.

7. A list of constants and some formulas are given on Page 2.

List of Constants and Formulas

Free-fall acceleration, $g = 9.80\ \mathrm{m\,s^{-2}}$

Moment of inertia of a hollow cylinder about its long axis of symmetry is $I = \frac{1}{2}M(R_1^2 + R_2^2)$

Moment of inertia of a uniform disk about its axis of symmetry is $I = \frac{1}{2}MR^2$

Moment of inertia of a rod about its centre of mass is $I = \frac{1}{12}ML^2$

Specific heat of water, $c = 4190\ \mathrm{J\,kg^{-1}K^{-1}}$

$$\int x^\alpha dx = \begin{cases} \dfrac{x^{\alpha+1}}{\alpha+1} & (\alpha \text{ is real, } \alpha \neq -1) \\ \ln x & (\alpha = -1) \end{cases}$$

$$ax^2 + bx + c = 0 \text{ has roots } x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

PART I

This part of the examination paper contains **six** short-answer questions from pages 3 to 5. **4 marks each**. Answer **all** questions.

1. A pendulum, comprising a string of length L and a small sphere, swings in the vertical plane. The string hits a peg located a distance d below the point of suspension.

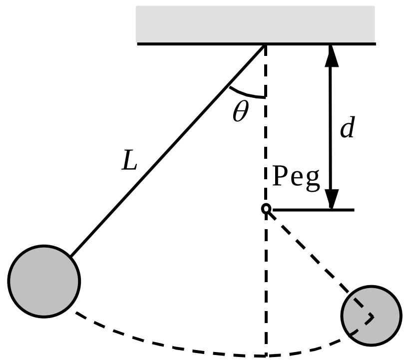

Figure 1

(a) Explain why if the sphere is released from a height below that of the peg, it will return to this same height after striking the peg. [1]

(b) If the pendulum is released from the horizontal position ($\theta = 90^\circ$) and is to swing in a complete circle centered on the peg, find the minimum value of d to keep the string taut throughout its motion. [3]

2. An amusement park ride consists of a large vertical cylinder that spins about its axis fast enough that any person inside is held up against the wall as shown in Figure 2. The coefficient of static friction between person and wall is μ_s, and the radius of the cylinder is R.

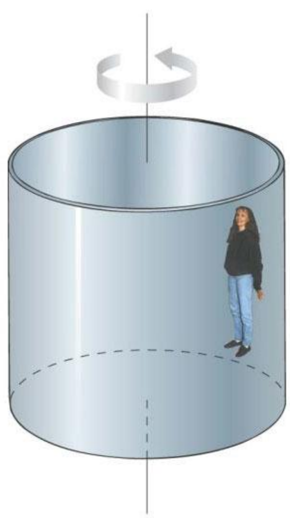

Figure 2

(a) Find the maximum period of revolution necessary to keep the person from falling down. [2]

(b) If the rate of revolution of the cylinder is increased from the value computed in (a), what happens to the motion of the person in the vertical direction? Explain. [2]

3. A point mass m = 0.25 kg is attached to a string which passes through a hole in a horizontal, frictionless table. It is rotating in a circle of radius r = 0.75 m with velocity v = 25 m/s.

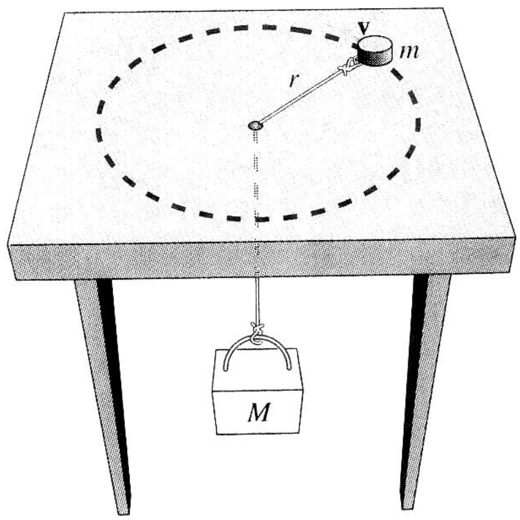

Figure 3

(a) What mass M must be attached to the end of the string under the table to maintain this motion? [1]

(b) Suppose that mass M is slowly increased by an amount that makes it descend 0.10 m. Calculate this change in M. [3]

4. A uniform disk, of mass M and radius R, is pivoted about a point P on its edge. It is lifted to one side such that its centre of mass O is at the same level as the pivot as shown in the Figure 4.

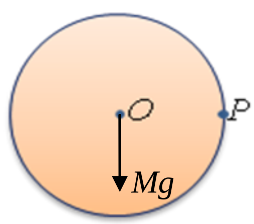

Figure 4

(a) What is the angular acceleration of the disk immediately after the disk is released from this position? [2]

(b) When O passes directly below the pivot, what is the linear velocity of its centre of mass? [2]

5. An ideal gas of volume V_0 and pressure p_0 undergoes an adiabatic expansion until the pressure drops to $p_0/8$.
   (a) What is the final volume? [2]
   (b) How much work is done? [2]
   Express your answers in terms of $\gamma\,(=C_p/C_V)$, V_0, and p_0.

6. A kilogram of water at $0^\circ\mathrm{C}$ is brought into contact with a heat reservoir at $100^\circ\mathrm{C}$. When the water has reached $100^\circ\mathrm{C}$, what is the total entropy change of the water and the heat reservoir? [4]

END OF PART I

PART II

This part of the examination paper contains **three** long questions from pages 6 to 9. **12 marks each**. Marks allocated to each part of a question are given within the square brackets. Answer **all three** questions.

7. Two gliders are set in motion on a horizontal *frictionless* air track. A light spring of force constant k is attached to the rear side of one glider. The first glider of mass m_1 has velocity $\mathbf{v}_1$ and the second glider of mass m_2 moves more slowly, with velocity $\mathbf{v}_2$, as shown in Figure 5. When m_1 collides with the spring attached to m_2 and compresses the spring to its maximum compression x_{max}, the gliders will move with a common velocity $\mathbf{v}$.

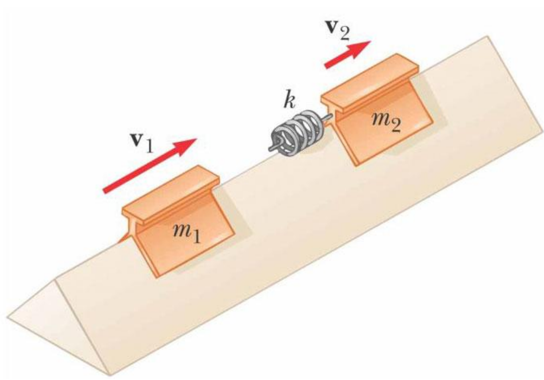

Figure 5

In terms of $\mathbf{v}_1$, $\mathbf{v}_2$, m_1, m_2, and k, find

(a) the velocity $\mathbf{v}$ at maximum compression. [2]

(b) the maximum compression x_{max} . [3]

(c) the velocity of each glider after m_1 has lost contact with the spring. [5]

(d) the condition under which the gliders end up exchanging velocities in the end. [2]

8. A wheel, as shown in the Figure 6, is constructed with the following parts.
   (1) The rim, of mass 8.0 kg, is made of a circular strip with outer radius R and inner radius 0.80 R.
   (2) The inner hub is a uniform cylinder of radius 0.20 R with mass of 4.0 kg.
   (3) There are 12 spokes connecting the inner hub to the rim. You may treat them as thin rods of length 0.60 R with mass of 1.0 kg each.

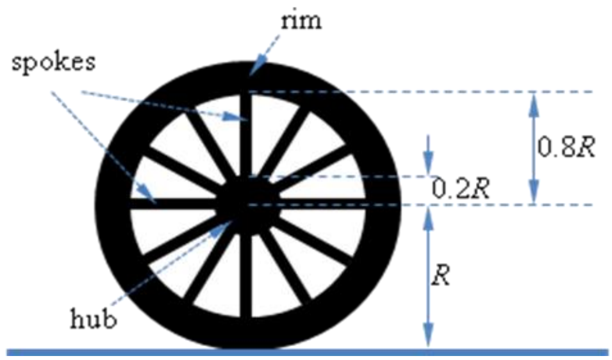

Figure 6

(a) Find the moment of inertia of this wheel about its symmetric axis perpendicular to the wheel. Express your final answer in the form: $I = cMR^2$, where M is the total mass of the whole wheel and c is a value you need to determine. [3]

(b) The wheel rolls without slipping down an inclined plane with $\theta = 30°$.

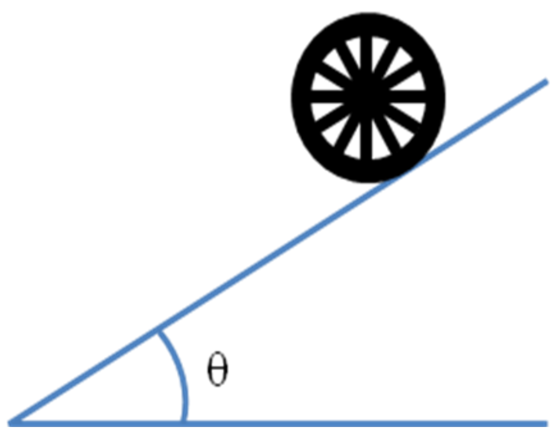

Figure 7

Find
(i) the acceleration of its centre of mass and
(ii) the friction that acts on the wheel. [3]

(c) A thin rope is wound around the hub and the free end leaves the hub at its bottom as shown in Figure 8.

Figure 8

When the rope is pulled to the right with a force of 150 N, what is the acceleration (magnitude and direction) of the centre of mass of the wheel? You may assume that the wheel rolls without sliding. [3]

(d) The wheel, with some rope wound around the hub, is now placed on the inclined plane. The rope is taut and parallel to the plane. Its free end is tied to a fixed support on the plane as shown in Figure 9.

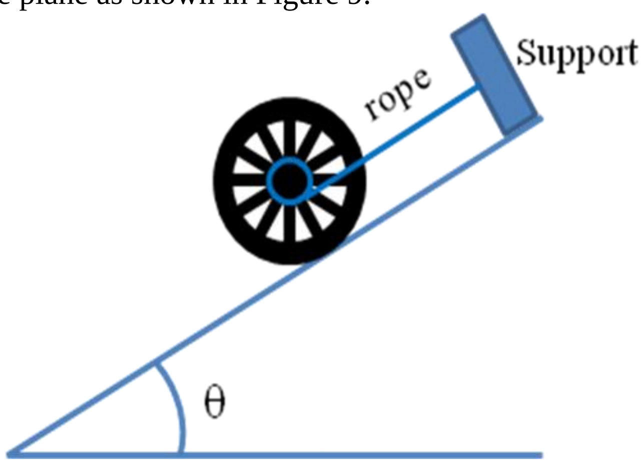

Figure 9

Will the wheel move along the plane? If so, calculate the acceleration of its centre of mass. If not, justify your answer with the values of the relevant quantities. You may assume the coefficients of static and kinetic friction between the wheel and the surface to be 0.40 and 0.30 respectively. [3]

9. Figure 10 represents a **heat engine cycle** involving an ideal gas.

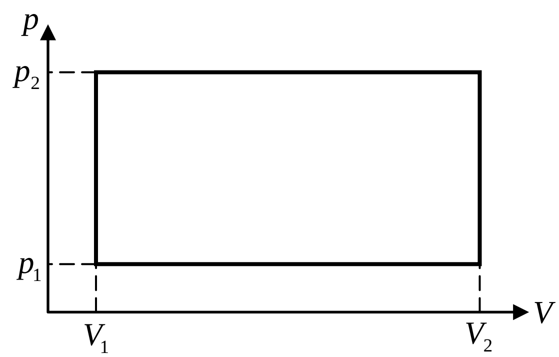

Figure 10

Calculate

(a) the work done W in one cycle. [1]

(b) the total amount of heat Q_H flowing into the gas in one cycle. [3]

(c) the total amount of heat Q_C flowing out of the gas in one cycle. [3]

(d) $Q_H + Q_C - W$ in one cycle. [1]

Express your answers in terms of p_1, V_1, p_2, V_2, R, C_V, and C_p.

Now suppose $p_2 = \alpha p_1$ and $V_2 = \alpha V_1$, where α is a constant greater than 1.

(e) Find the thermal efficiency e of this engine. [2]

(f) If the above cycle can be **reversed**, find the coefficient of performance K of the corresponding **refrigerator**. [2]

Express your answers in terms of α and $\gamma (= C_p / C_V)$ only.

END OF PART II