SINGAPORE JUNIOR PHYSICS OLYMPIAD 2012
SPECIAL ROUND

25 August, 2012

9:00 – 12:00 noon

Time Allowed: THREE HOURS

INSTRUCTIONS

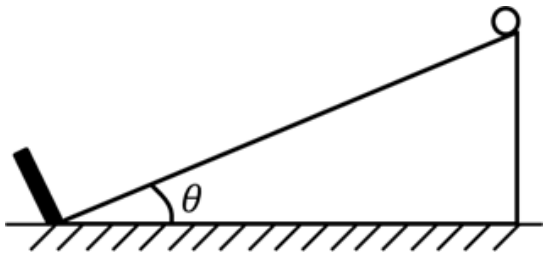
1. This paper contains **10** structural questions and **8** printed pages.
2. The mark for each question is indicated at the end of the question.
3. Answer **ALL** the questions in the booklets provided. Answers for **Questions 1 – 5** are to be written in the booklets labelled **A** while answers to **Questions 6 – 10** are to be written in the booklets labelled **B**.
4. Scientific calculators are allowed in this test.
5. A table of information is given in page 2. Not all information will be used in this paper.

TABLE OF INFORMATION

Acceleration due to gravity at Earth surface, g	=	$9.80\ \mathrm{m/s^2}$
Universal gas constant, R	=	$8.31\ \mathrm{J/(mol \cdot K)}$
Newton's gravitational constant, G	=	$6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$
Vacuum permittivity, ϵ_0	=	$8.85 \times 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}$
Vacuum permeability, μ_0	=	$4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$
Speed of light in vacuum, c	=	$3.00 \times 10^{8}\ \mathrm{m/s}$
Speed of sound in air, v	=	$331\ \mathrm{m/s}$
Charge of electron, e	=	$1.60 \times 10^{-19}\ \mathrm{C}$
Planck's constant, h	=	$6.63 \times 10^{-34}\ \mathrm{J \cdot s}$
Mass of electron, m_e	=	$9.11 \times 10^{-31}\ \mathrm{kg}$
Mass of proton, m_p	=	$1.67 \times 10^{-27}\ \mathrm{kg}$
Boltzmann constant, k	=	$1.38 \times 10^{-23}\ \mathrm{J/K}$
Avogadro's number, N_A	=	$6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
Density of water, ρ_{water}	=	$1.00 \times 10^{3}\ \mathrm{kg/m^3}$
Density of aluminium	=	$2.70 \times 10^{3}\ \mathrm{kg/m^3}$
Standard atmospheric pressure	=	$1.01 \times 10^{5}\ \mathrm{Pa}$

Please use booklets labelled 'A' for Questions 1 – 5

1. As shown in the figure below, a ball slides along a frictionless ramp of length L. As it reaches the bottom, it hits the board and slides up along the slope again. If the speed of the ball after the collision is 4/5 times of the speed of the ball just before the collision, find the total distance travelled by the ball when it comes to a complete stop. [8]

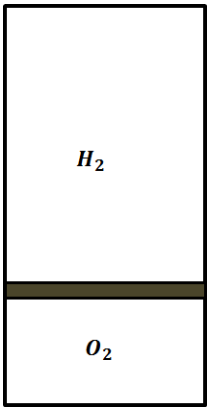


2. An aluminium block of mass m is hung from a steel wire of length L in air. The fundamental frequency for transverse standing waves on the wire is 300 Hz.

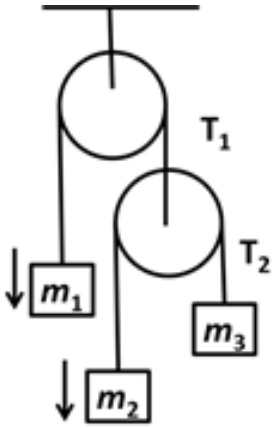
   (a) If the diameter of the wire is doubled, what is the new fundamental frequency.

   (b) Using the original wire, the block is then immersed in water so that half of its volume is submerged. What is the new fundamental frequency? (You may assume that the mass of the wire is small compared to the mass of the block and the change in length of the wire under different loads is negligible.) [8]

3. An enclosed, upright cylinder as shown on the right has a movable, frictionless massive piston of the same area as its base. The piston divides the cylinder into 2 compartments, one containing hydrogen gas and the other containing oxygen gas. The piston is also a good conductor of heat and does not leak. The compartment above the piston contains 1.5 moles of hydrogen gas and the compartment below contains 1 mole of oxygen gas. The two gases have the same temperature throughout. It is known that at 320 K, the volume of the hydrogen gas is 4 times that of oxygen gas. At what temperature would the volume of the hydrogen gas be 3 times that of the oxygen gas? [10]



4. Three objects are connected through pulleys and strings as shown in graph.



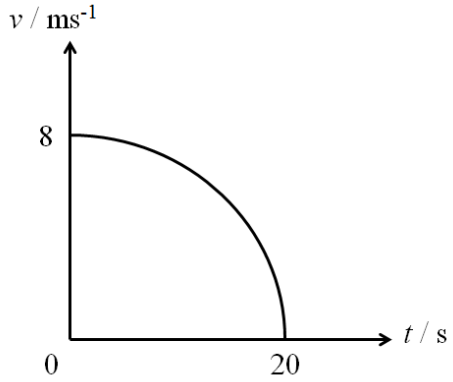
Assuming massless pulleys and frictionless surfaces everywhere, find

(a) the acceleration of m_1 and

(b) the tensions T_1 and T_2. [8]

5. (a) An ant is leaving its nest along a straight line, with its velocity inversely proportional to the distance away from the nest. When it is 1.0 m away, its velocity is 2.0 cm/s. How long will it take for the ant to travel 1.0 m further?

(b) A point mass is moving along a straight line. The velocity-time graph happens to be a quarter of a circle, tangential with t and v axes at 20 s and 8 m/s respectively as shown below.



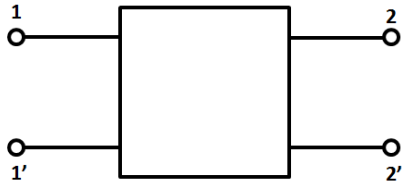
i. What is the displacement of the point mass in 20 s?

ii. What is the acceleration at 10 s? [11]

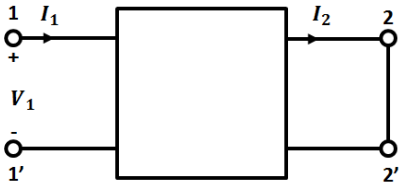
Please use booklets labelled 'B' for Questions 6 – 10

6. A research vessel has a round glass window in the bottom for observing the seabed. The diameter of the window is 60 cm, the thickness of the glass is 20 mm, and the index of refraction of water is 1.33; that of the glass is 1.55. The seabed is 6.0 m beneath the window. Estimate the area of the seabed that can be seen through the window. [8]

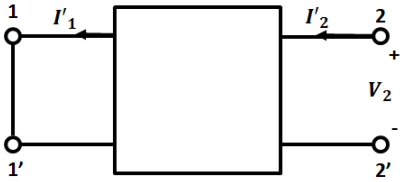
7. A black box of resistors is made up of a configuration of resistors. As shown below, there are 4 electrical leads from the black box (1, 1′, 2, 2′).



I. When 2-2′ are shorted and a potential of 9.0 V is applied across 1-1′, a current of $I_1 = 3.0$ A, $I_2 = 3.0$ A and direction of the current is as given below.

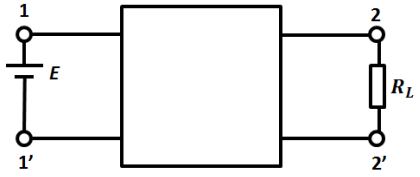


II. When 1-1′ are shorted and a potential of 3.0 V is applied across 2-2′, a current of $I_1' = 1.0$ A, $I_2' = 1.5$ A and direction of the current is as given below.



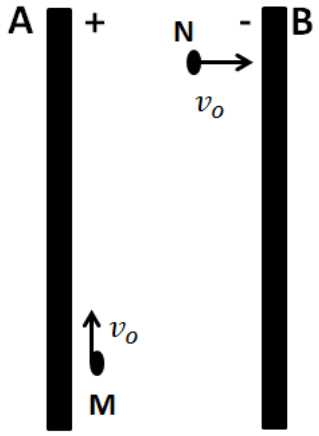
(a) Draw the simplest configuration of resistors that can give such a resistor, indicating the resistor values and the necessary wires.

(b) When 1-1′ is connected to an emf of $E = 7.0$ V with internal resistance $r = 1.0\ \Omega$ and 2-2′ is connected to a resistive load of $R_L = 6.0\ \Omega$ as shown below, what is the power delivered to the resistive load?

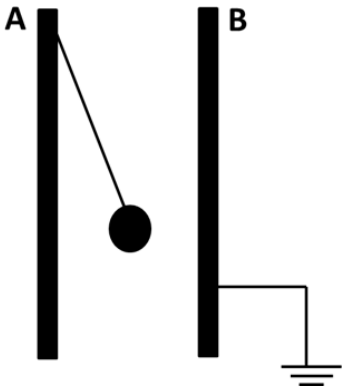


[10]

8. (a) Two large parallel plates A and B with a potential difference of V are placed at a distance d from one another. A small mass m is moving *vertically upward* with speed v_0 at position M as indicated. In its motion between the plates, its velocity remains as v_0 when it reaches N with its direction horizontal. What is the potential difference between M and N? We can ignore induction effect.



(b) The two plates are now placed 0.050 m apart and the setup has an equivalent electrical capacitance of $C = 4$ pF. Both plates A and B are initially grounded. A silvered coated light ball of mass $m = 1.0\times10^{-4}$ kg and radius $a = 3.0\times10^{-3}$ m is suspended from a non-conducting string of 0.10 m with one end attached to plate A as shown in the diagram below. Plate A is suddenly raised to a voltage is 6×10^4 V and then disconnected so that no further charges are added to plate A. At all times, plate B remains grounded. The ball is noticed to bounce between plates A and B before coming to a rest.



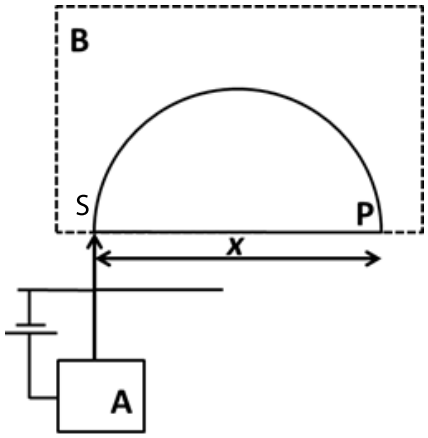
i. Explain why the ball bounces.

ii. What is the final electric potential difference between the two plates?

iii. How many times would the ball hit plate B before coming to a rest?

Assume that all collisions are perfectly inelastic, i.e., the ball loses all its kinetic energy whenever it collides with plate A or B. [16]

9. As shown in figure below, ion source **A** can provide positive ions with negligible velocities. The positive ions are accelerated over a potential difference V before entering a region of uniform magnetic field (out of the page of paper) at point **S**. Due to the magnetic force acting on the positive ions, they travel in semi-circular paths in the magnetic field before they leave the region. The exit point is denoted as **P** and the distance between **P** and **S** is known as x.



Given that there are 2 different positive ions, with charge q_1 and q_2, mass m_1 and m_2 respectively coming out from **A**. If the distance **PS** for first ion is denoted as x_1, for second ion is x_2, and $\dfrac{x_1}{x_2} = \alpha$, find the ratio of t_1 to t_2 in terms of $q_1,\ q_2,\ m_1,\ m_2$ and α, when t is the duration the ions are in circular motion inside the uniform magnetic field. [8]

10. (a) In 1995, the American CDF groups and DO groups in Fermi Lab, while conducting proton-antiproton collisions in the TEVATRON, observed the top quark, a fundamental particle of mass $m = 1.75 \times 10^{11}$ eV$/c^2 = 3.1 \times 10^{-25}$ kg and of lifetime $\tau = 0.4 \times 10^{-24}$ s. This is one of the most important development in the field of particle physics and completes the verification of baryonic particle family.

    i. The top quark-antiquark pair has a potential of $V(r) = -k\dfrac{4a_s}{3r}$, r being the distance between the quark and antiquark, a_s being the gluonic interaction constant, and k is related to the fundamental constants with a value of 0.319×10^{-25} Jm. In order to estimate if it is possible for such a pair to be stable in a bound state, we can imagine the pair to be circling around the center of the line joining the two particles. Suppose that the bound quark-antiquark pair exists in its fundamental ground state, use Bohr model postulate: $2mv\left(\dfrac{r_0}{2}\right) = n\left(\dfrac{h}{2\pi}\right)$ where $n = 1, 2, 3, \ldots$ to estimate the distance between the particles, r_0.

Note that mv is the momentum of each particle in the bound pair and the radius of the circular path is $r_0/2$, n is the quantum number and h is the Planck's constant.

ii. What is the period of revolution of the particles in the bound state? Would you consider such a quark-antiquark bound state possible?

(b) Recently, it was reported that a new elementary particle that resembles the Higgs boson has been discovered. This particle's mass is 130 times that of the proton and can be formed by colliding two streams of high energy protons. Assuming the Higgs-like particle is formed by colliding two protons of equal energy together and the Higgs-like particle produced is stationary after production, what is the momentum of each proton in the rest frame? Mass of proton = 938 MeV/(c^2) [13]

— End of Paper —