

# Indian Olympiad Qualifier in Physics (IOQP) 2021-2022

conducted jointly by

Homi Bhabha Centre for Science Education (HBCSE-TIFR)

and

Indian Association of Physics Teachers (IAPT)

## Part II: Indian National Physics Olympiad (INPhO)

Homi Bhabha Centre for Science Education (HBCSE-TIFR)

Date: 13 March 2022

Time: **10:30-12:30 (2 hours)**

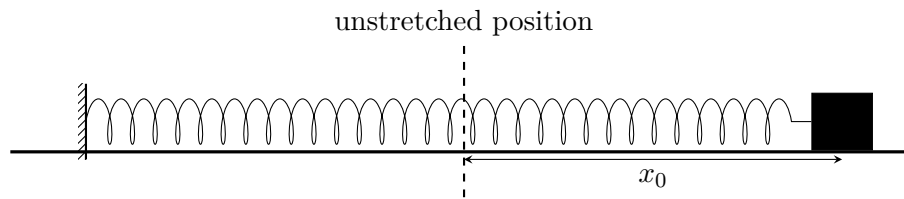
Maximum Marks: **50**

### Instructions

Roll No.:

1. This booklet consists of 4 pages and total of 5 questions. Write roll number at the top wherever asked.
2. Booklet to write the answers is provided separately. Instructions to write the answers are on the Answer Booklet.
3. Marks will be awarded on the basis of what you write on both the Summary Answer Sheet and the Detailed Answer Sheets in the Answer Booklet. Simple short answers and plots may be directly entered in the Summary Answer Sheet. Marks may be deducted for absence of detailed work in questions involving longer calculations.
4. Strike out any rough work that you do not want to be considered for evaluation. You may also use the space on the Question Paper for rough work – this will NOT be evaluated.
5. Non-programmable scientific calculators are allowed. Mobile phones **cannot** be used as calculators.
6. **Please submit the Answer Booklet at the end of the examination.** You may retain the Question Paper.

1. A block of mass  $m = 0.1 \text{ kg}$  is attached to a spring (one end fixed to the wall) with spring constant  $k = 50 \text{ N m}^{-1}$ . The block slides on a rough horizontal table along the  $x$ -axis. Assume that both the coefficients of kinetic ( $\mu_k$ ) and static friction ( $\mu_s$ ) are same and constant ( $\mu_k = \mu_s = \mu = 0.25$ ). The block is initially displaced to  $x_0 = 0.1 \text{ m}$  from the unstretched position (normal length of the spring,  $x = 0$ ) of the spring and released from rest as shown below. Neglect any air resistance. Take the acceleration  $g$  due to gravity to be  $10 \text{ m/s}^2$ .



- (a) [3 marks] How many times ( $n$ ) will the block cross the unstretched position before coming to rest permanently?
- (b) [1 marks] Determine the total distance  $D$  covered by the block before coming to rest.
- (c) [6 marks] Let us divide one complete oscillation of the block, starting from a fully stretched condition of the spring, into four distinct sections, requiring the following times in order:
- $t_1$ : time taken for the block to move from fully stretched to the unstretched position,
  - $t_2$ : time taken for the block to move from the unstretched position to fully compressed position,
  - $t_3$ : time taken for the block to move from fully compressed to the unstretched position,
  - $t_4$ : time taken for the block to move from the unstretched position to fully stretched position.

Let the distance covered during the above intervals be  $d_1, d_2, d_3$ , and  $d_4$ , respectively.

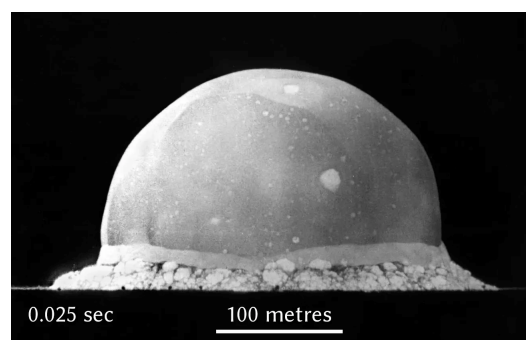
Also, let  $T_1$  and  $T_2$  be the time taken to complete the first and the second oscillations, respectively, starting from the initial displacement,  $x_0$ .

Compare the above times and distances by inserting an appropriate sign (from among  $<$ ,  $>$ , or  $=$  only) between the given quantities in each of the boxes below. Note that you will be penalised for 0.5 marks for giving each incorrect answer in this part. You need not to justify your answer.

$t_1$	$t_2$	$t_2$	$t_3$	$t_1$	$t_3$
$d_1$	$d_2$	$d_2$	$d_4$	$T_1$	$T_2$

- (d) [2 marks] Qualitatively plot the displacement  $x$  from the unstretched position vs the time  $t$ .

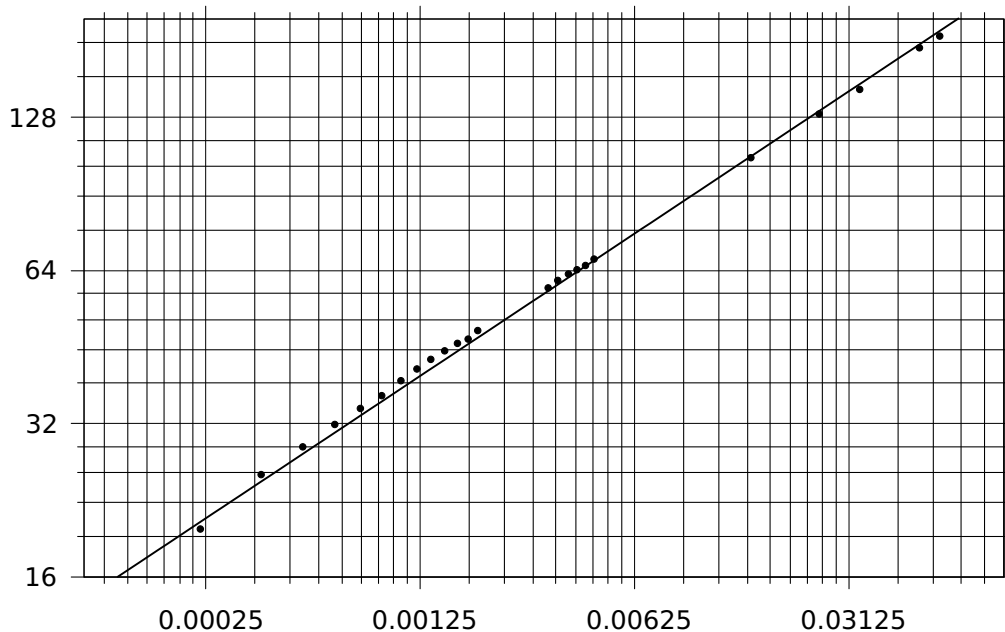
2. The first explosion of an atomic bomb was the Trinity test in New Mexico in 1945. This explosion released a very large amount of energy  $E$  which created an expanding fireball (known as the Trinity fireball). A snapshot of this fireball taken  $0.025 \text{ s}$  after the explosion is shown in the photograph below.



A scientist, Prof. Geoffrey Taylor, could make an estimate of the energy released by the bomb from an analysis of such photographs. Here we try to follow in his footsteps, with some suitable simplifications.

To begin, we assume that the fireball is spherical in nature. Its radius ( $R$ ) increases with time ( $t$ ) depending on the explosion energy  $E$  and the density  $\rho$  of the surrounding air (which is taken as constant and uniform).

We are also given a graph of the data obtained by Prof. Taylor, as shown below. However, the axes labels of the graph are missing.



Given data:

1 kiloton (kt) of TNT =  $4.2 \times 10^{12}$  J

Density  $\rho$  of air outside the fireball =  $1.22 \text{ kg/m}^3$ .

- [3 marks]** What are the quantities represented by the axes of the graph? Also state the respective units in which they are expressed. In the detailed answer sheet, justify your answer.
- [4 marks]** Find the slope ( $s$ ) of the best fit line shown in the graph. What are the dimensions of the quantity  $s$ ?
- [3 marks]** From a dimensional analysis based on the above simplified model, make an estimate of the energy  $E$  released (in kt of TNT) in the Trinity test.

- Consider an air filled spherical balloon comprised of elastic material of surface tension  $\gamma = 500 \text{ kg/s}^2$ . The pressure outside the balloon is the atmospheric pressure ( $P_{\text{atm}} = 101 \text{ kPa}$ ) and the density of air outside is  $\rho_{\text{atm}} = 1.22 \text{ kg/m}^3$ .

The balloon starts deflating slowly. Assume that the average velocity of air inside the balloon is negligible, and air leaves the balloon in a streamline fashion. Consider  $\gamma$  to be constant throughout, and the air to be incompressible.

- [8 marks]** Write an expression for the time  $t$  required to deflate the balloon through a small opening of cross-sectional area  $A$  from an initial radius  $R_0$  to a final radius  $R$ .
- [1 marks]** Obtain the value of this time for  $A = 1 \times 10^{-5} \text{ m}^2$ ,  $R_0 = 0.15 \text{ m}$ , and  $R = 0.05 \text{ m}$ .

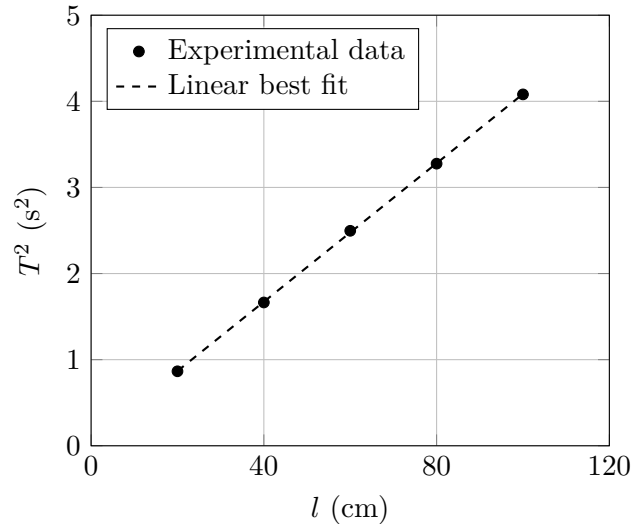
- A student performed an experiment to determine the acceleration due to gravity ( $g$ ) using a simple pendulum which has a spherical bob of diameter  $d$  hung with a long string. She varied the length

of the string  $l$ , and measured the period of oscillation  $T$  every time. She calculated the value of  $g$  from each measurement as shown in the table below.

She noticed that not only was the average value of  $g$  smaller than the expected value, each one of the measurements had yielded a value smaller than the true value.

Next, she plotted a graph between  $T^2$  and  $l$  from the same data, and obtained the value of  $g = 981 \text{ cm/s}^2$  from the slope of the best fit line.

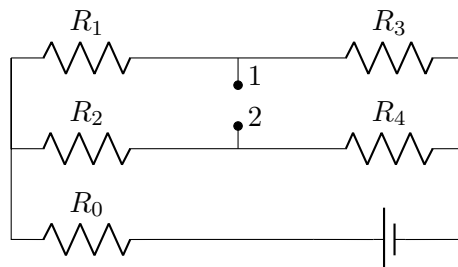
$l$ (in cm)	$T$ (in s)	$g$ (in cm/s)
20	0.93	912
40	1.29	948
60	1.58	948
80	1.81	963
100	2.02	967
Average $g$		947



- (a) [3 marks] What do you think might be the main cause for the consistently low values of  $g$  that she obtained from each of her measurements?
- (b) [4 marks] Explain in detail why she still obtained a correct value of  $g$  from the slope of the graph plotted from the same data.

Assume that the instruments of measuring time and length were accurate enough, and all the measurements of the stated quantities were correct within the accuracy of the instruments. It is verified that the graph and the linear best fit were correctly plotted, and all numerical calculations in the above are correct. Note that you are not expected to plot any graph (no graph paper is provided to you).

5. [12 marks] A circuit consists of an emf source and five resistors with unknown resistances. When an ideal ammeter is connected between points 1 and 2, its reading is  $I_A$ . If instead a resistor  $R$  is connected to the same two points, the current through that resistor is  $I_R$ . If instead an ideal voltmeter is connected between points 1 and 2, its reading is  $V$ . Obtain  $V$  in terms of  $I_A$ ,  $R$  and  $I_R$  only.



\*\*\* END OF THE QUESTION PAPER \*\*\*