cmi **TESSELLATE PRESENTS**

STEMS

Scholastic Test of Excellence in Mathematical Sciences

Physics Category A

Exam Date : 7th January, 2023
Exam Timing : 9 AM - 12 PM IST

Rules and Regulations

Marking Scheme

1. Time duration is **3 hours: 9 AM - 12 PM IST**. You have **20 minutes** to scan and upload your papers after that.
2. This paper contains **9 Objective** and **3 Subjective** questions. The maximum score one can obtain is **100 points**. Each objective question from $1-7$ is worth **4 points**, 8 and 9 are **4 points individually** and **12 points** if both are correct, and each subjective question is worth **20 points**. There is no negative marking.
3. **The subjective part will be graded only if you score above a certain cut-off (to be decided later) in the objective section of the paper.**
4. **The final cut-off shall be based on your total score (Objective + Subjective).**

Miscellaneous

1. Submit your answers through `https://forms.gle/c4mvimyaCkzi3Zja7`.
2. Write your solutions to the subjective problems neatly, then scan and generate a PDF, which you must submit through the same form. Solutions should be brief and should contain all the necessary details. Name your file as **STEMS_Physics_Roll number.pdf**, for example, **STEMS_Physics_6900.pdf**.
3. Use a good application to scan handwritten text into PDF. Kindly make sure that the answers are legible and that your furniture or flooring is not a part of the submission.
4. Make sure your PDF has a size below 10 MB.
5. Ambiguous or illegible answers will not gain credits. If you strike something out, strike it out properly so that it is clear to the evaluator what you want to read. Please avoid overwriting your answers.
6. Answers should be your own and should reflect your independent thinking process.
7. Do **NOT** post the questions on any forums or discussion groups. It will result in immediate disqualification of involved candidates when caught.
8. Sharing/discussion aimed towards solving or distribution of problems appearing in the contest while the contest is live in any kind of online platform/forum shall be considered as a failure in complying with the regulations.
9. Any form of plagiarism or failure to comply with aforementioned regulations may lead to disqualification.
10. SI Units are used throughout unless specified otherwise.

Contact details

- For subject related queries, clearly mention your **name** and **category (A)** in the mail or WhatsApp text.
- For **subject related** queries, contact **stemsphysics2023@gmail.com**. Below are two more contacts, but **please use these only if the previous one is down.**
  - Adhvik Jagannathan: **adhvik@cmi.ac.in**
  - Anand Balivada: **anandb@cmi.ac.in**
- For **technical** queries, contact **tessellate.cmi@gmail.com**. Below are two more contacts, but **please use these only if the previous one is down.**
  - Siddhant Shah: **siddhants@cmi.ac.in**
  - Rohan Goyal: **rohang@cmi.ac.in**
- Your should fill in your answers to the objective questions in the google form we sent along with this question paper. Upload the scanned PDF containing the answers to subjective questions with the forementioned file name to the same form (that contained the drive link for the question paper) along with your **name, subject, category and your registered email ID** on it. Submissions by emails will be accepted only till **12:20 PM IST.**

Questions

Objective

1. In music theory, we divide notes into octaves of doubling frequency. In a certain octave, the note A has the frequency 880 Hz, and the note B has the frequency 950 Hz. Assuming that you can hear all frequencies possible and can distinguish beats of frequency upto 16 Hz, **how many octaves below do A and B start producing beats you can hear, and what is the frequency of these beats?**
   (a) 3, 10.25 Hz.
   (b) 4, 8.75 Hz.
   (c) 3, 8.75 Hz.
   (d) 4, 10.25 Hz.
2. **Which of the following statements are FALSE:**
   (a) An object has a lower apparent weight submerged in a fluid which is denser than another.
   (b) An object has a lower apparent weight at the equator than at the poles of Earth.
   (c) An object has a lower apparent weight in an elevator moving down with constant speed than up.
   (d) An object has a lower apparent weight on Earth compared to Jupiter.
3. A zero point is a point in space where the electromagnetic and gravitational fields vanish. **Which of the following hold:**
   (a) If three identical masses are placed at the vertices of an equilateral triangle, then there are four zero points.
   (b) If three identical masses are placed at the vertices of an equilateral triangle, then there is only one zero point.
   (c) If three identical masses are placed at the vertices of an equilateral triangle, then there are three zero points.
   (d) If two identical current carrying circular loops are placed coaxially with opposite directions of current, there are 3 zero points.
4. A person suffering from an eye disorder can't see objects beyond 30 cm. **What lens does this person need, and of what power?**
   (a) $-6.67D$, concave.
   (b) $3.33D$, convex.
   (c) $6.67D$, convex.
   (d) $-3.33D$, concave.

5. Hvaldimir's boat is frozen in ice in the middle of a lake in Russia. He manages to break it free somehow, and now wishes to take it to shore, which is 2 km away. If the boat weighs 1 metric tonne and has a coefficient of friction of 0.1 with the ice, **how much force must Hvaldimir constantly apply to it so that he reaches shore exactly in an hour?**

   (a) 980.309 N.

   (b) 980.258 N.

   (c) 908.455 N.

   (d) 980.154 N.

6. Ajay and Rahul are going for a bicycle ride in Siruseri, with travelling at speeds of v_A and v_R respectively, with a distance of d between them, along a straight line.

   Since $v_A > v_R$, Rahul accelerates at a_R to catch up with Ajay. Suddenly, Ajay spots a pigeon on the road, immediately pressing the brakes, decelerating his bicycle at a magnitude a_A.

   It takes Rahul ρ seconds to realise this, after which he also presses his brakes. **How strong should Rahul's brakes be** (i.e., what magnitude of deceleration x should they cause) **in order for him to not crash into Ajay?** Assume all expressions below are well-defined.

   (a) $x \geq \dfrac{(v_R + a_R\rho)^2}{2d - 2v_R\rho - a_R\rho^2}$.

   (b) $x \geq \dfrac{v_R^2}{2d + \frac{v_A^2}{a_A} - 2v_R\rho}$.

   (c) $x \geq \dfrac{v_R^2}{2d + \frac{v_A^2}{a_A}}$.

   (d) $x \geq \dfrac{(v_R + a_R\rho)^2}{2d + \frac{v_A^2}{a_A} - 2v_R\rho - a_R\rho^2}$.

7. A point source of light S is placed at the bottom of a vessel containing a liquid of refractive index $\frac{2}{\sqrt{3}}$. There is an opaque disc of radius r floating on the surface, with its center directly above S. The liquid is gradually drained out from the vessel. **What is the maximum height of the liquid at which the source cannot be seen by an observer above the surface?**

   (a) r.

   (b) $\sqrt{3}r$.

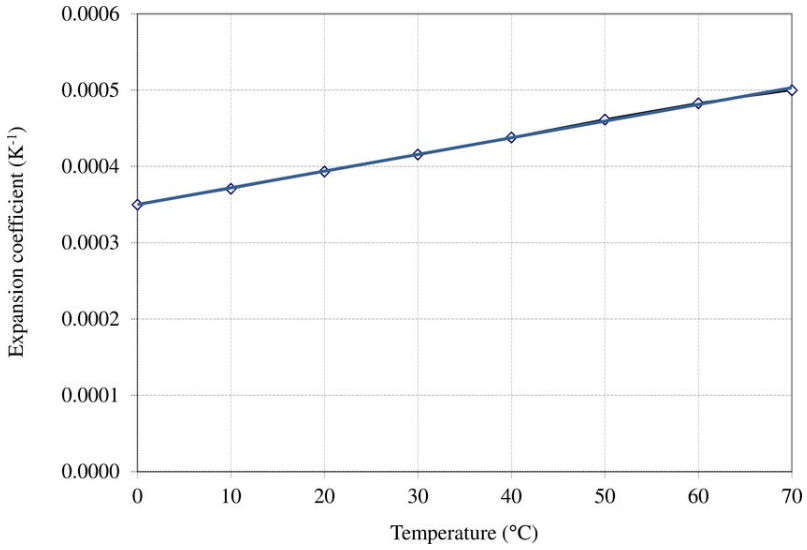
   (c) $\frac{r}{\sqrt{3}}$.

   (d) $2r$.

Questions 8 and 9 are based on the paragraph below.

CMI wanted to send ISI Bengaluru paneer soda (a drink native to parts of Tamil Nadu) as a peace offering, so we filled a thin cylindrical steel drum of radius $25cm$ and height $70cm$ with paneer soda up to $50cm$. The temperature in Chennai when the soda was dispatched was $30°C$, and when it arrived in Bangalore, a cool and pleasant $20°C$, with the temperature strictly decreasing along the path from Chennai to Bangalore. The coefficient of linear expansion of steel is $10^{-5}K^{-1}$.

The following graph shows how the volume expansion coefficient of paneer soda varies with temperature -



8. **What is the new volume of the soda?**
   (a) $97779.4\ mL$
   (b) $97381.2\ mL$
   (c) $97209\ mL$
   (d) $94321\ mL$
9. **What is the current height of the soda in the drum?**
   (a) $49.508\ cm$
   (b) $49.518\ cm$
   (c) $49.596\ cm$
   (d) $49.605\ cm$

Subjective

1. The planet *Xylo* orbits the star *Galahad* 20,000 light years away from us. It is a hypothetical example of a planet with intelligent life. A certain species of plant, which we have named *Neotropis predictus*, here on abbreviated as Neotropis, grows in a strangely predictable fashion. A day on Xylo lasts for 10 earth hours. The intensity of light reaching Xylo from Galahad as a function of time is given by the function:

$$I_x(t) = \begin{cases} 0.2\left(1 - \dfrac{t}{5}\right) + 1.8\left(\dfrac{t}{5}\right) \quad \text{units} & 0 \le t \le 5 \\ 1.8\left(1 - \dfrac{t-5}{5}\right) + 0.2\left(\dfrac{t-5}{5}\right) \quad \text{units} & 5 < t < 10 \end{cases}$$

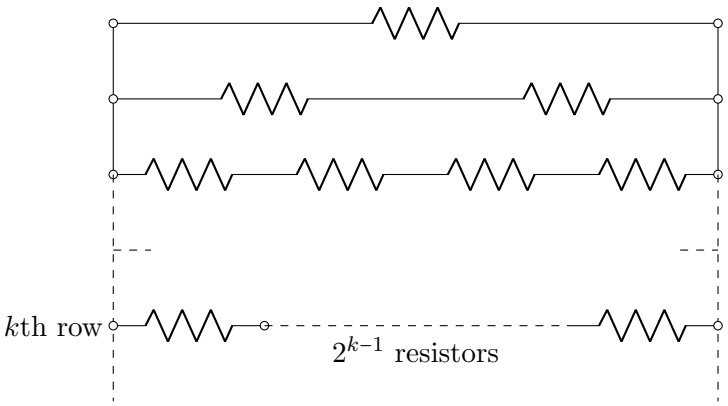
Neotropis grows at a rate of $k(I_x - 1)\ mh^{-1}$ if the intensity I is greater than 1 units, and does not grow when the intensity is below the same. k above is a constant of proportionality.

(a) **Calculate how much a specimen of Neotropis grows in one Xylo day.**

(b) A farmer on Xylo fertilizes the soil of their Neotropis fields everyday at the 5th Earth hour. This causes the growth rate to increase temporarily for two Earth hours, by a factor of 5. **Calculate how much Neotropis the farmer grows in 30 Xylo days.**

(c) **If you were a Neotropis farmer, which Earth hour of the Xylo day would you fertilize the soil to maximise your earnings? You only need to state your reasoning verbally.**

2. A system of infinitely many resistors is as shown below:



Each resistor has a resistance of R, and each row has twice as many resistors as the previous one.

(a) **How much power would be generated by this combination if the kth row had a potential source of V connected across it?**

(b) There is a current I flowing through the kth row. **What is the potential difference across a single resistor in the lth row?**

(c) **Calculate the effective resistance across the two ends of the first resistor from the left in the kth row.**

3. The Sun produces a power of $6.42 \times 10^7\ Wm^{-2}$ at its surface. A cylindrical resistor of resistance 1Ω and mass $1\ g$ is connected to a battery of potential difference $5\ V$ in a lab on Earth. A surface area of $3.93\ cm^2$ of the resistor is exposed to sunlight. The radius of Earth's orbit (which we assume is circular) is $1.5 \times 10^{11}\ m$, and the radius of the Sun is $6.97 \times 10^8\ m$. The specific heat capacity of the resistor is given to be $450\ Jkg^{-1}K^{-1}$ and its linear expansion coefficient is $1.5 \times 10^{-5}\ K^{-1}$. If the resistor has an efficiency of 75% while absorbing the energy from light, **calculate the change in the current through the resistor after a short time interval Δt, to the first order.**

All the Best!!