36th Singapore Physics Olympiad Theory Paper 1

Organised by

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Instructions to Candidates

1. This is a 2-hour paper.
2. This paper consists of five (5) questions printed on fourteen (14) pages. The second page is a General Information Sheet.
3. Attempt all questions.
4. Write your answers in the space provided in the question booklet.
5. You may request working paper from the invigilators.
6. You may not refer to any books or documents relevant to the competition.

NAME:_______________________________________ INDEX NO: ___________

SCHOOL: ____________________________________

For Examiner's Use

Question No.	Marks Awarded
1	/ 10
2	/ 10
3	/ 11
4	/ 9
5	/ 10
Total	/ 50

GENERAL INFORMATION SHEET

Acceleration due to gravity at Earth surface,	$g = 9.81$ m s^{-2}
Stefan-Boltzmann constant,	$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}
Speed of light in vacuum,	$c = 3.00 \times 10^{8}$ m s^{-1}
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}
Charge of electron,	$e = 1.60 \times 10^{-19}$ C
Planck's constant,	$h = 6.63 \times 10^{-34}$ J s
Mass of electron,	$m_e = 9.11 \times 10^{-31}\ kg$
Mass of proton,	$m_p = 1.67 \times 10^{-27}\ kg$
Avogadro's number	$N_A = 6.02 \times 10^{23}$ mol^{-1}

1. (a) A car of total mass 1200 kg is travelling at a constant speed of 20 ms^{-1} down a sloping road inclined at $10°$ to the horizontal. The engine of the car is producing a power of 112.5 kW. What is the resistive force experienced by the car (from air resistance and friction on the road) during the motion? You may assume the resistive force to be constant.

[3 marks]

1. (b) While travelling down the slope at 20 ms^{-1}, the driver suddenly sees an obstacle at a distance 40 m directly in front of the car. He immediately stops the engine of the car and then steps hard on the brake in an attempt to stop the car. Assuming that the reaction time of the driver is 0.5 s, what is the minimum force that the brake must exert on the car to avoid collision with the obstacle? Take the resistive force calculated in part 1(a) to remain constant.

[4 marks]

1. (c) Suppose the braking force on the car is only 95% of the minimum value found in part 1(b). What is the impulse experienced by the car during the impact?

[3 marks]

2. (a) Fig. 1 shows a schematic diagram of a sonometer which is an instrument for studying the properties of transverse stationary waves in a stretched string.

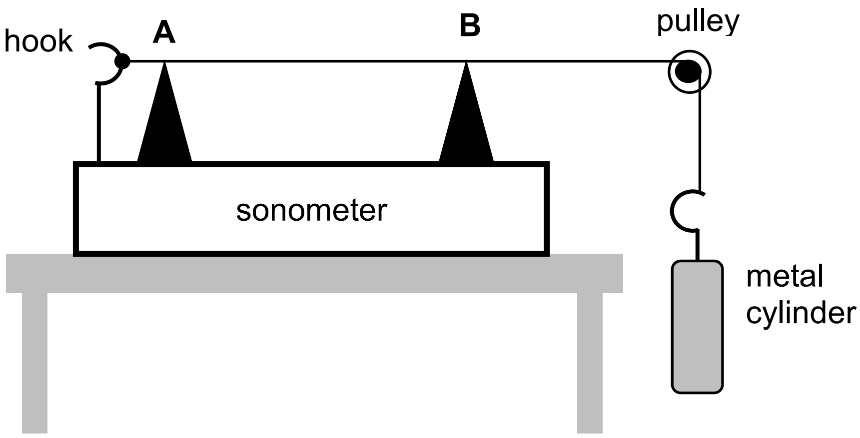

Fig. 1.

The string can be vibrated using an electrical vibrator. Stationary waves can be formed in the portion of the string between the two wedges (labelled A and B in Fig. 1). The tension in the string is provided by a metal cylinder hanging from one end of the string as in Fig. 1. In a particular experiment, the mass of the cylinder is 2.0 kg. The string has a circular cross-section with uniform diameter of 1.5 mm and the density of the material of the string is 8830 kg m^{-3}. The string is vibrating in its fundamental mode with a frequency of 22.0 Hz. What is the distance between the two wedges?

[2 marks]

2. (b) The metal cylinder has a density 8400 kg m $^{-3}$ and a diameter of 5.0 cm. While still hanging from the end of sonometer wire, the cylinder is completely immersed in water. What **changes** must be made to the distance between the two wedges so that the frequency of fundamental mode still remains at 22.0 Hz?

[Density of water = 1000 kg m $^{-3}$]

[4 marks]

2. (c) The distance between the two wedges is now adjusted back to the value as calculated in part 2(a). The metal cylinder is now immersed in brine which has a density of 1220 kg m^{-3}. The string is now allowed to vibrate in the second overtone mode. The sound waves produced by the string and the sound waves from a piano note of frequency 64 Hz are sounded together. What is the frequency of the beat produced?

[4 marks]

3. (a) A parallel plate capacitor with the space between the plates filled with air has a capacitance of $6\mu F$. It is charged by connecting to a 24-volt battery. With the capacitor still connected to the battery, an insulating material having dielectric constant of 2.5 is inserted into the space between the plates of the capacitor so that it fills exactly 50% of the space (see Fig. 2). Calculate the amount of charge flowing through the battery during the process (i.e., from the instant the insulating material is inserted to when it fills up 50% of the space).

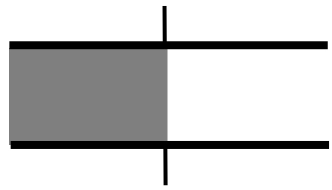

Fig. 2.

[5 marks]

3. (b) A thin rod, AB, of negligible mass and length 60 cm is suspended at its ends by two identical springs each with a force constant of 20 $\mathrm{N m^{-1}}$. The rod is charged and the linear charge density at a point on the rod distance x from A is $0.9x$. The rod and the springs are placed in a uniform electric field of magnitude 24 $\mathrm{V m^{-1}}$ and directed vertically downwards. What is the inclination of the rod to the horizontal when the system is in equilibrium? Assume that the springs remain vertical when the rod is inclined.

[6 marks]

4. (a) The distance between the objective lens and the eyepiece of an astronomical telescope in its normal adjustment, i.e., the final image is formed at infinity, is 105 cm. When the eyepiece is moved 1.0 cm towards the objective lens, a final virtual image is formed at a point 20 cm from the eyepiece. Calculate the focal lengths of the objective lens and of the eyepiece.

[3 marks]

4. (b) The intensity of solar radiation at the surface of the Earth is $1.38\ \text{kW m}^{-2}$. The orbital radii of Earth and Mars are respectively 1.496×10^{8} km and 2.280×10^{8} km. Estimate the surface temperature of Mars assuming that both planets behave like blackbodies.

[6 marks]

5. (a) A beam of monochromatic UV light with wavelength 50 nm is incident onto a blackened flat plate of total area 200 cm^2. The direction of the beam is normal to the surface of the plate. The beam has an intensity of 24 W m^{-2}. Calculate the force exerted by the light beam on the surface of the plate. State any assumption you make in your calculation.

[4 marks]

5. (b) Radioactive nucleus A with half-life of 1 hour decays into another radioactive nucleus B which has a half-life of 6 hours. Nucleus B decays into nucleus C which is stable. At time $t = 0$, a specimen contains 10^{-3} mole of A but none of B and C. Nucleus B in the specimen reaches a maximum quantity of X nuclei at time t = T hours. Find X and T.

[For the first order differential equation, $\dfrac{dy}{dx} + c_1 y = c_2 e^{-kx}$,

where c_1, c_2 & k are constants, the solution is

$$y = \frac{c_2}{c_1 - k}\left(e^{-kx} - e^{-c_1 x}\right)$$]

[6 marks]