IPhR 2024: First Round

STEM October Physics Club

August 8, 2024

§1 Questions

1. Gravitational force is

   a) conservative

   b) non-conservative

   c) sometimes negative

   d) none of the above

   Solution: a

2. Which of the following statements is correct?

   (a) A hot object contains a lot of heat.

   (b) A cold object contains only a little heat.

   (c) Statements a and b are true.

   (d) Objects do not contain heat.

   Solution: d

3. On an experiment, the results were 1.41, 1.43, 1.40, and 1.41. If the real result was 2.1, then those results are

   a) Precise and accurate

   b) Precise but not accurate

   c) Not precise but accurate

   d) Not precise nor accurate

   Solution: b

4. The capacitance is directly proportional to

a) Potential difference

b) Electric charge

c) Plate separation distance

d) Area of the plates

Solution: d

5. A stone is connected to a vertical spring and oscillates up and down between points F and R. At what position is the mass when its kinetic energy is at its maximum?

   a) at either F or R

   b) midway between F and R

   c) one-fourth of the way between F and R

   d) Three-fourths of the way between F and R

   Solution: b

6. A dielectric material is placed between the plates of a capacitor. What happens to the capacitance?

   a) No change

   b) Becomes smaller

   c) Becomes larger

   d) Becomes zero

   Solution: c

7. Which law states that the radius vector drawn from the Sun to a planet sweeps out equal areas in equal time intervals.

   a) Kepler's first law

   b) Kepler's second law

   c) Kepler's third law

   d) Kepler's fourth law

   Solution: b

8. When a particle travels 5 cm from point A to point B in an electric field of $5\frac{V}{n}$, the electric potential of A with respect to B is

   a) 100

   b) -0.25

   c) 0.25

d) -100

Solution: c

9. What is the angular frequency of a simple pendulum with a length of 2 meters?

   a) 2.00

   b) 2.21

   c) 12.3

   d) 3.14

   Solution: b

10. An IPhR Problem Author filled a balloon with warm gas and then placed it in a cold room. Which of the following signs signifies that the balloon has reached thermal equilibrium with the room's air?

    a) The balloon stopped expanding.

    b) The balloon stopped contracting.

    c) The balloon rose to the ceiling.

    d) The balloon sank to the bottom.

    Solution: b

11. Moment of inertia is:

    a) how a mass moves

    b) how the mass is distributed on a moving body

    c) how the mass is distributed on a rotating object

    d) how the mass is distributed on a still object

    Solution: c

12. If the work done by the force $\vec{F} = (x)\vec{i} + 3\vec{j}$ on an object that moved in a displacement $\vec{D}_1 = 4\vec{i} + 9\vec{j}$ is 35 J, what the work done by the same force on an object with a displacement vector of $\vec{D}_2 = (6)\vec{i} + 8\vec{j}$?

    a) $24J$

    b) $48J$

    c) $12J$

    d) $36J$

    Solution: d

$$W_1 = \vec{F} \cdot \vec{D}_1 = 4x + 27 = 35 \implies x = \frac{8}{4} = 2 \implies \vec{F} = 2\vec{i} + 3\vec{j}$$

Therefore,

$$W_2 = \vec{F} \cdot \vec{D}_2 = 2 \times 6 + 3 \times 8 = 12 + 24 = 36$$

13. A solid sphere and a hollow sphere of the same mass and radius roll down an incline without slipping. Which sphere reaches the bottom first and why?

    a) The solid sphere reaches the bottom first because it has less moment of inertia.

    b) The hollow sphere reaches the bottom first because it has a greater moment of inertia.

    c) The solid sphere reaches the bottom last because it has a greater moment of inertia.

    d) Both spheres reach the bottom at the same time because their moments of inertia do not affect the time.

    Solution: a

14. If a shark can swim at approximately $80km/h$ and a tuna at $60km/h$. How long will it take for the shark to catch the tuna if it is 50 m ahead?

    a) $5s$

    b) $7s$

    c) $9s$

    d) $11s$

    Solution: c

15. The y position of a particle at $x = 5m$ in the medium of a transverse wave of wave function $f(x,t)$ moving to the left with velocity $v = 2m/s$ at $t = 10s$ is the same as:

    a) $f(25,0)$

    b) $f(-15,0)$

    c) $f(0,25)$

    d) $f(0,-15)$

    Solution: a

16. The surface of the Sun has a temperature of approximately 5778 K, while the temperature of the Earth's surface is about 300 K. Calculate the total entropy change when 10^6 J of heat energy is transferred from the Sun to the Earth. Round your answer to the nearest integer.

    (a) 2890 J/K

    (b) 3275 J/K

    (c) 3160 J/K

(d) 3970 J/K

Solution: c

17. A physics club member was eager to design an experiment to test if different media affect the speed of a light pulse. He designed an experiment where 2 light pulses were emitted from different sources simultaneously through the same total length of air to a detector. However, one pulse passes through $6.20m$ of ice ($n_{ice} = 1.309$) along the way. Determine Δt that represents the difference between the pulses' time of arrival.

a) $6.39ns$

b) $5.39\mu s$

c) $5ps$

d) $6ns$

Solution: a The pulses are in step with each other until one enters the ice, then that pulse slows down.

$$\begin{aligned}\Delta t &= \frac{L}{v_{ice}} - \frac{L}{v_{air}} \\ &= \frac{L}{c/n_{ice}} - \frac{L}{c/n_{air}} \\ &= (n_{ice} - n_{air})\frac{L}{c} = 6.39ns\end{aligned}$$

18. Consider a series RLC circuit powered by an AC power source. If the capacitance, inductance, and resistance of the circuit are $25mF$, $8H$, and 75Ω respectively, calculate the phase angle of the circuit if it operates on $60Hz$.

a) $42.56°$

b) $65.22°$

c) $88.56°$

d) $73.19°$

Solution: c

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) = \tan^{-1}\left(\frac{2\pi f L - \frac{1}{2\pi f C}}{R}\right)$$

19. In a random late night, one of IPhR's problem authors was hungry and went to the kitchen to cook some food. Accidentally, he dropped the cover of the pot making a thunderous noise. Knowing that the intensity of the sound was $1.0 \times 10^{-10} W/m^2$ and the reference intensity is $1.0 \times 10^{-12} W/m^2$. Calculate the intensity level in decibels.

a) $20db$

b) $-20db$

c) $\frac{1}{10}db$

d) $-\frac{1}{10}db$

Solution: a

$$B = 10log(\frac{I}{I_0})$$

$$B = 10log(\frac{1.0 \times 10^{-10}}{1.0 \times 10^{-12}})$$

$$B = 20db$$

20. Two coils are placed next to each other. If a change in the electric current of the first coil of $3A$ in $0.2s$ induces an emf of $5V$ in the second coil, what is the coefficient of mutual induction?

a) $\frac{1}{3}H$

b) $\frac{1}{4}H$

c) $\frac{1}{2}H$

d) $\frac{2}{5}H$

Solution: a

$$V = M\frac{\Delta I}{\Delta t} \implies 5 = M \cdot \frac{3}{0.2} \implies M = \frac{1}{3}H$$

21. For a total internal reflection to happen what is necessarily true?

a) The angle of incidence in the denser medium must be lesser than the critical angle for the two media

b) The angle of refraction in the denser medium must be greater than the critical angle for the two media

c) The angle of incidence in the rarer medium must be greater than the critical angle for the two media

d) The angle of incidence in the denser medium must be greater than the critical angle for the two media

Solution: d

22. A car was moving with an initial velocity of $60\frac{m}{sec}$ and had to stop. It decelerates with $5\frac{m}{sec^2}$. At what distance will the car stop?

a) 720

b) 360

c) 12

d) 24

Solution: b

23. The electric potential energy associated with a pair of charges of equal magnitude $q = 5\mu C$ separated by a distance of $d = 2m$ is

a) $2 \times 10^{-11} J$

b) $1.5 \times 10^{-11} J$

c) $0.1125 J$

d) $1 \times 10^{-11} J$

Solution: c

The electric potential energy associated with a pair of point charges separated by a distance d is given by

$$U_E = k_e \frac{q^1 q^2}{d} = 0.1125 J$$

(Note: the question is eliminated from the exam's marks)

24. A object is moving in a circle under the effect of a centripetal acceleration of $a_c = 15 m/s^2$. If the object is moving with a tangential velocity of $v = 5 m/s$, what is the period of its motion?

a) $\frac{1}{3}\pi s$

b) $\frac{2}{3}\pi s$

c) πs

d) $2\pi s$

Solution: b

25. Which of the following statements is false?

a) You are attracting the screen by a gravitational force right now

b) One unit for measuring pressure is psi

c) The magnitude of the buoyant force on an object equals the weight of the object

d) A system is isolated in terms of angular momentum if there are no net external torque acting on the system

Solution: c

26. What is the physical theory explaining the sharp frequency change of sonic booms?

a) Doppler effect

b) Wave superposition

c) Snell's theory

d) Bernoulli's principle

Solution: a

27. if a negative particle is moving to the left in a magnetic field directed into the page then:

a) the direction of the force is to the right

b) the direction of the force is down

c) the direction of the force is up

d) the direction of the force is to the left

Solution: c

28. One of the IPhRs' authors wanted to visit an imaginary planet called "isotones". This planet differs from the Earth as it only contains nothing but pure water. IPhR's author wanted to measure the electric force between two charges by Coulomb's law. Please help him to measure it.

a) He won't be able to measure it as the electric force doesn't appear in water.

b) He can use Coulomb's law normally and Coulomb's constant will not change by changing the medium.

c) He can use Coulomb's law normally but he has to calculate Coulomb's constant as it is not constant by changing the medium.

d) He can't use Coulomb's law to measure the electric force in this situation and he must use another law or formula.

Solution: c

Coulomb's constant, denoted as K. it is related to the permittivity of a medium $\epsilon_\circ$ by the equation:

$$K = \frac{1}{4\pi\epsilon}$$

by changing the medium ϵ changes which leads to the change of Coulomb's constant.

29. An aluminum rod has a diameter of 10cm and length of 10m at $20°C$. What is the increase in its diameter and length at $70°C$ respectively? (Linear expansion coefficient (α) of aluminum = 24×10^{-6})

a) 5.99×10^{-3} cm and 0.2 cm

b) 11.99×10^{-3} cm and 1.2 cm

c) 17.99×10^{-3} cm and 2.2 cm

d) 24.99×10^{-3} cm and 3.2 cm

Solution: b From the law of thermal expansion in two dimensions:

$$\Delta A = \beta A_i \Delta T = 2\alpha A_i \Delta T$$

So,

$$A_f = 2\alpha A_i \Delta T + A_i = 7.87 \times 10^{-3} m^2$$

Then the final diameter of the rod = 10.01199 cm which is longer than the initial diameter by 11.99×10^{-3}. Secondly, to calculate the increased length, the law of thermal expansion in one dimension will be used:

$$\Delta L = L_i \alpha \Delta T$$

By substituting with the provided data, ΔL is found to be = 1.2 cm.

30. If an astronaut were to travel at the speed of light, they would cover a distance of 1 light year instantaneously, just like a photon. However, if the astronaut travels at a speed slightly less than the speed of light, they would take some time to traverse the 1 light year. What percentage of the speed of light would the astronaut need to travel in order to cover the distance of 1 light year within one year?

    a) 30%

    b) 50%

    c) 70%

    d) 90%

    Solution: c

$$c \cdot 1\ year = v\Delta t = v\gamma\Delta\tau$$

$$c \cdot 1\ year = v\gamma \cdot 1\ year$$

$$\frac{v}{c} = \frac{1}{\gamma} = \sqrt{1 - \frac{v^2}{c^2}}$$

$$2v^2 = c^2$$

$$v = \frac{c}{\sqrt{2}} \approx 0.7c$$

31. The time constant for an RC circuit with an 2, 3, 5 Ω resistors connected in series and 2, 3, 5 μF capacitors connected in series is . . .

    a) $\frac{300}{31} s$

    b) 100 s

    c) 20 s

    d) $\frac{220}{50} s$

    Solution: a

$$\tau = RC \tag{1}$$

$$R = R_1 + R_2 + R_3$$

$$R = 2 + 3 + 5$$

$$R = 10\Omega \tag{2}$$

$$C = (\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3})^{-1}$$

$$C = (\frac{1}{2} + \frac{1}{3} + \frac{1}{5})^{-1}$$

$$C = \frac{30}{31}F \tag{3}$$

$$\tau = \frac{30}{31} \times 10 = \frac{300}{31}s \tag{4}$$

32. What happens to a pulse on a string when collides with a movable thing like a ring on a frictionless rod?

    a) Totally reflected but not inverted.

    b) Totally reflected and inverted.

    c) Isn't reflected nor inverted.

    d) Isn't reflected but inverted.

    Solution: a

33. Consider a step-down transformer that lowers the voltage from 200 V to 20 V, if the number of turns of the primary coil is 640 turns and the efficiency of the transformer is 80%, then what is the number of turns of the secondary coil ?

    a) 80 turns

    b) 70 turns

    c) 40 turns

    d) 20 turns

    Solution: a

$$\eta = \frac{V_s N_p}{V_p N_s} \times 100$$

$$80 = \frac{20 \times 640}{200 \times N_s} \times 100$$

$$N_s = 80$$

34. An iceberg is floating on water. If the density of ice is $900\frac{kg}{m^3}$, what percentage of the iceberg is in water.

    a) 10%

    b) 90%

    c) 100%

    d) 0%

    Solution: b

35. A tank contains a gas under pressure = 19 atm and temperature of 0^oC If you withdraw 95% of the gas in the tank and change its temperature to change the gas' pressure to 35 atm. Find the new temperature in (^oC) assuming no change in the tank's volume.

    a) 256^oC

    b) -529^oC

    c) 529^oC

    d) -256^oC

    Solution: a

$$\frac{P_f V}{P_i V} = \frac{n_f R T_f}{n_i R T_i} \implies T_f = \left(\frac{P_f}{P_i}\right)\left(\frac{n_i}{n_f}\right) T_i = 529K = 256^oC$$

36. Consider a wrench rotating about a fixed point and take the of force application to be the origin. If the force vector is $F = 3\hat{i} + 4\hat{j}$ and the displacement vector which has the magnitude of the length of the wrench and points from the axis of rotation to the point of application is $r = 5\hat{j}$. Find the torque on the wrench.

    a) $20\hat{j}$

    b) $20\hat{k}$

    c) $10\hat{j}$

    d) $10\hat{k}$

    Solution: b

37. A fluid is flowing in 10-cm-diameter pipe with a volume flow rate 0f $0.9m^3/s$, what's the average fluid speed?

    a) $114.6m/s$

    b) $282.7m/s$

    c) $115.6m/s$

    d) $349m/s$

    Solution: a

$$v = \frac{0.9}{\pi \times 0.05^2} = 114.6m/s$$

38. Helmy bought a steel stick to punish whoever solves this question wrong. To make it taller, he puts it in an oven operating at 300°C. If the stick had the length of 2 meter in 25°C, what is its new length. (the steel coefficient of thermal expansion is equal to 11×10^{-6})

    a) 3.03×10^{-3}

    b) 6.06×10^{-3}

    c) 2.006

d) 2.003

Solution: c

39. What is the amplitude of the resultant of two waves with a phase difference ϕ between them?

a) $2A$

b) $2\sqrt{2}A$

c) $2A \sin \frac{\phi}{2}$

d) $2A \cos \frac{\phi}{2}$

Solution: d The equation for the resultant of two waves is the sum of the two waves: $Y = y_1 + y_2$

$$Y = A \sin kx - \omega t + A \sin kx - \omega t + \phi$$

Using the sum of two sin functions identity: $\sin A + \sin B = 2 \sin \frac{A+B}{2} \cos \frac{A-B}{2}$

$$2A \cos \frac{\phi}{2} \sin kx - \omega t + \frac{\phi]}{2}$$

The amplitude of the resultant is the coefficient of the sin function so the answer is $2A \cos \frac{\phi}{2}$

40. What is the average intensity of an electromagnetic wave with a maximum electric field (E_{max} = 500N/C)?

a) 231.6 W/m^2

b) 331.6 W/m^2

c) 431.6 W/m^2

d) 531.6 W/m^2

Solution: b