IPhR 2023: Trial Round

STEM October Physics Club

August 12, 2023

§1 Questions

1. What is the ripple voltage of a full wave rectifier with a 14 μF filter capacitor connected to a load drawing 4 mA?

   a) 143 V

   b) 286 V

   c) 571 V

   d) 686 V

   Solution: d
   The ripple voltage of a full-wave rectifier is given by

   $$V_r = \frac{2.4V_{dc}}{R_L C}$$

   Since

   $$\frac{V_{dc}}{R_L} = I_L$$

   Therefore

   $$V_R = \frac{2.4I_L}{C} = \frac{2.4 \times 4 \times 10^{-3}}{14 \times 10^{-6}} = 686 \text{ V}$$

2. A 1500-kg Tok-tok (some kind of vehicle) accelerates uniformly from 0 m/s to 23 m/s in 8.6 s. What is the maximum power delivered by this car?

   a) 30.3 kW

   b) 41.7 kW

   c) 52.4 kW

   d) 92.3 kW

   Solution: d
   Because acceleration is constant, F is also constant; therefore,

   $$P_{\max} = F \times v_{\max} = m \times \frac{v_f - v_i}{\Delta t} \times v_f = 92.3 \text{ kW}$$

3. Two waves of amplitude $A = 2$ cm interfered together. What is the amplitude of the formed wave if the two constituent waves were shifted by 60°?

   a) 1.00 cm

   b) 1.73 cm

c) 2.00 cm

d) 3.46 cm

Solution: d

By adding the wave equations, we get that the amplitude of the formed waves A_{new} is

$$A_{\text{new}} = 2A\cos\left(\frac{\phi}{2}\right) = 3.46 \text{ cm}$$

4. At what angle of incidence will a ray of light be completely polarized given that it travels from air ($n = 1$) to glass ($n = 1.52$)?

   a) 36.7°

   b) 45.7°

   c) 56.7°

   d) 63.7°

   Solution: c

   The angle at which light is completely polarized θ is easily calculated using Brewster's law

$$\tan\theta = \frac{n_2}{n_1} = 1.52 \Rightarrow \theta = 56.7^\circ$$

5. A 30 cm radius car tire accelerates uniformly from rest at a constant rate to a speed of 10 rad/s in 7 seconds. What is the tangential acceleration of the tire during the 7-second interval?

   a) 0.24 m/s^2

   b) 0.43 m/s^2

   c) 0.82 m/s^2

   d) 0.75 m/s^2

   Solution: b

$$a = r\alpha = 0.3 \times \frac{10}{7} = 0.43 \text{ m/s}$$

6. Frank and his bicycle have a total mass of 85.0 kg. At the top of an 18 m high hill, his speed is 8.0 m/s, and his speed doubles as he reaches the bottom of the hill. How much energy is lost to friction?

   a) 3.14 kJ

   b) 4.11 kJ

   c) 6.83 kJ

   d) 8.16 kJ

   Solution: c

$$E_{\text{loss}} = -\Delta M- = m[\frac{1}{2}u^2 + gh - \frac{1}{2}(2u)^2] = 6.83 \text{ kJ}$$

7. A light ray strikes the height of an isosceles right-angled prism perpendicularly. The light then passes through the hypotenuse, making an angle of 20° with the incident beam direction. What is the refractive index of the prism? Assume that the prism is surrounded by air, which has a refractive index of 1.00.

   a) 1.28

b) 1.33

c) 1.42

d) 1.56

Solution: a
Using Snell's law, we know that the refractive index of the prism n_2 is

$$n_2 = \frac{n_1 \sin \theta_i}{\sin \theta_r}$$

where θ_i is the incident angle and θ_r is the refraction angle. We can use the givens to find n_2 easily:

$$n_2 = \frac{1(\sin(45 + 20))}{\sin(45)} = 1.28$$

8. An AK-47 gun of mass 3.8 kg is famous for its high recoil velocity. The bullet's mass is 7.5 g, and the bullet's speed is 370 m/s. The final recoil speed of AK-47 is

a) 0.24 m/s

b) 0.47 m/s

c) 0.73 m/s

d) 1.00 m/s

Solution: c
Momentum shall be conserved.

$$p_{\mathrm{AK-47}} + p_{\mathrm{bullet}} = 0$$

Taking the direction of the bullet to be negative,

$$v_{\mathrm{AK-47}} = \frac{0.0075 \times 370}{3.8} = 0.73 \text{ m/s}$$

9. Sameh, weighing 980 N, is in an elevator that is accelerating upward at 9.8 m/s^2. The force exerted on him by the elevator floor is

a) 0 N

b) 490 N

c) 980 N

d) 1960 N

Solution: d
The net force is

$$9.8m = \sum_{i=1}^{2} F_i = F_{\mathrm{elevator}} + F_g = F_{\mathrm{elevator}} - 9.8m$$

Therefore,

$$F_{\mathrm{elevator}} = 2 \times 9.8m = 1960 \text{ N}$$

10. For a step-up transformer with a 200-turn secondary coil and an input voltage of 2 V, which of the following could be the number of turns of the primary coil?

a) 100

b) 200

c) 300

d) 400

Solution: a
Since this is a step-up transformer, the number of turns in the primary coil has to be less than that of the secondary coil. Thus, answer **a** is correct.

11. An electron of velocity 1×10^6 m/s enters a perpendicular magnetic field region $B = 5$ mT and starts moving in a circular orbit. What is the radius of the path taken by the electron?

a) 0.570 mm

b) 1.14 mm

c) 1.71 mm

d) 2.28 mm

Solution: b
The magnetic force will provide the centripetal force needed to sustain this circular motion. Therefore,

$$qvB = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{qB} = 1.14 \text{ mm}$$

12. What is the net potential energy associated with four charges, three of which have a charge q and one of which has a charge $-q$, placed on the vertices of a square of side length l?

a) 0

b) $\frac{kq^2}{l}$

c) $-\frac{kq^2}{l}$

d) $\frac{kq^2}{\sqrt{2}l}$

Solution: a
From the symmetry of the question, one could guess it's 0. However, we can easily solve this by assigning a potential V between two positive charges and a potential $-V$ between a negative and a positive charge. We would get that the net potential V_{net} is

$$V_{net} = 2V + (-2V) + \frac{V}{\sqrt{2}} + \left(-\frac{V}{\sqrt{2}}\right) = 0$$

13. What is the energy required to increase the temperature of 100 g of H_2O from 80°C to 120°C? Specific heat capacities of liquid water and water vapor are 4200 J/kg°C and 2000 J/kg°C, while the latent heat of vaporization is 2.3×10^6 J/kg.

a) 2400000 J

b) 240000 kJ

c) 240000 J

d) 2.4 kJ

Solution: c

$$Q = mc_1\Delta T + mc_2\Delta T + mL = m\left(\Delta T[c_1 + c_2] + L\right) = 240000 \text{ J}$$

14. A light source of frequency 7×10^{14} Hz is incapable of ejecting photoelectrons from a certain metal. In an attempt to use this source to eject photoelectrons, the source is given a velocity toward the metal. If when the speed of the source is equal to $0.28c$ photoelectrons are barely getting ejected, then the work function of the metal is

    a) 4.03 eV

    b) 3.86 eV

    c) 3.71 eV

    d) 2.09 eV

    Solution: b
    Since the Doppler effect increases the apparent frequency of the source, the new frequency becomes

    $$f' = \sqrt{\frac{1+v/c}{1-v/c}} f = \sqrt{\frac{1+0.28c/c}{1-0.28c/c}} \times 7 \times 10^{14} = 9.33 \times 10^{14} \text{ Hz}$$

    Subsequently,

    $$\phi = hf' = 6.626 \times 10^{-34} \times 9.33^{14} \times \frac{1}{1.6 \times 10^{-19}} = 3.86 \text{ eV}$$

15. The temperature of some gas can be defined as the

    a) internal energy of the gas

    b) average kinetic energy of the gas particles

    c) heat energy of the gas

    d) average nuclear energy of the gas atoms

    Solution: b
    Temperature is the average kinetic energy of an object's particles; in this case, the object is some gas.

16. Two objects, A and B with masses 1 kg and 6 kg, are dropped from a certain height on Jupiter, whose gravity is 2.4 times the gravity of Earth. If air resistance is negligible, then at the end of their fall,

    a) the velocity of object B would be 6 times that velocity of object A.

    b) the velocity of object A would be 2.4 times that velocity of object B.

    c) the velocities of A and B will be the same.

    d) the relation between the A's and B's velocities would be indeterminable (i.e., given values are not enough).

    Solution: c
    Velocities change due to acceleration, and acceleration does NOT depend on the mass of a free-falling object as

    $$F_g = ma_g \implies a_g = \frac{\frac{GM\cancel{m}}{r^2}}{\cancel{m}} = \frac{GM}{r^2}$$

    Therefore the final velocities of A and B will have changed by the same amount starting from rest; in short, they'll be equal.

17. Two bodies, x and y, have equal kinetic energies. The mass of x is four times that of y. The ratio of the momentum of x to that of y is

    a) 1:2

    b) 2:1

    c) 3:1

    d) 9:1

    Solution: b
    The kinetic energy K is equal to

    $$K = \frac{p^2}{2m}$$

    The ratio between their linear momenta is

    $$\frac{p_x^2}{2m_x} = \frac{p_y^2}{2m_y} \Rightarrow \frac{p_x}{p_y} = \sqrt{\frac{m_x}{m_y}} = 2$$

18. A spring connected to a mass m is pulled a distance of 0.1 m and is left to oscillate in a frictionless medium. Its oscillation period was 1 s. Find the velocity of the spring when it was at a position 0.05 m from its rest position.

    a) 0.355 m/s

    b) 0.544 m/s

    c) $\pm$0.355 m/s

    d) $\pm$0.544 m/s

    Solution: d
    Using the conservation of energy, we get that

    $$\frac{1}{2}kx^2 + \frac{1}{2}mv^2 = \frac{1}{2}kA^2 \Rightarrow v = \pm\omega\sqrt{A^2 - x^2}$$

    We can directly substitute in this equation while knowing that $\omega = \frac{2\pi}{T}$ and get that

    $$v = \pm 0.544 \text{ m/s}$$

19. Which of the following is a valid measuring unit of resistivity?

    a) Ωm

    b) Ωm^2

    c) Ω/m

    d) Ω/m^2

    Solution: a

    $$R = \rho\frac{l}{A} \implies \rho = \Omega\text{m}$$

20. If a railroad of length 10 m is laid on the road at 20°C and is fastened so that it's not allowed to move, what would be the magnitude of stress developed within the railroad at 40°C? The Young's modulus of steel is 20×10^{10} N/m^2 and the expansion coefficient of steel is 11×10^{-6}.

a) 11×10^6 N/m^2

b) 22×10^6 N/m^2

c) 33×10^6 N/m^2

d) 44×10^6 N/m^2

Solution: d
This question is solved by substituting in the linear expansion formula. The new length L is

$$\Delta L = \alpha L_i \Delta T \Rightarrow \Delta L = 0.0022 \text{ m}$$

The formula for tensile stress σ is

$$\sigma = Y\frac{\Delta L}{L_i} \Rightarrow \sigma = 44 \times 10^6 \text{ N/m}^2$$

21. Which of the following examples involves random error?

a) Failing to account for the possibility of a zero error on a moving pointer balance.

b) Neglecting to subtract the background count rate when determining the count rate from a radioactive source.

c) Using 12 m/s^2 as the gravitational acceleration when calculating the weight of an object.

d) Reading a value from a volumetric flask from different angles.

Solution: d
Option d is the only option where a unpredictable error is affecting measurements.

22. Sound waves of velocity 343 m/s propagate through a 0.5-meter air-filled pipe opened from both ends. Which of the following represents the first harmonic?

a) 172 Hz

b) 206 Hz

c) 343 Hz

d) 686 Hz

Solution: c
The first harmonic happens at

$$f = \frac{v}{2L} = 343 \text{ Hz}$$

23. Steel's density at 25°C is 8000 kg/m^3. If steel's coefficient of linear expansion is $\alpha = 11 \times 10^{-6}$ °C^{-1}, what is steel's density at 100°C? (This question was incorrect in the exam's form. Sorry for the inconvenience.)

a) 7750 kg/m^3

b) 7780 kg/m^3

c) 7980 kg/m^3

d) 7995 kg/m^3

Solution: c

$$\frac{m_i}{V_i[1 + 3\alpha\Delta T]} = \frac{8000}{1 + 3\alpha\Delta T} = 7980 \text{ kg/m}^3$$

24. Given the equations of angular velocity ω and angular acceleration α

$$\omega = -\frac{\pi}{2}t^2 + 3t$$

$$\alpha = 3 - \pi t$$

find the maximum angular velocity.

a) 1.4 rad/s

b) 2.2 rad/s

c) 2.8 rad/s

d) 3.5 rad/s

Solution: a
When the angular acceleration is zero, the angular velocity is maximum.

$$0 = 3 - \pi t \implies t = \frac{3}{\pi} \implies \omega_{\max} = -\frac{\pi}{2}\left(\frac{3}{\pi}\right)^2 + 3\left(\frac{3}{\pi}\right) = 1.4 \text{ rad/s}$$

25. The wave equation of a mechanical wave is

$$y = 3\sin(2x - 10t)$$

where x is in meters and t is in seconds. What is the velocity of this wave?

a) 0.2 m/s

b) 2 m/s

c) 5 m/s

d) 6 m/s

Solution: c
Since $v = \lambda f$, we can rewrite it as follows

$$v = \frac{2\pi}{k} \times \frac{\omega}{2\pi} = \frac{\omega}{k} = 5 \text{ m/s}$$

26. The peak value of an electric field in a traveling electromagnetic wave is 6 V/m, then the peak value of the magnetic field is

a) 0.2 nT.

b) 2 nT.

c) 20 nT.

d) 200 nT.

Solution: c

$$\frac{E_{max}}{B_{max}} = c$$

$$B_{max} = \frac{E_{max}}{c} = \frac{6}{3 \times 10^8} = 2 \times 10^{-8} \text{ T} = 20 \text{ nT}$$

27. A supersonic plane has a Mach number of 3. What is its Mach angle? The Mach number represents the ratio between the plane's velocity and the velocity of sound waves generated by it.

a) 18.4°

b) 19.5°

c) 70.5°

d) 71.6°

Solution: b
One could use some geometry to deduce that

$$\theta = \arcsin\left(\frac{1}{M}\right)$$

where θ is the Mach angle and M is the Mach number. Therefore, we get that

$$\theta = 19.5^\circ$$

28. Two capacitors, 1.7 mF and 53 mF, are connected in parallel together and in series with a 88 mF capacitor. If they are charged by a 5 V battery, the energy stored in the capacitor is

a) 0.0843 J

b) 0.422 J

c) 1.12 J

d) 371 J

Solution: b
The equivalent capacitance is calculated first

$$C_{\text{equivalent}_{\text{parallel}}} = \sum_i^n C_i = 1.7 \text{ mF} + 53 \text{ mF} = 54.7 \text{ mF}$$
$$\frac{1}{C_{\text{equivalent}_{\text{series}}}} = \sum_i^n \frac{1}{C_i} = \frac{1}{54.7 \text{ mF}} + \frac{1}{88 \text{ mF}}$$
$$\implies C_{\text{equivalent}} = 0.0337 \text{ F}$$

The energy stored is then calculated

$$E = \frac{1}{2}CV^2 = 0.422 \text{ J}$$

29. An AC voltage $V = V_{\max}\sin(\omega t)$ is applied to an RLC circuit, resulting in a case of resonance. Which of the following expressions correctly expresses the current in the circuit?

a) $I_{\max}\sin(\omega t)$

b) $I_{\max}\sin(\omega t + \frac{\pi}{2})$

c) $I_{\max}\sin(\omega t + \pi)$

d) $I_{\max}\sin(\omega t - \pi)$

Solution: a
At resonance, the voltage and current in an RLC are in sync (i.e., the phase angle is 0).

30. When a person eating accidentally drops a fork on a table, which of the following correctly describes a pair of action and reaction forces involved in this situation?

a) The action force is the force exerted by the fork on the table, and the reaction force is the normal force exerted by the table on the fork.

b) The action force is the force exerted by the fork on the table, and the reaction force is the resistive force exerted by the air on the fork.

c) The action force is the force exerted by the fork on the table, and the reaction force is the gravitational force exerted by the table on the tuning fork.

d) The action force is the force exerted by the table on the fork, and the reaction force is the gravitational force exerted by the fork on the table.

Solution: a

The only valid force pair is the fork-table contact force pair, which is option a.