Spooky Quiz (Cycle 2) Experimental Round Objective Questions

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August 2020

Note: Questions - 4,9,13,19,20 are Multi Correct Option type and rest of the questions are Single Correct Option type.

Consider the following setup where a metallic ball is hung from ceiling top through massless, in-extensible threads. The square metallic plates are connected across a source of voltage U. Let the distance between the plates be d, length of the thread be L, radius of metallic ball be r and mass be m.

There are three major factors at play: air resistance, collisions with the plate and gravity. Assume that the charge remains constant during the motion between the plates, unless other mentioned. Consider the oscillations with frequency stabilized.

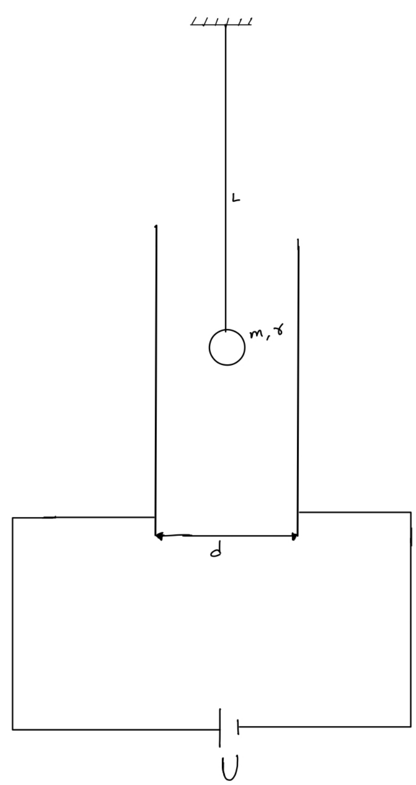

Figure 1: Experimental Setup

1. If q was actually a point charge, what would be your observations?
   a. Sparking
   b. Sticking to a plate
   c. greater velocity
   d. no difference
2. Assume dissipation of energy as kv^2 and ignoring gravity, then which of the following is true?
   a. $v \propto U$
   b. $v \propto \sqrt{U}$
   c. $v \propto 1/\sqrt{U}$
   d. $v \propto U^2$
3. If gravity is not neglected, then the equation of motion is

$$m\frac{dv}{dt} = \underbrace{-mg\frac{x}{L}}_{\text{term 1}} + qE$$

   What is the origin of term 1?
   a. Component of tension
   b. Component of gravity
   c. Relativistic correction
   d. Component of resistive force
4. Suppose the setup is taken into space where its perfectly vacuum and collisions with plate are inelastic. The ball is given some initial velocity. Pick the option that may be correct.
   a. The avg speed of the ball will increase at first but gradually stabilises.
   b. The avg speed of the ball continues to increase because of the force due to electric field.
   c. The avg speed of the ball decreases first and then gradually stabilises.
   d. The avg speed of the ball doesn't change.
5. Select the correct statement when the setup is kept in a fluid ($\rho_{fluid} \sim 1kg/m^3$, $D_{ball} \sim 1cm$, $v \sim 10cm/s$, $\eta_{fluid} \sim 10^{-5}$)
   a. Drag force on the ball is linearly dependent on velocity
   b. Drag force on the ball is dependent on velocity in a quadratic fashion
   c. Drag force on the ball is dependent on sq root of velocity
   d. Drag force on the ball is independent of the velocity
6. Suppose we keep the setup in water and the readings are taken for different water temperatures. At a particular voltage across plates,
   a. Frequency of the ball increases as temperature is increased
   b. Frequency of the ball decreases as temperature is increased
   c. Frequency of the ball is independent of temperature
   d. Frequency of the ball first increases then decreases.
7. First we consider only the air resistance $\mathbf{F} = -k_r v^2 \hat{\mathbf{v}}$. Which of the following is false?
   a. To stabilise frequency, speed in intermediate part is constant.

b. $\nu \propto \frac{1}{\sqrt{k_r}}$

c. $\nu \propto \frac{U}{(d-2r)\sqrt{d}}$

d. $\frac{1}{d-2r}\sqrt{\frac{U}{d}}$

In general, we can obtain an expression for the time period using the average speed of the ball in one half oscillation.

8. Consider the effect of coefficient of restitution only($k_e < 1$). Take $k_e = 1/2$, $U = 3kV$, $d = 5cm$, $r = 1cm$, $m = 25g$. Assuming the ball is charged to its full capacity each time and there is no dissipation, time period of oscillation is:

   a. $4.82s$

   b. $3.16s$

   c. $2.82s$

   d. $3.46s$

Define the sensitivity of frequency w.r.t a parameter as the percent change in the frequency per 1% change in the parameter.

9. Which of the following are true?

   a. Always more sensitive to k_e

   b. At $k_e = 1/2$, more sensitive to k_e

   c. At $k_e = 0.2$, more sensitive to k_e

   d. At $k_e = \sqrt{2} - 1$, more sensitive to k_e

10. Now consider the effects of both gravitation and collisions. As earlier, the average velocity can be used to calculate frequency. Given that $\omega_0 = \sqrt{\frac{g}{L}}$, which of the following is true?

    a. $\gamma < \frac{\omega_0}{2\pi}$

    b. $\gamma \geq \frac{\omega_0}{2\pi}$

    c. $\gamma = \frac{\omega_0}{2\pi}$

    d. $\gamma \in (\frac{\omega_0}{4\pi}, \frac{\omega_0}{\pi})$

11. When length of the string is doubled, which of the following is true?

    a. γ increases

    b. γ decreases to $\frac{1}{\sqrt{2}}$ times its value

    c. γ decreases to less than $\frac{1}{\sqrt{2}}$ times its value

    d. γ decreases to more than $\frac{1}{\sqrt{2}}$ times its value

12. When coefficient of restitution increases, which of the following is true?

    a. γ decreases

    b. γ increases

    c. first increases and then decreases

    d. first decreases and then increases

Now we can tackle the most general case with all three factors taken into account. Instead of trying to solve this equation, we will try to calculate some parameters.

13. Which of the following are true?

a. The ball always oscillates freely
b. The ball oscillated freely only above a certain voltage.
c. The usual range of voltage(few kV), electrostatic force << gravitational force
d. The usual range of voltage(few kV), electrostatic force >> gravitational force

14. If at the applied voltage, the electric force exactly compensates the energy lost due to resistive force in one half oscillation, which of the following is true?

    a. $\bar{\nu}$ will be like a damped simple pendulum
    b. $\bar{\nu}$ will be like an undamped simple pendulum
    c. $\bar{\nu}$ will be linear
    d. $\bar{\nu}$ will have a non trivial nature which cant be analytically determined

15. Assuming the ball is charged to its full capacity, which is the required value of the applied voltage above?

    a. $4.743kV$
    b. $3.674kV$
    c. $6.124kV$
    d. $2.846kV$

16. Now, assume the charge on the ball dissipates exponentially with time. Which of the following is true about oscillations?

    a. T increases
    b. T decreases
    c. T remains unchanged
    d. Depending upon the parameters, all of the above are possible.

17. (Questions 17-20) Lets solve few different questions now, not necessarily related to Franklin's bell. Two parallel plates are connected by a wire so that they remain at the same potential. Let one plane coincide with the xz plane (Plate 1) and other with the plane $y = s$ (Plate 2). The distance s between the plates is much smaller than the lateral dimensions of the plates. A point charge Q is located between the plates at $y = b$. What is the magnitude of the total charge on the inner surface of both the plates approximately ?

    a. $\frac{Q}{2}$
    b. Q
    c. 0
    d. $\frac{Q}{2}+\frac{b}{s}Q$

18. Now if one tries to solve the above problem using method of images, how many image charges one needs to consider ?

    a. 1
    b. 2
    c. 3
    d. ∞

19. The magnitude of total surface charge on the inner surface of the two plates are-

    a. Plate 1: $\frac{Q}{2}$

b. Plate 1: $\frac{s-b}{s}Q$

c. Plate 2: $\frac{Q}{2}$

d. Plate 2: $\frac{b}{s}Q$

20. In another world, instead of Coulomb's law, electric force $\bar{F}$ on a point like charge q due to another point like charge Q is found to obey the following law.

$$\overrightarrow{F} = \frac{Qq(1-\sqrt{\alpha r})}{4\pi\epsilon_0 r^3}\overrightarrow{r}$$

Here α is a positive constant and $\overrightarrow{r}$ is the position vector of charge q relative to the charge Q.

a. Electric field due to a point charge Q is $\overrightarrow{E} = \frac{Q(1-\sqrt{\alpha r})}{4\pi\epsilon_0 r^3}\overrightarrow{r}$

b. Line integral of this electric field $\oint \overrightarrow{E} \cdot d\overrightarrow{l}$ over a closed path is also zero as in our world.

c. Gauss' law $\oint \overrightarrow{E} \cdot d\overrightarrow{s} = \frac{q_{enclosed}}{\epsilon_0}$ also holds true for this electric field.

d. All the above statements are true but this electric field is not conservative.