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Date of experiment: 11th March, 2009

Experiment 2 - Centripetal force

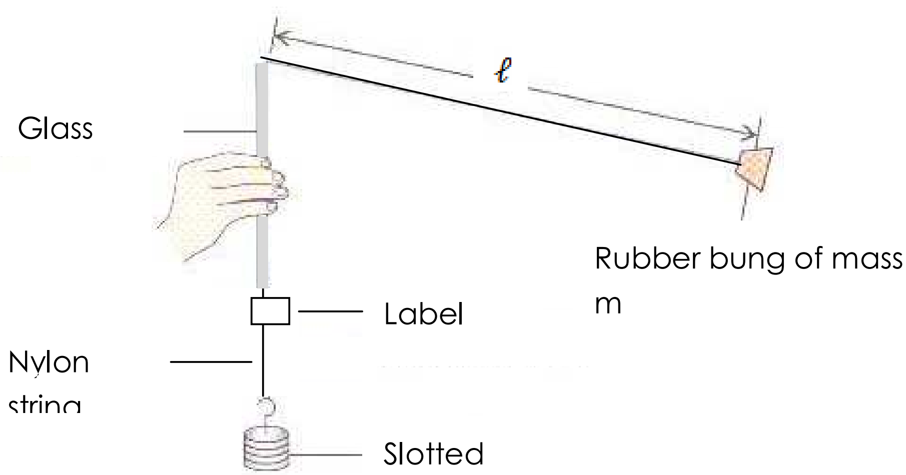
Objective

In this experiment, we are going the centripetal force for whirling a mass around a horizontal circle; then we compare experimental result with the theoretical value given by the formula $F = m\omega^2 r$.

Apparatus

- Rubber bung
- Glass tube about 15cm long(wrapped by rubber tubing)
- 50g slotted weight
- Wire hook
- 1.5m of nylon string
- Labels
- Meter rule
- Stop-watch

Setup



Theory

When a mass m attached to a string id whirled around a horizontal circle with radius r, according to the Newton's First Law of Motion, there must be a force acting on it. It is a centripetal force for maintaining the circular motion. To produce centripetal acceleration, a centripetal force is needed. The centripetal force is · en by

$$F = m\omega^2 r$$

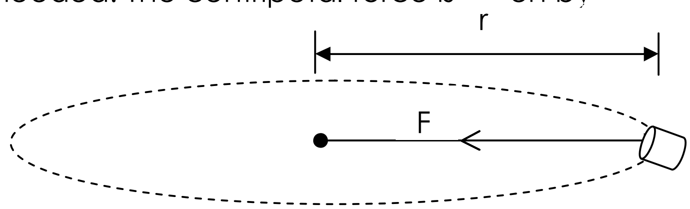


Figure 2

where ω is the angular velocity of the circular motion. The force is provided by the tension of the string and it must be directed towards the centre of the circular path.

We can substitute $\omega = \frac{v}{r}$ into the formula for F,

$$F = \frac{mv^2}{r}$$

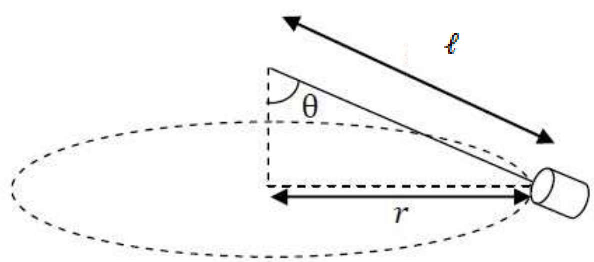


Figure 3

The string may not be horizontal as there is a rubber bung moves around. Actually, the bungs moves in a circle of radius $r = \ell \sin\theta$. The tension T provides a centripetal force and a force to support the weight of the bung. We can then resolve T into its horizontal and vertical components, it is easy to show that $T = m\omega^2 \ell$ regardless of the angle θ. The label acts as a marker which tells us if the centripetal force is balanced by the weight due to gravity.

Procedure

1. The centripetal force apparatus was constructed as shown as figure 1.
2. The mass of the rubber bung was measure by the balance. The weight of the slotted weight gives the tension T in the string.
3. A length of the nylon string from the rubber bung was measured to the glass tube.
4. The Length of string ℓ was marked with a label. ℓ was recorded.
5. The glass tube was held vertically and the rubber bung was whirled around. The paper marker was just below the glass tube without touching it. (figure 1)
6. 50 revolutions of the bungs was timed and the angular velocity ω was calculated.
7. The experiment was repeated in several times using different lengths L of the string.

Precautions

1. The position of the label should be just below the glass tube. The position should remain unchanged since the length of the string should be kept constant.
2. Since we need to whirl the rubber bung around. We should be careful and do not hit anything around us during the experiment.
3. Try to whirl the rubber bung in a horizontal circle in order to minimize the error.
4. The glass tube should be held vertically.
5. The mass of slotted weight should be constant during each experiment.
6. The glass tube is east to break, therefore, we should handle it with care.

Data

Tabulate the results as follows:
Mass of rubber bung m = 0.01369g
Mass of slotted weight M: 0.05kg

Length of string ℓ /m	0.25	0.4	0.5	0.7
Time for 50 revolutions 50 t/s	28	32	35	44

Data analysis and Results

Tabulate the results as follows:

Mass of rubber bung m = 0.01369g

Mass of slotted weight M: 0.05kg

Tension in string T = Mg = 0.05x9.8N = 0.49N

Length of string ℓ /m	0.25	0.4	0.5	0.7
Time for 50 revolutions 50 t/s	28	32	35	44
$\omega = \frac{2\pi}{T}$/rad s^{-1}	11.22	9.82	8.98	7.14
$m\omega^2\ell/N$	0.4309	0.5281	0.5520	0.4885

Mean $m\omega^2\ell$ = (0.4309+0.5281+0.5520+0.4885) =0.4999 N

Standard deviation σ = 0.0458

Discussion

The percentage error between the theoretical value of the tension □ and the experimental value $m\omega^2\ell$ is :

$$\frac{0.4999 - 0.49}{0.49} \times 100\% = 2\%$$

The experimental value $m\omega^2\ell$ is larger than theoretical value tension □, since there is some source of error in this experiment.

Firstly, the position of the paper clip may not be the same, since the label indicate the length of the string, L fluctuates during the experiment, the length of the string beyond the upper opening is not constant. From the formula :

$$mg = m\omega^2\ell$$

when the value of L is increased, the experimental result will be larger than the theoretical result. Oppositely, when the value of ℓ is decreased, the experimental result will be smaller than the theoretical result. Therefore, the results are affected by different value of ℓ.

Secondly, there is a friction existing between the glass tube and the string. Some of the centripetal force is lost as friction instead of providing centripetal acceleration. It can affect the results.

Thirdly, the rubber bung is not set into a horizontal circular path. It is not possible to set into a horizontal circular path. It is because it dips at an angle θ to the vertical line since the vertical component of the tension ($T\cos\theta$) balances the weight of the rubber bung. The force $T\sin\theta$ acts towards the centre of the circle is not equal to the tension T. ℓ is not equal to the radius of the circle. This causes the error.

Fourthly, The rubber bungs may not move in a constant speed. This affect the time for the experiment, and cause a error on period T and the angular velocity ω.

Fifthly, there is an error on our reaction time to start and stop the timer. Although we take the time of 50 revolutions, the reaction time of humans directly affect the experimental results.

Sixthly, the experiment involves measurement error. The apparatus for measurement is not enough, for example, the metre rule can just measure the length of string which is correct to the nearest 0.1 cm. By the following equation,

$$\frac{\delta T}{T} = \pm\left[\frac{\delta m}{m} + 2\frac{\delta\omega}{\omega} + \frac{\delta\ell}{\ell}\right]$$

The largest possible error:

$$\delta T = \pm\left[\frac{\delta m}{m} + 2\frac{\delta\omega}{\omega} + \frac{\delta\ell}{\ell}\right] \times T$$

$$\delta T = \pm\left[\frac{0.000001}{0.01369} + 2\frac{1}{34.75} + \frac{0.0001}{0.4625}\right] \times 0.4999$$

$$\delta T = \pm 0.0289 \text{ N}$$

For the vertical equilibrium of the rubber bung:

$$T\cos\theta = mg$$

$$Mg\cos\theta = mg$$

$$\cos\theta = \frac{m}{M}$$

$$\therefore \theta = \text{constant}$$

For the horizontal circular motion:

$$r = \ell\sin\theta$$

$$T\sin\theta = m\omega^2\ell\sin\theta$$

$$T = m\omega^2\ell$$

From the equation,

$F_{net\ radial} = m\omega^2\ell$
$T\sin\theta = m\omega^2\ell$
We can know that when the angular velocity ω increases, θ will also increase.

Conclusion

In this experiment, we try to measure the centripetal force by whirling a mass in a horizontal circle for circular motion. We show that $T = m\omega^2\ell$ regardless of the angle θ.

We compare the experimental value to theoretical value and find that the experimental one is a bit larger than the theoretical value, which is due to the error of this experiment.
It is also clear to show that θ is a constant. And from the formula, $T\sin\theta = mr\omega^2$, we can know the relationship between m and r, which is $\omega \propto r^{-\frac{1}{2}}$.

We can improve the experiment by moving the rubber bung in a constant speed. Also, the rubber bung should be set in a horizontal circular path. We should also keep the length of the string beyond the upper opening constant. The time for more revolutions of the circular motion could be taken for a more precise result.

Reference

- New Way Physics for Advance Level – Book1(Mechanics) ; Manhattan Press (H.K.) LTD, page 172-173
- http://en.wikipedia.org/wiki/Centripetal_force