Circular Motion

In this lab you are using two simulations:

Part I – Exploring variables associated with circular motion.
The Physics Aviary Circular Motion Learning Lab found here:
https://www.thephysicsaviary.com/Physics/singlepage.php?ID=21

Part II – Exploring force associated with circular motion. Centripetal force.
The Physics Aviary Classic Circular Force lab, found here:
https://www.thephysicsaviary.com/Physics/singlepage.php?ID=22

Part I – Exploring variables associated with circular motion

1. Click on first simulation url to open The Physics Aviary Circular Motion Learning Lab:
https://www.thephysicsaviary.com/Physics/singlepage.php?ID=21

2. Click on grid area to access simulation start page. This simulation experiment has onscreen guided instructions which you follow and complete associated task, in order to get to the next round of simulation. There are seven short sessions/rounds of this experiment. Please read fully and follow onscreen instructions.

3. Click 'Begin' to start experiment. Upon completion of all eight iterations of this experiment enter your first and last name in the slot provided. The next screen shows your completion certificate. Take a screenshot of this completion certificate complete with your name and date, time of completion and eight rows of results. Include this screenshot in your lab report.

Instructions and Hints for the Exercises

- The first exercise asks you to find the number of revolutions per minute. There is no need to run the timer for 60 seconds and there is no need to watch the timer. Just time approximately 10 revolutions (it can be many more or a few less).
    - Focus on starting the timer when the dot is along an axis,
    - stopping the timer when the dot is along the same axis,
    - and count the revolutions.
    - You do not have to watch the timer, just position your mouse on it.
    - Once you stop the timer, you have the time for the number of revolutions that you counted.
    - Divide the time by the revolution number, to obtain the **time for one revolution (this is also called the period)**. Then divide 60 seconds by the period.
    - If you prefer to watch the timer until it hits 60 seconds, and count the revolutions, that would work too, of course.

- In general, it is much easier to do the exercises by timing several cycles, as opposed to a single one. This way, various errors, e.g. due to reaction time, do not spoil the measurement as much. To get the timing for a single cycle, you simply divide the total time by the number of cycles.

- The frequency is the number of cycles per unit of time (seconds, in this case).

  - Note that in the first exercise, we were finding a frequency also (number of revolutions per minute) but the unit of time was a minute
  - So use same procedure. Time several cycles, obtain the period by dividing. But now we are dividing 1 by the period in second, since we want the cycles per second, instead of per minute.

- The angular speed is similar to a frequency, but it counts angle traversed per unit time instead of revolution number per unit time.
  - The angle is measured in radians here,
    so **one revolution corresponds to angle 2π**
  - so **angular speed is 2π/(period) or equivalently 2π*(frequency)**.
  - Note, that if you are used to considering angles that differ by 2π as being the same, here, they are physically distinct. 3π as opposed to π indicates the arrival of object at the same point on the circle for the second time.
  - The symbol for angular speed is usually ω.

- To connect with our familiar notion of speed as distance over time (for the case of constant speed), convert the traversed angle into a distance.
  - The **circumference of a circle is 2π*(radius).**
  - Similarly, **any distance travelled along a circle, is (traversed angle in radians)*radius**.
  - So **speed along a circle's circumference (sometimes referred to as linear speed) is just (angular speed)*(radius) or equivalently 2π*(radius)/(period)**

- The last exercise asks you to state the time when the velocity is in a particular direction.
  - Do not confuse the *position* of the object and its direction with respect to the origin with the *velocity* and its direction.
  - When the object's *position* is on the right, its *direction of motion, equivalently the direction of its velocity* is down.
  - Note that the direction of the velocity i.e. the direction of motion is changing all the time, so a particular direction is only at an instant.

Part II – Circular Motion, Centripetal Acceleration, Centripetal Force

You can see the real life version of this experiment here:

https://www.youtube.com/watch?v=ISU1g_R9ieM

and/or

https://www.youtube.com/watch?v=Gt3y7r08aTs

1. Click on second simulation link to open The Physics Aviary Classic Circular Force Lab: https://www.thephysicsaviary.com/Physics/singlepage.php?ID=22

2. Click on illustrated rectangle on simulation screen to get to experiment start page. Now click 'Begin' to start experiment.

3. Read onscreen instructions. Click on 'Masking tape' on string, to change radius, r. Click on the "washers" to change the hanging mass. Click on the arrows to change the rotating mass. To change values, you must reset the simulation.

Exercise and Questions

- **Choose values for your radius and moving (revolving) mass and keep these fixed**.
    - For five different choices of washer number, record the value of the period of rotation. (See Table below)

- The weight of the washers is providing the centripetal force for the moving mass, by causing tension in the string.
    - Recall **the weight is the force of Earth's gravity W=Mg**.
    - Each washer has a mass M_w = 10 grams.
    - Do not forget to convert the mass to kilograms.

- **In order to have circular motion, we must have centripetal acceleration: v^2/r**.
    - Recall **angular speed $\omega = 2\pi/T$**
    - **where T is the period**
    - **Linear speed, $v = r\omega$**.
    - **Hence $v^2/r = r*\omega^2 = 4\pi^2*r/T^2$**

- **For revolving mass, m, there must be a centripetal force in the amount $F_C = m*4\pi^2 r/T^2$.**
    - *Notice this is not a new force! This is simply the right hand side of equation F=m*a*
    - Put another way, this is the amount of force required to cause the observed circular motion.

Radius, r (in meters)	Moving mass, m (in kilograms)	Time period, T (in seconds)	Centripetal acceleration, $\omega^2 * r = 4\pi^2 * r / T^2$ (in meters/seconds^2)	Number of Washers, N	Weight of Washers, $W = M * g = N * M_w * g$ (in Newtons)	$F_C = m * r * \omega^2$ (in Newtons)

- Make a scatter plot of $\omega^2 * r$ as a function of the washer weight i.e.
    - put $\omega^2 * r$ on the vertical axis and the washer weight, W, on the horizontal axis.
- Add a trendline using linear fit.
- Include the plot and table in your report

Questions

1. Find the slope of the above graph.

2. From the last two columns of our table we should see that the weight of the washers is indeed equal to the required centripetal force.

$$\mathbf{N * M_w * g = m * r * \omega^2}$$

or

$$\mathbf{W * (1/m) = r * \omega^2}$$

Based on this, what should the slope of your graph be?

3. Discuss whether the slope of your graph agrees with this prediction.
   Note that we are just checking Newton's Law for the case of circular motion.

4. If you watch the videos of the real world version of the experiment, is the string holding the ball actually perfectly horizontal?

5. If the string is not horizontal, is the centripetal force still equal to the full tension in the string and equivalently to the weight of the washers?
If not equal, is the centripetal force bigger or smaller?
Hint: The tension in the string is equal to the weight of the washers and is the same throughout the string. The direction of the tension force is along the string. The direction of the centripetal force must be horizontal since the revolving mass stays in the horizontal plane. Draw a picture!

6. If the string is not perfectly horizontal, is the radius of the revolution bigger, smaller, or the same compared to the length of the string.
Hint: The radius of the revolution is horizontal. Draw a picture!

7. Why is it impossible to have the string be perfectly horizontal?
Hint: If the string is perfectly horizontal, what is balancing the vertical gravitational force on the revolving mass?

Comment: It turns out that the effect of the radius of revolution being a little different from the length of the string exactly cancels the effect of the tension (equivalently the washer weight) being a little different from centripetal force, so that the period can be expressed in terms of just the masses and length of string (without referencing the angle).

Extra Credit:

8. Show that the effect of the radius of revolution being a little different from the length of the string exactly cancels the effect of the tension (equivalently the washer weight) being a little different from centripetal force, so that the period can be expressed in terms of just the masses and length of string (without referencing the angle).

9. Find the angle of the string in terms of the hanging mass and the revolving mass.

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