Lab 4: Centripetal Force

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By:

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Submitted to:
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PS253 Physics III Lab - Fall 2018

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1 Objective

In this lab the objective is to discover what forces are involved when an object with a large mass is brought along a curved path. Observing these forces will allow us to explore the concept of force, centripetal acceleration, and instantanious velocity.

2 Theory

Throughout this lab we spun a triple beam balance to determine forces on an observed mass. To do so, we will need a few equations.

$$a_c = \frac{v^2}{r} \tag{1}$$

Centripetal Acceleration

$$v = \frac{\Delta x}{\Delta t} = \frac{2\pi r}{T} \tag{2}$$

Velocity

$$r = \frac{F_c}{4\pi^2 M}T^2 \tag{3}$$

Radius of Rotation

$$F_c = Ma_c \tag{4}$$

Centripetal Force

3 Equipment

In this lab we will use a Centripetal Force Apparatus to determine forces on the objects on it when spun. We will use a pulley for hangin masses off of. A string will connect out masses with out machines. Masses are to be used for every piece of equipment that mentions a mass. A mass hangas will elevate the masses for the purpose of the lab. We will use a bubble level to ensure out tooling is level. A triple beam balance will be used to determine the mass of out masses.
All equipment is displayed in the Appendix.

4 Procedure

We begin the lab by ensuring that the center post assembly is at the center of the track. We then adjust the leveling screws to ensure that the Apparatus is level. We then select a mass to attach to the hangar and move the side post assembly to our specified radius of 15 cm. We adjust the system to find an equilibrium point where all strings are staight. We adjust the height of the indicator bracket to match the pink disk. We remove the mass and spin the apparatus to return the pink disk to the indicator. We log data for multiple radii.

Table 1: Varying the Radius

Trial #	M (kg)	r (m)	$F_c = mg(N)$	T (s)
1	0.1365	0.150	0.2418	1.597
2	0.1365	0.170	0.2418	1.140
3	0.1365	0.180	0.2418	1.101
4	0.1365	0.140	0.2418	2.360
5	0.1365	0.160	0.2418	1.430

We repeat the steps above with multiple forces.

Table 2: Varying the Force

Trial #	M (kg)	r (m)	$F_c = mg(N)$	T (s)
1	0.1365	0.160	0.5396	1.335
2	0.1365	0.160	1.0301	1.000
3	0.1365	0.160	0.7358	1.163
4	0.1365	0.160	1.2263	0.948
5	0.1365	0.160	0.4415	1.386

We repeat the steps above with multiple masses.

Table 3: Varying the Mass

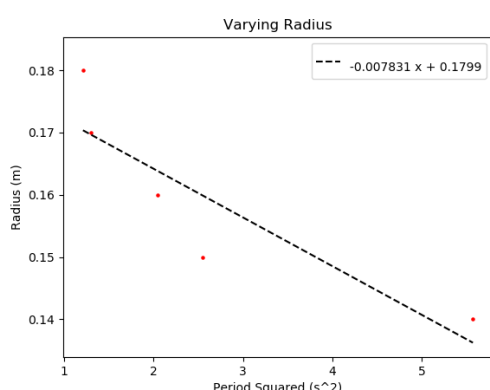| Trial #	M (kg)	r (m)	$F_c = mg(N)$	T (s)
1	0.1462	0.160	0.7358	1.211
2	0.1065	0.160	0.7358	1.045
3	0.2063	0.160	0.7358	1.339

5 Analysis

Part 1
We can rewrite equation (4) in the form

$$r = \left(\frac{F_c}{4\pi^2 M}\right)T^2 \qquad (5)$$

It is expected that plotting r vs. T^2 should be a straight line $y = \alpha x$ with a slope of $\alpha = \frac{F_c}{4\pi^2 M}$. Plotting the data, we produce the following graph
Figure 1

Radius of mass to center of rotation of the Apparatus vs. the square of the period.

experimental slope:	-0.007831
theoretical slope:	0.048708
percent difference:	-117.45%

The slope observed from our data is not consistent with our prediction of the slope. It is possible that we had an error in our data collection that disrupted the data.
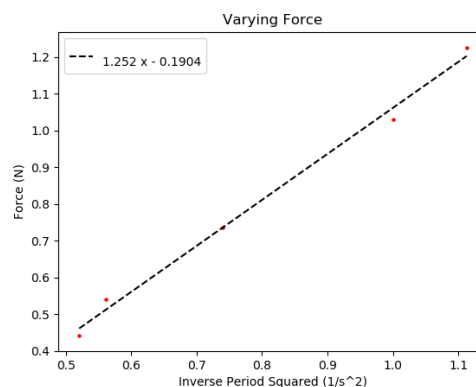
Part 2
We can rewrite equation (4) in the form

$$F_c = (4\pi^2 M r)\frac{1}{T^2} \qquad (6)$$

It is expected that plotting F_c vs. $\frac{1}{T^2}$ should be a straight line $y = \alpha x$ with a slope of $\alpha = (4\pi^2 M r)$. Plotting the data, we produce the following graph
Figure 2

Centripetal force (mg) induced by the spinning Apparatus vs. the inverse of the period squared.

experimental slope:	1.252
theoretical slope:	0.862
percent difference:	45.22%

The slope observed from our data is not consistent with our prediction of the slope. It is significantly closer to our theoretical slope than when we varied the radius that the mass was spun at. This is still likely to be the result of some data collection error or experiment execution error.

Part 3
For our experiment where we vary the mass we use (Eq. 6) and compare out experimental force to (6)'s theoretical force. We then calculate the percent difference.

Table 4: Expected and Theoretical forces

F_{exp}	$F_{theoretical}$	$\%_{diff}$
0.7358	0.7626	-3.51
0.7358	0.6437	14.30
0.7358	0.4732	-24.39

6 Error Analysis

In this las be experienced some large % differences from the theoretical values that were expected. Possible sources of error arise when we look at the data collection process. We have to determine what level the pink indicator disk needs to be at for equilibrium. This is a source of error.

Another source of error is determining what a complete spin is considered. This could be mitigated by an encoder attached to the apparatus that measures the angle. Manually timing is another source of error. This causes variation in out recorded times. In addition to the aforementioned encoder we could mitigate this error by choosing initial conditions that produce a large period. This reduces the fractional error from hand timing.

7 Conclusion

The purpose of this lab was to experimentally observe the variable that influence centripetal force. The results we got mainly supported the formula that we were testing but our varying radius experiment failed to support out formulas due to human error. From this lab we were able to determine the effects of radius and mass on the centripetal force of a spinning object.

8 Appendix

Full Sized Figures

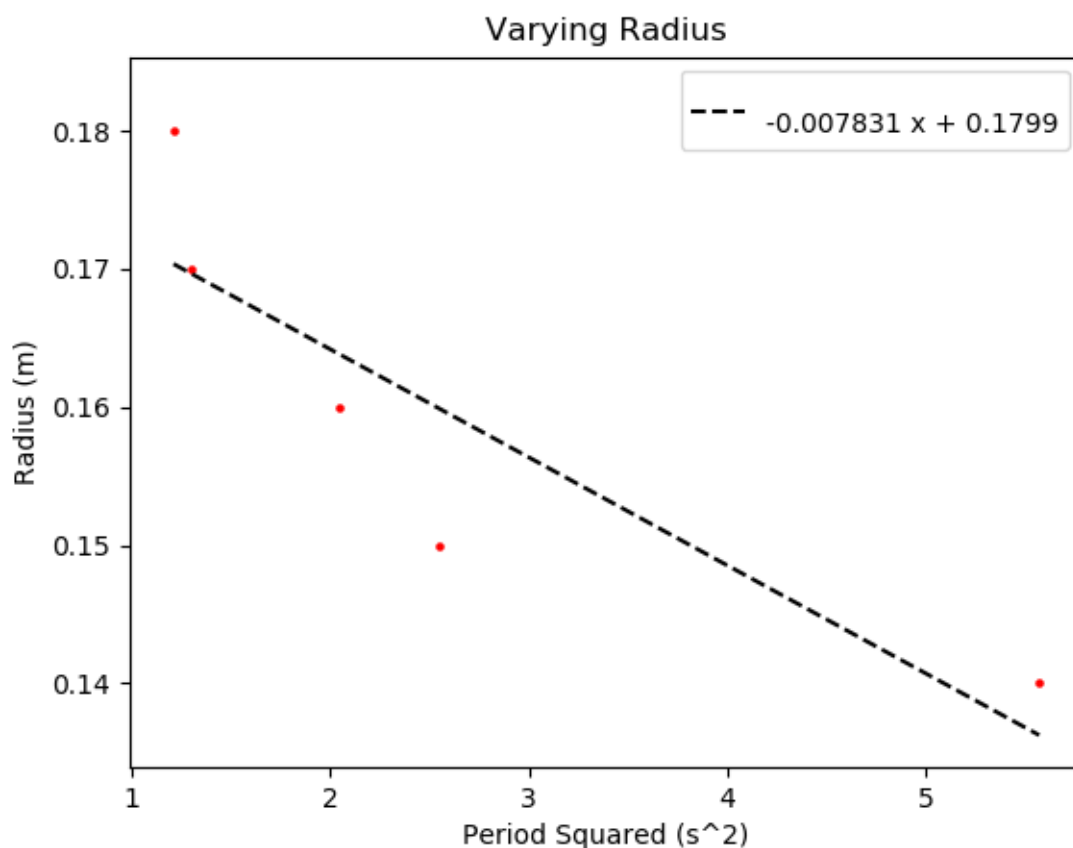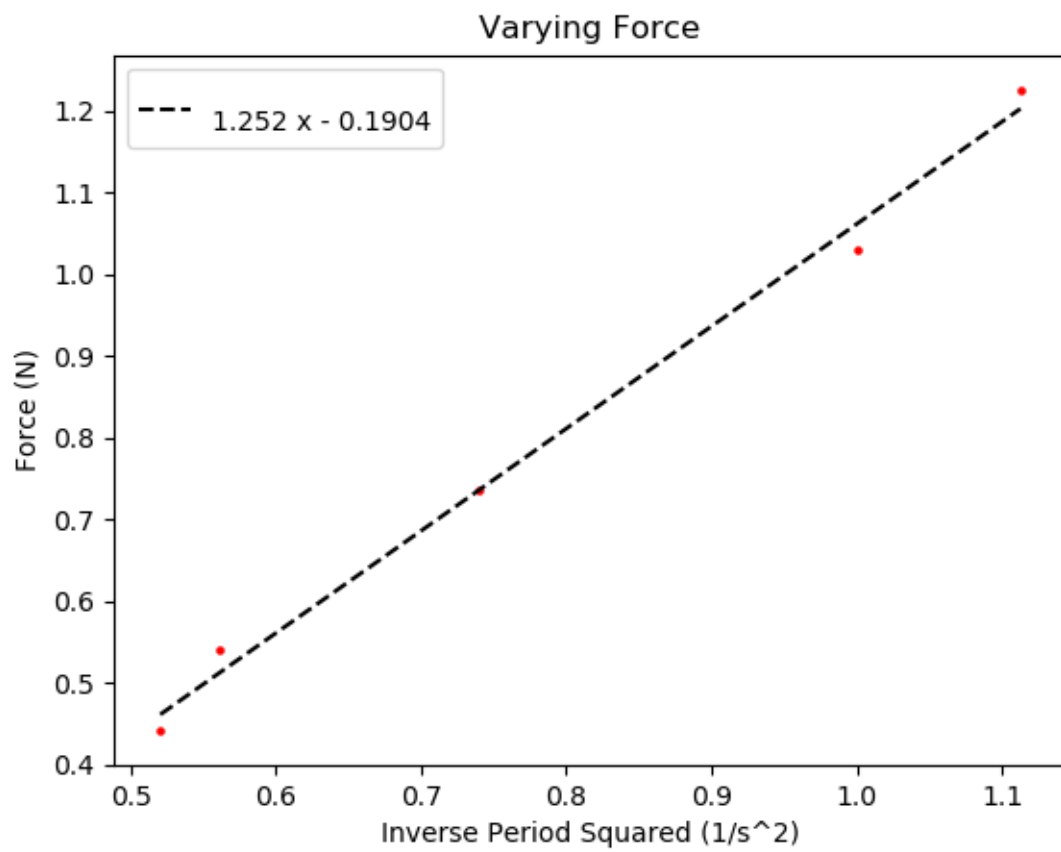

Figure 1: Varying Radius

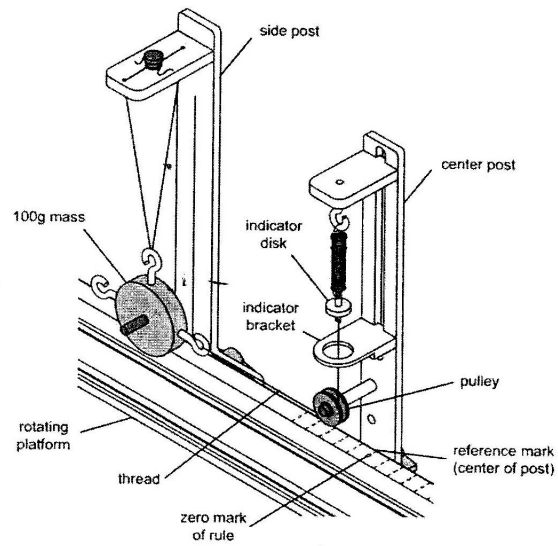Figure 2: Varying Force
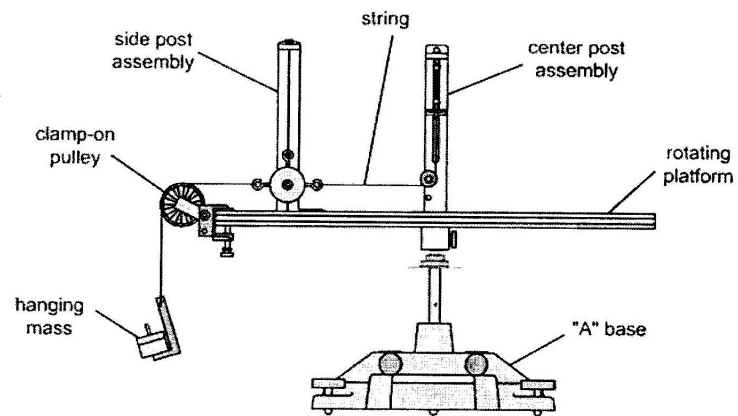
Equipment Sketches

Figure 3: Spinning Apparatus

Lab Code

```
import numpy as np
from scipy import stats
import matplotlib.pyplot as plt

#Varying the radius
plt.figure("Varying Radius")
r = np.array([0.15, 0.17, 0.18, 0.14, 0.16])
t = np.array([1.597, 1.14, 1.101, 2.36, 1.43])
t_squared = t**2
goal_slope = 0.2418/(4*np.pi**2*0.1365) #Fc/(4pi^2M)T^2
x,y = t_squared, r
plt.scatter(x,y, c='r', s=5)

best_fit = np.poly1d(np.polyfit(x, y, 1))
actual_slope = best_fit.c[0]
best_fit_s = str(best_fit)

plt.plot(np.unique(x), np.poly1d(np.polyfit(x, y, 1))(np.unique(x)), 'k--'
label=best_fit_s)
plt.legend()

plt.title('Varying Radius')
plt.xlabel('Period Squared (s^2)')
plt.ylabel('Radius (m)')

print(f'''
Varying Radius
The ideal slope is {goal_slope}
The actual slope is {actual_slope}
The percent difference is {(actual_slope-goal_slope)/goal_slope*100}%
    ''')
plt.savefig('VaryingRadius.png')

#Varying the force
plt.figure("Varying Force")
f = np.array([0.5396, 1.0301, 0.7358, 1.2263, 0.4415])
t = np.array([1.335, 1, 1.163, 0.948, 1.386])
inverse_t_squared = 1/(t**2)
goal_slope = 4*np.pi**2*0.1365*0.16 #4pi^2Mr * 1/T^2

x,y = inverse_t_squared, f
plt.scatter(x,y, c='r', s=5)

best_fit = np.poly1d(np.polyfit(x, y, 1))
actual_slope = best_fit.c[0]
best_fit_s = str(best_fit)
```

```python
plt.plot(np.unique(x), np.poly1d(np.polyfit(x, y, 1))(np.unique(x)), 'k--',
    label=best_fit_s)
plt.legend()

plt.title('Varying Force')
plt.xlabel('Inverse Period Squared (1/s^2)')
plt.ylabel('Force (N)')

print(f'''
Varying Force
The ideal slope is {goal_slope}
The actual slope is {actual_slope}
The percent difference is {(actual_slope-goal_slope)/goal_slope*100}%
    ''')
plt.savefig('VaryingForce.png')




#Varying the mass
m = np.array([0.1462, 0.1065, 0.2063])
t = np.array([1.211, 1.045, 1.339])
f = 0.7358
for index in range(3):
    expected_force = 4*np.pi**2*m[index]*0.16/t[index]
    print(f'''
Varying Mass
The ideal mass is {expected_force}
The actual slope is {f}
The percent difference is {(f-expected_force)/expected_force*100}%
    ''')


plt.ion()
plt.show()
plt.pause(10)
```