VANDERBILT STUDENT VOLUNTEERS FOR SCIENCE
http://studentorgs.vanderbilt.edu/vsvs

NEWTON'S SECOND LAW

Knex Cars

2018-2019 VINSE/VSVS Rural

Goal: To investigate a relationship between the input force and the acceleration of a mass. This relationship is described by Sir Issac Newton's Second Law of Motion, known by its equation: **F= ma**

1st Law: An object in motion stays in motion unless acted upon by a force and an object at rest stays at rest unless acted upon by a force
2nd Law: The force applied by an object is equal to the object's mass times its acceleration
3rd Law: For every action there is an equal and opposite reaction.

Materials
8 Knex cars
8 measuring tapes
8 stopwatches
8 sets of 6 washers and rubber bands
1 roll masking tape

I. Demonstration: Testing Newton's 1st Law of Motion

a. Place a K'nex car on the desk so that all students can see it.
Tell the students that the car is at rest and will remain at rest unless a force acts upon it.
This is Newton's First Law of Motion.
Push the car with enough force that the car rolls about a meter, (but stops by itself before rolling off the desk). Tell the students that you applied a force to the car to set it into motion. It is no longer at rest.

Motion is defined by an object changing position relative to its surroundings (i.e. the car moved from one position on the table to another.).

b. Ask the students; if Newton's Law says the car will remain in motion unless a force acts upon it, why did the it stop? Ask the students what force is acting on it?
Tell the students that a frictional force is acting in the opposite direction of the motion to cause the car to stop.

II. Demonstration: Testing Newton's 3rd Law of Motion

Wind the rubber band a few times, place it on the table but have someone block the front of the car with a hand.
Tell them that the car is at rest.
Remove the hand and let the car travel about 1 meter before stopping it again with a hand.
Ask them why the car moved forward after you released it.

Explain that two equal forces are acting on the car: the force provided by the hand which is acting in one direction and the force provided by the wound-up rubber band which is acting in the opposite direction.

Since, the forces are equal and in opposite directions, the car does not move.
However, tell them that once we let go of the car, the force provided by the hand is no longer acting on the car and therefore the force provided by the rubber band pushes the car forward.

III. Experiment - Testing Newton's 2nd Law of Motion

Write the following equations on the board and tell the students that they are the mathematical relationship of Newton's Second Law of Motion:
*Force = Mass * Acceleration* *F=M*A*

In the experiment that the students are going to do, the car is initially at rest, so the initial velocity is zero. Similarly, the initial distance and time are zero.

Put these equations on the board and tell the students that these relate time and distance together.
Velocity (final) = distance / time, V= D/t
Acceleration = velocity (final)/time, A=V/t

Set-up:

Students are in teams of 3 – 1 student controlling the car, 1 student controlling the stopwatch, start time, and monitoring the finish time, and 1 recorder.
Place masking tape to mark the **starting line** on the floor for each group.
Place masking tape to mark the **finishing line** on the floor for each group. In the VSVS lab, we used 2 meters for the distance.

Testing the car:

- Make sure the wheels are rotating freely by turning the car upside down and spinning the rear wheels. If not, make sure wheels are not rubbing against the sides of the car.
- Sometimes the clips holding the wheels become loose (see picture)
- Fix this by inserting the pin into the hole seen in the frame of the wheel as show in the picture.
- Make sure the rubber band holder (purple) is centered on the axle (rotating shaft connecting wheels)

Put on your safety glasses.

Your Notes:
____

____

____

____

Experiment 1 – Changing the Force (changing the number of times the rubber band is turned around the axle).

Ask students what variables are being held constant, and what variable is being changed? How does this relate to the equation F = ma?

In this experiment the mass is being held constant and the force (F) is being changed by the number of rubber band turns. The acceleration is being calculated after the time is measured.

IMPORTANT:

The rubber bands lose their elasticity after several uses.

If the distance travelled by the car does not make sense (eg the car suddenly travels a much shorter distance with the same number of windings), change the rubber band and start the trials for that set again.

Change out the rubber bands for every new **experiment** and if necessary, for a new set of windings.

In the VSVS lab, we found that we could use the same rubber band for Experiment # 1.

Discard used rubber bands. Hand used rubber bands to the teacher. Do NOT put back into kit.

The student controlling the car (**the driver**) should:

Make sure the purple rubber band holder is in a vertical position (see picture).

Attach one end of the rubber band to it.

Hold the wheels and place other end of the rubber band over the bottom of ALL 3 white prongs.

Wind the rubber band **once** clockwise by rotating the rear wheels (look at the rubber band holder to count the complete turns). Place the FRONT of the car at the start line. Hold the car in position by placing 2 fingers on the car, as shown in the picture.

Make sure all team members are ready. The timekeeper needs to be at the finish line, focusing on the finish line only (the timekeeper cannot be distracted by the movement of the car).

Timekeeper calls 1, 2, 3, GO, and simultaneously (on GO), starts the stopwatch. The driver releases the car on the word “GO”. Release the hold on the wheels and let the car roll to the finish line.

The timekeeper stops the stopwatch as soon as the front wheels of the car cross the finish line.

Record the time in column 2 in the data table (Table 1.)

Repeat this trial 2 more times. Average the data (time).

Your Notes:

____

____

____

____

Now change the number of times the rubber band is wound up (see data table) and repeat the experimental steps above.

Table 1.

Trial #	Time (seconds) with 1 rotation of rubber band	Time (seconds) with 2 rotations of rubber band	Time (seconds) with 3 rotations of rubber band	Time (seconds) with 4 rotations of rubber band
1	3.80	3.09	2.10	1.87
2	4.60	3.51	2.08	1.86
3	4.20	3.55	2.15	1.97
4				
Average	4.20	3.38	2.11	1.90

(5 – 1.69)

Use the averaged time, calculate the velocity, and acceleration for the different number of rotations.

Table 2.

Mass of car = ~155gm = .155Kg

# of Rotations	Distance (m)	Average Time $_{Final}$ (seconds)	Velocity$_{Final}$ = D/T (m/sec) (calculated)	Acceleration= Velocity/time (m/sec/sec) (calculated)
1	2m	4.20	.48	.11
2	2m	3.38	.59	.18
3	2m	2.11	.95	.45
4	2m	1.90	1.1	.58

We tried 5 rotations 1.7 1.18 .69 but feel it is a bit extreme!

Graph the results.

Experiment 2. Changing the Mass of the Car.

In this experiment, the only variable is the **mass** (that of the car plus added masses of the washers).

The **Force** is kept constant by winding the rubber band **three times.** Make sure this is the same each time.

Use fresh rubber bands at the start of this experiment and as needed after.

Note the mass of your car (about .155 Kg), written on the orange piece of the car) and enter it in your table. Make sure students enter the mass as **Kg**

a) Repeat the steps above, with no washers and 3 turns.
   Note the mass of your car (~.155Kg) and enter it in your table (Table

Your Notes:

____

____

____

____

b) Add 2 washers – place a washer on each of the side posts (see picture).
Add the masses of the 2 washers (written on washer) plus the mass of the car. Record mass in Table 3.
Repeat the steps above and record the time it takes for the car to travel 2m in the table.
Repeat 2 times for a total of 3 trials, and average the times.

c) Add another 2 washers for a total of 4 (2 on each post) plus mass of car
Record the total mass for each trial.
Repeat trials and record the times.

d) Add another 2 washers for a total of 6 (3 on each post).
Record the total mass.
Repeat trials and record the times.

e) We found 8 washers slowed the car enough so that it barely crossed the line. Students may want to try it.

Table 3.

Trial #	Time (seconds) with 0 washers added	Time (seconds) with 2 washers added	Time (seconds) with 4 washers added	Time (seconds) with 6 washers added	Time (seconds) with 8 washers added - optional
Mass of car + washers					
1	1.97	2.57	3.15	3.25	3.87
2	2.08	2.44	3.12	3.37	4.44
3	2.15	2.59	3.09	3.26	
4					
Average	2.01	2.53	3.12	3.29	

Use the averaged time, calculate the velocity and acceleration for the different masses of the car.
Mass of car ~1.55 Kg
For these calculations, mass of 2 washers = 75g= .075Kg

Your Notes:
____

____

____

____

Table 4.

Mass of Car (kg)	Distance (m)	Average Time $_{Final}$ (seconds)	Velocity $_{Final}$ (m/sec)	Acceleration (m/sec/sec)
~.155 Kg	2m	2.01	1.00	.50
~.230Kg	2m	2.53	.79	.31
.304	2m	3.12	.64	.21
.379	2m	3.29	.61	.19

Graph the results.

Experiment 3 – Optional.
Changing the force by changing the # of rubber bands.
Another way to increase the Force is to increase the number of rubber bands from those used in Experiment 1.

Replace the 1 rubber band with 2 fresh ones. Repeat the experimental steps and record the data.

IV. Calculations and Graphing.
Have the students predict (from their graphs) what the values for a trial using

a. Another turn of the axle (as in experiment 1).
b. Adding another 2+ washers (as in experiment 2).
c. Adding another rubber band to the axle

Your Notes:
____

Newton's 2nd Law K'nex Cars Observation sheet.

Name ________________________________

Describe Newton's second law of motion

____

What is the formula? What does each part mean?

____

Experiment 1. – Changing the Force and observing the change in acceleration
Now change the number of times the rubber band is wound up (see data table) and repeat the experimental steps above.

Table 1.

Trial #	Time (seconds) with 1 rotation of rubber band	Time (seconds) with 2 rotations of rubber band	Time (seconds) with 3 rotations of rubber band	Time (seconds) with 4 rotations of rubber band
1				
2				
3				
Average				

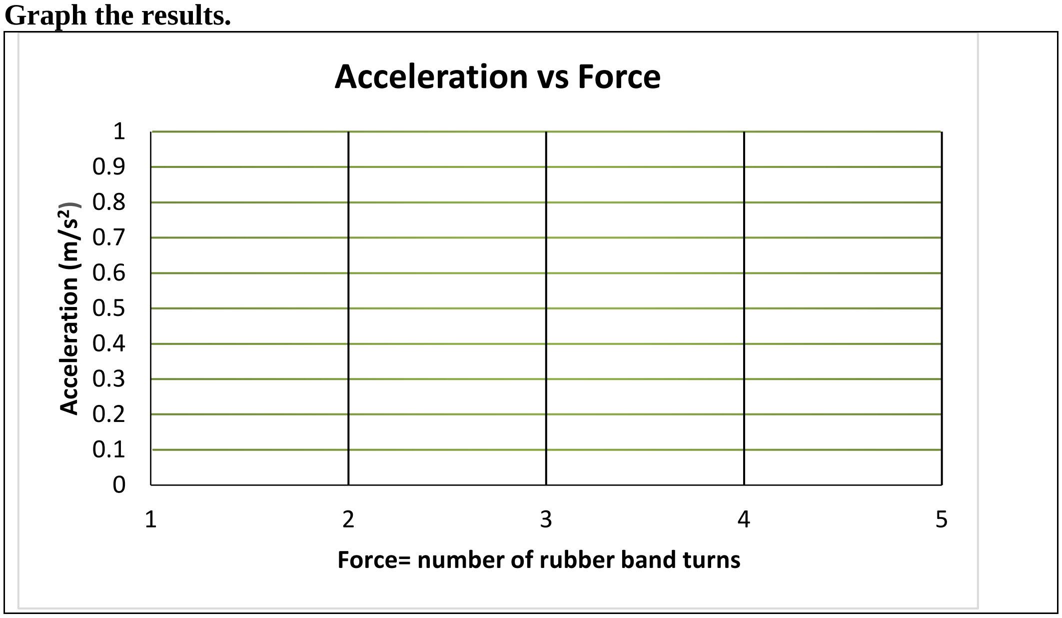
Use the averaged time, calculate the velocity and acceleration for the different number of rotations.

Table 2.

Mass of car = ____gm = _____ Kg

# of Rotations	Distance (m)	Average Time $_{Final}$ (seconds)	Velocity $_{Final}$ (m/sec)	Acceleration (m/sec/sec)
1	2m			
2	2m			
3	2m			

Graph the results.



How does increasing the force change the acceleration?

____

Experiment 2. Changing the Mass and Observing the Change in Acceleration

Table 3.

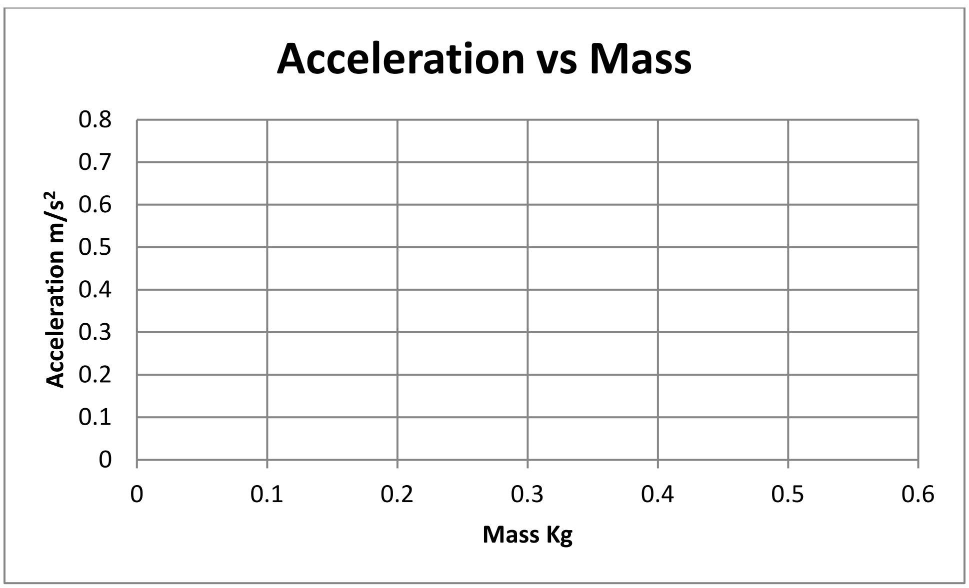
Trial #	Time (seconds) with 0 washers added	Time (seconds) with 2 washers added	Time (seconds) with 4 washers added	Time (seconds) with 6 washers added	Time (seconds) with 8 washers added - optional
1					
2					
3					
Average					

Use the averaged time, calculate the velocity, and acceleration for the different masses of the car.

Table 4.

Mass of Car (kg)	Distance (m)	Average Time $_{Final}$ (seconds)	Velocity $_{Final}$ (m/sec)	Acceleration (m/sec/sec)
	2m			
	2m			
	2m			

Graph the results.



With constant force, how does increasing the mass change the acceleration?

____

____

Newton's 2nd Law K'nex Cars Answer sheet.

Describe Newton's second law of motion

____

What is the formula? What does each part mean?

____

Experiment 1. – Changing the Force and observing the change in acceleration
Now change the number of times the rubber band is wound up (see data table) and repeat the experimental steps above.

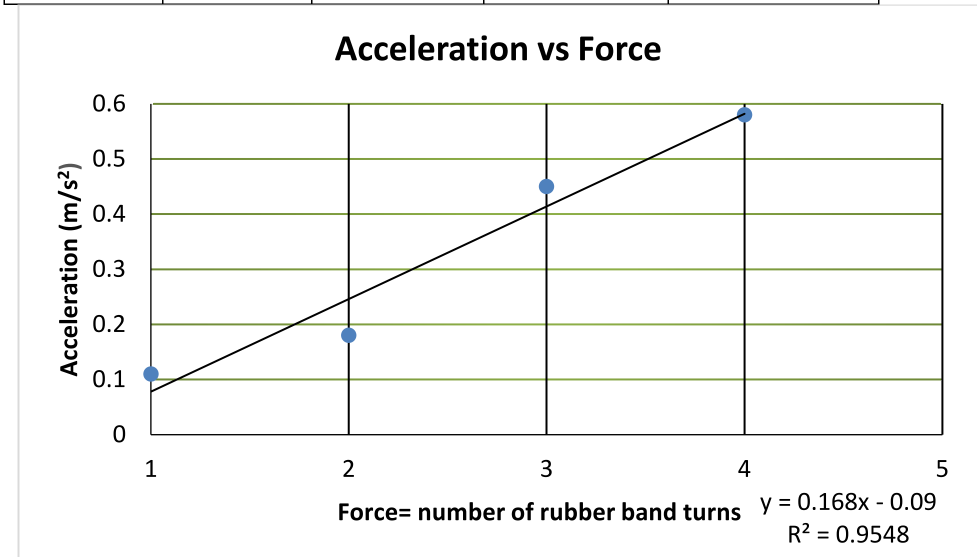
Table 1.

Trial #	Time (seconds) with 1 rotation of rubber band	Time (seconds) with 2 rotations of rubber band	Time (seconds) with 3 rotations of rubber band	Time (seconds) with 4 rotations of rubber band
1	3.80	3.09	2.10	1.87
2	4.60	3.51	2.08	1.86
3	4.20	3.55	2.15	1.97
4				
Average	4.20	3.38	2.11	1.90

Table 2.

Use the averaged time, calculate the velocity and acceleration for the different number of rotations.
Mass of car ~.155Kg

# of Rotations	Distance (m)	Average Time $_{Final}$ (seconds)	Velocity$_{Final}$ = D/T (m/sec) (calculated)	Acceleration= Velocity/time (m/sec/sec) (calculated)
1	2m	4.20	.48	.11
2	2m	3.38	.59	.18
3	2m	2.11	.95	.45
4	2m	1.90	1.1	.58



How does increasing the force change the acceleration?

____

Experiment 2. Changing the Mass and Observing the Change in Acceleration

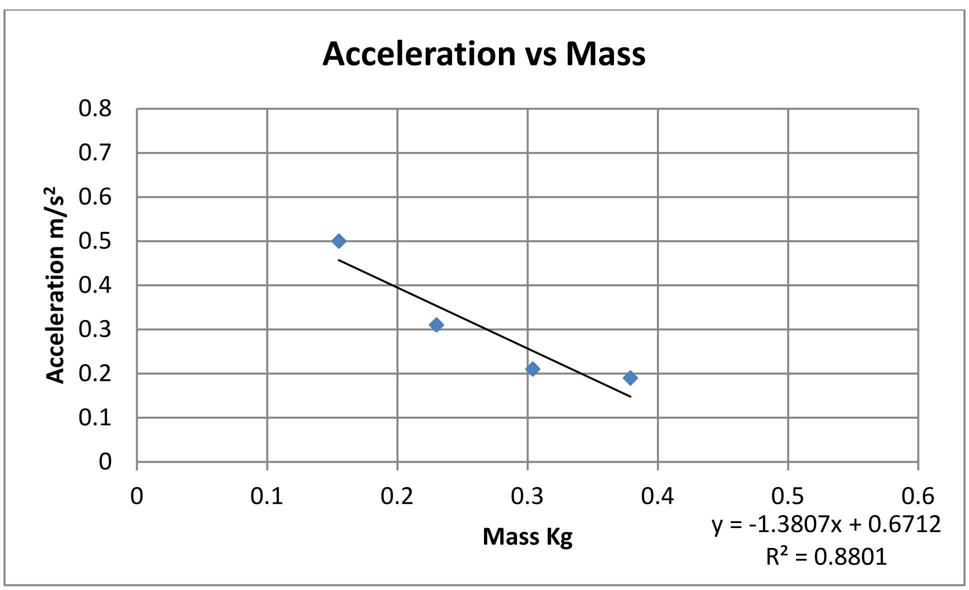
Table 3.

Trial #	Time (seconds) with 0 washers added	Time (seconds) with 2 washers added	Time (seconds) with 4 washers added	Time (seconds) with 6 washers added	Time (seconds) with 8 washers added - optional
Mass of car + washers					
1	1.97	2.57	3.15	3.25	3.87
2	2.08	2.44	3.12	3.37	4.44
3	2.15	2.59	3.09	3.26	
4					
Average	2.01	2.53	3.12	3.29	

Use the averaged time, calculate the velocity and acceleration for the different masses of the car.
Mass of car ~1.55 Kg
For these calculations, mass of 2 washers = 75g= .075Kg

Table 4.

Mass of Car (kg)	Distance (m)	Average Time $_{Final}$ (seconds)	Velocity $_{Final}$ (m/sec)	Acceleration (m/sec/sec)
~.155 Kg	2m	2.01	1.00	.50
~.230Kg	2m	2.53	.79	.31
.304	2m	3.12	.64	.21
.379	2m	3.29	.61	.19



With constant force, how does increasing the mass change the acceleration?

____

Instruction Sheet Newton's Second Law

I. Demonstration: Testing Newton's 1st Law of Motion

Watch your teacher demonstrate Newton's 1st Law.   What force is acting on the car to cause it to stop?

II. Demonstration: Testing Newton's 3rd Law of Motion

Watch your teacher demonstrate Newton's 2nd Law.

III. Experiment - Testing Newton's 2nd Law of Motion

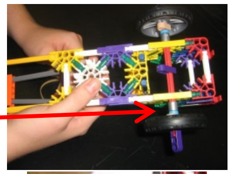
Force = Mass * Acceleration   F=M*A
Acceleration = velocity (final)/time, A=V/t
Velocity (final) = distance / time, V= D/t

Each member in your team is assigned a task..

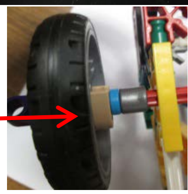
1 student controls the car, 1-2 students control the stopwatch, start time, and monitoring the finish time, and 1 student is the recorder.

Place masking tape to mark the **starting and finishing lines** on the floor for each group.

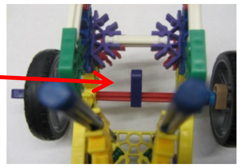
Testing the car:



Make sure the wheels are rotating freely by turning the car upside down and spinning the rear wheels. If not, make sure wheels are not rubbing against the sides of the car.



Sometimes the clips holding the wheels become loose
Fix this by inserting the pin into the hole seen in the frame of the wheel as show in the picture.



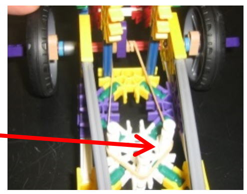
Make sure the rubber band holder (purple) is centered on the axle (rotating shaft connecting wheels)

Put on your safety glasses.

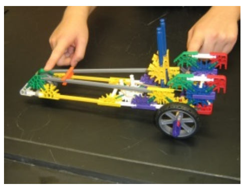
IMPORTANT: The rubber bands lose their elasticity after several uses. If the distance travelled by the car does not make sense (eg. the car suddenly travels a much shorter distance with the same number of windings), **consult your teacher** and then change the rubber band and restart the trials for that set.
Change out the rubber bands for every new **experiment** and if necessary, for a new set of windings.
Discard used rubber bands. Hand used rubber bands to the teacher. Do NOT put back into kit.

Experiment 1 – Changing the Force (changing the number of times the rubber band is turned around the axle).

What variables are being held constant, and what variable is being changed?



1. Make sure the purple rubber band holder is in the vertical position.
2. Put the one end of the rubber band over the purple holder. Stretch it over the bases of all 3 white prongs.
3. Wind the rubber band **once** clockwise by rotating the rear wheels (look at the rubber band holder to count the complete turns).
4. Place the FRONT of the car at the start line. Hold the car in position by placing 2 fingers on the car, as shown in the picture.



5. **Make sure all team members are ready.**

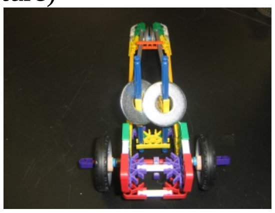
6. **The timekeeper** needs to be at the finish line, focusing on the finish line only (the timekeeper cannot be distracted by the movement of the car).
7. **Timekeeper** calls 1, 2, 3, GO, and simultaneously (on GO), starts the stopwatch.
8. **The driver** releases the car on the word "GO". Release the hold on the wheels and let the car roll to the finish line.
9. **The timekeeper** stops the stopwatch as soon as the front wheels of the car cross the finish line.
10. **Record** the time in column 2 in the data table **(Table 1.)** Repeat this trial 2 more times. Average the data (time).

Now change the number of times the rubber band is wound up (see **data Table 1**) and repeat the experimental steps above.
Use the **averaged time**, calculate the velocity, and acceleration for the different number of rotations.
Use the equations given on the observation sheet. Enter results in **Table 2**.
Graph the results.

Experiment 2. Changing the Mass of the Car.

What variables are being held constant, and what variable is being changed?
Use fresh rubber bands at the start of this experiment and as needed after.

1. Note the mass of your car (on the front orange bar) and enter it in your table (Tables 3 and 4)
2. Repeat the steps above, with no washers and 3 turns of rubber band
3. Add 2 washers – place a washer on each of the side posts (see picture)



4. Add the masses of the 2 washers (written on washer) plus the mass of the car. Record mass in Tables 3 and 4.
5. Repeat the steps above and record the time it takes for the car to travel 2m in the table. Repeat 2 times for a total of 3 trials, and average the times.
6. Add another 2 washers for a total of 4 (2 on each post) plus mass of car Record the total mass for each trial. Repeat trials and record the times.
7. Add another 2 washers for a total of 6 (3 on each post). Record the total mass. Repeat trials and record the times.
8. Use the averaged time, calculate the velocity, and acceleration for the different masses of the car Graph the results.

Experiment 3 – Optional. - Changing the Force by Changing the # of Rubber Bands.

Another way to increase the Force is to increase the number of rubber bands from those used in Experiment 1. Replace the 1 rubber band with 2 fresh ones. Repeat the experimental steps and record the data.

IV. Calculations and Graphing.

Predict (from the graphs) what the values for a trial using

d. Another turn of the axle (as in experiment 1).
e. Adding another 2+ washers (as in experiment 2).
f. Adding another rubber band to the axle.