Relationship between Force, Mass, and Acceleration

Consider a very low-friction car moving along a straight track. Thus far, we have seen that if a constant force acts on an object, the velocity of the object will change at a constant rate. We have used the term *acceleration* to denote the rate of change of velocity. Imagine applying a constant force on the car in the same direction as it is already moving; and, let's say that this causes the car's speed to increase by 2 m/s every second. Why does the car have this particular acceleration and not some other acceleration? Why does it not speed up at a rate of 4 m/s every second, or 1 m/s every second? Could we change something so that the car will accelerate at a rate of 4 m/s/s, or 1 m/s/s? To gain some understanding of why an object experiences the acceleration it does, we first need to think about what factors (or variables) might affect the acceleration.

Do you think that the *strength of the force* that we apply to the car might affect the acceleration?

Now make a specific prediction. If the strength of the force is increased, do you think that the acceleration will increase, decrease, or remain the same? Explain your reasoning as best you can.

Do you think that the *mass of the car* might affect the acceleration?

Now make a specific prediction. If we keep the force the same, but increase the mass of the car, will the car's acceleration increase, decrease, or remain the same? Explain your reasoning as best you can.

In the following experiments, you will test each of these variables (force and mass) to see whether or not they affect the acceleration.

Does Changing the Force Affect Acceleration?

Pre-Experiment Investigation

1) Set up the track at a fairly low angle.

2) Lay the force probe on the track, with the hook facing down the ramp, but do not attach it to the car yet. You may notice that even though nothing is attached to the force probe, the computer is registering a small force. Because of this, we need to zero out the force probe. Click the "Zero" button next to the big green "Collect" button in the toolbar, and then click OK. Before every measurement with the force probe, make sure that it is properly zeroed.

3) Place a paper clip hook into the hole at the back end of your car and place the car on the track. Hook the force probe to the car via the paper clip and hold the force probe up off of the track so that the paper clip and force probe are parallel to the track. Record the force that is pulling the car down the track.

Force at low angle = ________________ Newtons

4) Now, increase the height of the end of the track by several inches. Lay the force probe flat on the track with the hook facing down the ramp, and zero the probe again. Every time you change the ramp angle, you will likely need to re-zero the force probe.

5) Hook the force probe to the car via the paper clip and hold the force probe up off of the track so that the paper clip and force probe are parallel to the track. Record the force that is pulling the car down the track.

Force at higher angle = ________________ Newtons

Notice that as the ramp angle is increased, the strength of the force pulling the car down the ramp increases. We will use this fact to conduct our experiment to test whether the strength of the force affects the acceleration.

The Experiment

1) Set up the track so that the force acting on the car is 0.5 Newtons.

2) Place the motion detector at the top end of the track facing downhill.

3) Put the car about 20 cm in front of the motion detector. Start the motion detector, and as soon as you hear the clicking start, release the car.

4) Use the velocity-time graph to find the acceleration of the car. Remember to first highlight the area of the graph where you want to find the slope, then press the "Linear Fit" icon . Record this acceleration below. Repeat this experiment four more times for a total of five trials and record the values below.

Trial 1:__________m/s/s   Trial 2: __________m/s/s   Trial 3:__________m/s/s

Trial 4:__________m/s/s   Trial 5:__________m/s/s

5) Now, increase the ramp angle so that the force acting on the car is exactly twice as much, 1.0 Newtons. Release the car five times, find the acceleration, and record below.

Trial 1:__________m/s/s   Trial 2: __________m/s/s   Trial 3:__________m/s/s

Trial 4:__________m/s/s   Trial 5:__________m/s/s

6) Finally, increase the ramp angle so that the force acting on the car is 1.5 Newtons. Note that this is three times as large as the original force of 0.5 Newtons. Release the car five times, find the acceleration, and record below.

Trial 1:__________m/s/s   Trial 2: __________m/s/s   Trial 3:__________m/s/s

Trial 4:__________m/s/s   Trial 5:__________m/s/s

7) For each value of the force, average your five trials together and record the average value of the acceleration in the table below.

Force (N)	Average Acceleration (m/s/s)
0.5	
1.0	
1.5	

8) When the force was increased, did the acceleration increase, decrease, or remain the same? How does this compare with your prediction?

9) When the force was doubled from 0.5 N to 1.0 N, by what factor did the acceleration increase? In other words, did the acceleration double, triple, quadruple, or something else?

10) When the force was tripled from 0.5 N to 1.5 N, by what factor did the acceleration increase?

Does Changing the Mass Affect Acceleration?

We now know that the strength of the force does affect the acceleration; but what about the mass of the object? To test this, we need to **keep the force constant**, but change the mass of the car. We will change the mass of the car by stacking extra cars on top of it.

1) The last experiment you did involved a force of 1.5 N acting on the car. Leave the track set up at this angle for now. If you were to release the car, what acceleration would it experience (you have already done this experiment, so just look back at your data)? Record the average acceleration in the table in step 6 on the next page in the "1 car" row.

2) Now, double the mass by stacking a second car on top of the first car. Connect the force probe to this two car combination. What is the force pulling the two cars down the ramp? Is it 1.5 N?

3) Remember, we want to **keep the force constant** for this experiment, and only change the mass. But, when we added a second car, the force increased. To compensate for this and keep the force constant, you will have to lower the ramp angle. **Lower the ramp angle until the force acting on the two cars is 1.5 N**.

4) Now release the two cars and record their motion with the motion detector. Measure the acceleration and record this below. Repeat this experiment four more times for a total of five trials and record the values below.

   Trial 1:__________m/s/s   Trial 2: __________m/s/s   Trial 3:__________m/s/s

   Trial 4:__________m/s/s   Trial 5:__________m/s/s

5) Finally, stack a third car on top of the two cars. **<u>Readjust the ramp angle until the force pulling this three car system down the ramp is again 1.5 N</u>**. Release the car five times, find the acceleration, and record below.

   Trial 1:__________m/s/s   Trial 2: __________m/s/s   Trial 3:__________m/s/s

   Trial 4:__________m/s/s   Trial 5:__________m/s/s

6) For each value of the force, average your five trials together and record the average value of the acceleration in the table below.

Force (N)	Mass	Average Acceleration (m/s/s)
1.5	1 car	
1.5	2 cars	
1.5	3 cars	

7) When the force remained constant but the mass increased, did the acceleration increase, decrease, or remain the same? How does this compare with your prediction?

8) When the force was kept constant, and the mass was doubled from 1 car to 2 cars, by what factor did the acceleration change?

9) When the force was kept constant, and the mass was tripled from 1 car to 3 cars, by what factor did the acceleration change?

Putting it all Together

At this point, we know that both the strength of the force and the mass of the object affect acceleration. More specifically, increasing the force causes the acceleration to increase, while increasing the mass causes the acceleration to decrease. It would be nice to have an equation that reflects this behavior. The equation should allow us to calculate the acceleration (a) of an object if we know the mass (m) of the object and the strength of the applied force (F). Consider the alternatives below.

1) Consider the equation: $a = F \times m$
   a. According to this equation, if you keep the mass (m) the same, but double the force (F), what happens to the acceleration (a)?

   b. According to this equation, if you keep the force (F) the same, but double the mass, what happens to the acceleration (a)?

   c. Based on your answers to parts *a* and *b*, does this equation accurately reflect the behavior you saw in your experiments? Explain why or why not.

2) Consider the equation: $a = \dfrac{m}{F}$

   a. According to this equation, if you keep the mass the same, but double the force, what happens to the acceleration?

   b. According to this equation, if you keep the force the same, but double the mass, what happens to the acceleration?

   c. Based on your answers to parts *a* and *b*, does this equation accurately reflect the behavior you saw in your experiments?

3) Reflect on your answers to questions (1) and (2) above and come up with an equation that would accurately reflect the behavior you saw in your experiments. Write the equation below and explain why it makes sense.

The equation you have developed is known as Newton's Second Law. It describes the relationship between the force applied to an object and the acceleration the object experiences as a result of the applied force. It is a simple equation, and it should remind you that **<u>forces cause acceleration</u>**.

An Interesting Experiment

In the preceding experiment when you stacked up cars, you changed the angle of the ramp to keep the force on the cars the same. What do you think would happen if you were to measure the acceleration for 1, 2, and 3 cars on the **<u>exact same ramp</u>** without changing the angle? Explain your prediction below.

Now, pick a ramp angle and try this out. For each case, release the car 5 times and record the accelerations. Then, find the average acceleration.

<u>One Car:</u>

Trial 1:__________m/s/s Trial 2: __________m/s/s Trial 3:__________m/s/s

Trial 4:__________m/s/s Trial 5:__________m/s/s

Average Acceleration = __________ m/s/s

<u>Two Cars:</u>

Trial 1:__________m/s/s Trial 2: __________m/s/s Trial 3:__________m/s/s

Trial 4:__________m/s/s Trial 5:__________m/s/s

Average Acceleration = __________ m/s/s

Three Cars:

Trial 1:__________m/s/s Trial 2: __________m/s/s Trial 3:__________m/s/s

Trial 4:__________m/s/s Trial 5:__________m/s/s

Average Acceleration = __________ m/s/s

How do the accelerations compare with each other? Does this match your prediction? Use the equation for Newton's Second Law you came up with to explain why this result makes sense.