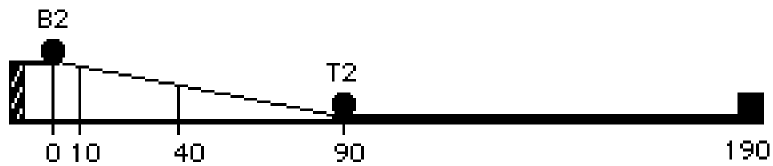
NEWTON'S SECOND LAW OF MOTION

PROBLEM PRESENTATION / EXPLORATION

A The purpose of this investigation is to formulate some idea about what effect a moving steel ball has on a stationary target ball.

1. Set up a one meter long ramp (old "Hot Wheels" track resting on a wooden board) with the angle of incline at about 5° with respect to the table top. Measure 10 cm from the top of the ramp and draw a starting line and label it 0 cm. Place a tape marker at the 40 cm and 90 cm marks. The 90 cm mark should coincide with the end of the ramp.
2. Place another one meter long track flat on the table so that it extends from the bottom of the ramp. Place a wooden block at the end of this second section of track to stop the rolling balls. The entire course is now 190 cm long.



3. Place the target ball (T2) at the bottom of the ramp at the position where the horizontal track attaches to the ramp. Before you release the smallest steel ball (B1) from the starting line of the ramp and allow it to roll down the ramp and hit the target ball, predict what will happen.
4. As in the previous experiment where we learned how to measure acceleration, determine what will be the acceleration of B1 is as it rolls down the ramp. (See the table in the CONCEPT INVENTION section of that experiment if you need to review how to compute the acceleration.) What value for the acceleration of B1 did you obtain? What happened to the target ball?

TABLE 1

Average Time (sec)	Total Distance (cm)	Average Speed (cm/sec)	Speed$_{(final)}$ (cm/sec)	Acceleration cm/sec^2
	10			
	40			
	90			

5. Replace B1 with the medium sized steel ball (B2). Place it at the starting line of the ramp, and roll it down the ramp at the same target ball (T2). What would you have to do to determine the acceleration of B2 down the ramp? [Nothing, remember we said that with all other conditions remaining constant that the mass of the ball doesn't effect the acceleration of the ball. Acceleration is constant.] Note what happens to the target ball when B2 hits it. Compare to when B1 hit it.
6. Replace B2 with the largest steel ball (B3), place it at the starting line of the ramp, and roll it down the ramp at the same target ball. Note what happens to the target ball when B3 hits it.

B. Now that you have had some experience with this experiment, repeat the experiment first with B1 but time how long it takes the target ball to cover the 100 cm distance. Repeat this three times so that an average time can be computed. which will then be entered in TABLE 3 (p. 3) for use later

B1 (T2)	t_1 =	t_2 =	t_3 =	t_{ave} =

Now do the experiment with B2. Repeat this three times so that an average time can be computed. Enter this average in TABLE 3.

B2 (T2)	t_1 =	t_2 =	t_3 =	t_{ave} =

Now do the experiment with B3. Repeat this three times so that an average time can be computed. Enter this average in TABLE 3.

B3 (T2)	t_1 =	t_2 =	t_3 =	t_{ave} =

C. What general conclusion can you formulate about how the target ball reacted when hit by each of the other three balls? [The larger the mass of the impacting ball, the faster the target ball covered the 100 cm.] In all of these experiments the target ball (T2) has been the same mass.

CLASS RESPONSE / CONCEPT INVENTION

A. Constant Mass and Changing Force

1. According to Newton's First Law, an object at rest remains at rest unless it is acted on by an unbalanced force. During the PROBLEM PRESENTATION we saw that the target ball was always at rest and when acted on by the different forces of B1, B2, and B3 began to move across the horizontal track at different rates of speed.
2. The force imparted to the target ball can be found by multiplying the mass and acceleration of B. Fill in the table below.

TABLE 2

Balls	Mass (g)	Acceleration* (cm/sec^2)	Force ($g\ cm/sec^2$)
B1			
B2			
B3			

* Remember the acceleration for B1, B2, B3 will be the same because acceleration is not dependent on mass.

3. Now lets turn our attention to the target ball and find the acceleration it had as it moved horizontally across the table when hit by B1, B2, and B3. The same type of calculation used to fill in TABLE 1 can be used to fill in TABLE 3 at the top of the next page.

TABLE 3

Impact Ball	Average Time of Target Ball (sec)	Distance Target Ball Moved (cm)	Average Speed of Target Ball (cm/sec)	Speed$_{(final)}$ For Target Ball (cm/sec)	Acceleration of Target Ball (cm/sec^2)
B1		100			
B2		100			
B3		100			

4. Let's sum up what we have found about force, mass, and acceleration for the target ball.

TABLE 4

Impact Ball	Force Imparted by Impact Ball (g cm/sec^2)	Mass of Target Ball (T2) (g)	Acceleration of Target Ball (cm/sec^2)
B1			
B2			
B3			

5. Focus on the force and acceleration columns. What happens to the acceleration when the force goes up? What kind of relationship is this in mathematical language? [This is called a direct relationship. As one variable goes up, the other one goes up proportionally. In other words, if you work twice as long, you expect twice as much pay.] So we can say that **if mass is held constant, that the force and acceleration are directly proportional**.

B. Constant Force and Changing Mass

1. There are only two more sets of collision experiments that we need to do to finish up this part of the experiment. We need to use B2 to hit two different target balls. The target ball that we have used for all of the experiments above has been the same size and mass as B2. What do you think would happen if we hit a target ball the same size and mass as B1 with B2? What do you think would happen if we hit a target ball the same size and mass as B3 with B2? Just to keep everything straight lets call the target ball that we have used in all the other experiments T2 (because it is the same as B2). Lets call the target ball that is the same as B1, T1; and lets call the target ball that is the same as B3, T3.
2. Repeat the experiment you did above in the PROBLEM PRESENTATION for B2 but substitute T1 for T2 that you used there. Remember, you are still using B2 for the impact ball.

B2 (T1)	t_1 =	t_2 =	t_3 =	t_{ave} =

Impact Ball	Average Time of T1 (sec)	Distance T1 Moved (cm)	Average Speed of T1 (cm/sec)	Speed$_{(final)}$ For T1 (cm/sec)	Acceleration of T1 (cm/sec^2)
B2		100			

3. Repeat the experiment you did above in the PROBLEM PRESENTATION for B2 but substituting T3 for T2 that you used there. Remember, you are still

using B2 for the impact ball.

B2 (T3	t_1 =	t_2 =	t_3 =	t_{ave} =

Impact Ball	Average Time of T3 (sec)	Distance T3 Moved (cm)	Average Speed of T3 (cm/sec)	$Speed_{(final)}$ For T3 (cm/sec)	Acceleration of T3 (cm/sec^2)
B2		100			

4. Let's sum up what we have found about force, mass, and acceleration for the target balls that were hit with the same force.

TABLE 5

Target Ball	Force Imparted by Impact Ball* ($g\ cm/sec^2$)	Mass of Target Ball (g)	Acceleration of Target Ball (cm/sec^2)
T1			
T2			**
T3			

* This will be the constant. B2 imparted the same force each time.
** This value can be found in TABLE 3.

5. Focus on the mass and acceleration columns. What happens to the acceleration when the mass goes up? What happens to the mass when the acceleration goes down? What kind of relationship is this in mathematical language? [This is called an indirect or inverse relationship. As one variable goes up, the other one goes down proportionally. In other words, if you drive your car twice as fast, you get where you are going in half the time.] So we can say that **if force is held constant, that the mass and acceleration are inversely proportional**.

C. Constant Acceleration and Changing Mass

1. Lets see if we can figure out what should happen here without actually doing another experiment.
2. If we think about it we have already done an experiment almost identical to this. In parts A and B above we looked at the acceleration, mass, and force exerted on the target ball and its subsequent motion along the horizontal track. But the ramp works the same way as the horizontal track except that gravity imparts the force instead of another ball hitting it to impart the force.
3. If you think back to the experiment on Acceleration (Inclined Plane) we found that the acceleration remained constant as balls with different masses rolled down the ramp. We found out in TABLE 2 that the force of impact was found by multiplying the mass and acceleration; and that the larger the mass, the larger the force.
4. So putting all of this together, we see that **if the acceleration remains constant, the force is directly proportional to the mass**. See the table in CONCEPT INVENTION part A2 to review this.

D. Now how can we put together what we have found out in parts A, B, and C?

Part A: **if mass is held constant, the force and acceleration are directly proportional.**

Part B: **if force is held constant, the mass and acceleration are inversely**

proportional.

Part C: **if the acceleration remains constant, the force is directly proportional to the mass.**

The only way that all three of these conclusions from parts A, B, and C can be true is to put them together like this:

$$\mathbf{F = m \cdot a}$$

This is one of the most famous equations in all of science. It is known as Newton's Second Law of Motion.

As in any equation, if you know two of the variables, the third one can be computed from the equation. Lets say that F = 100 and m = 20, what must the value be for **a**? What multiplied by 20 gives 100? Obviously **a** must be 5.

$$\mathbf{F = m \cdot a}$$
$$100 = (20) \bullet (5)$$

1. Okay, lets see whether part A holds true for Newton's Second Law. If mass is held constant (20), what happens to **F** if **a** is doubled? Well, 20 x 10 must give us 200. Did **F** double as **a** doubled? YES!!
$$200 = (20) \bullet (10)$$
2. Lets see whether part B holds true. If force is held constant (100), what happens to **m** if **a** is doubled? Well, 10 x what number will give 100? The value that for **a** must be 10 so that 10 x 10 can equal 100. Did **m** get half as big when **a** doubled? YES!!
$$100 = (10) \bullet (10)$$
3. Finally, lets see if part C holds true. If acceleration is held constant (5), what happens to **F** if **m** is doubled? Well, 40 x 5 is 200. Did **F** double as **m** doubled? YES!!
$$200 = (40) \bullet (5)$$
4. What this says is that if we know any two of the three variables for the balls rolling down the ramp, we can find the other one from **F = ma**.

CONCEPT EXTENSION

A. How could you go about finding the acceleration of the target ball T2 if the impact ball B2 were rolled down the ramp but the ramp had been raised so that it made and angle of 10° with the table instead of 5°.
   1. Do you think it would be twice as much as you found when the angle was only 5°?
   2. What would be the fewest steps you would have to carry out to find out the answer? [We want the a of the target ball. We already know the mass of the target ball. So the only thing we need to use F = ma is the force imparted to the target ball by B2. To find this we need the mass of B2 (which we already know) and the acceleration of B2 down the steeper ramp. Therefore all we have to do is start the ball at the starting line and measure the time it takes to reach the bottom of the ramp. From knowing that it traveled 90 cm in time t we can get the average speed. Knowing the average speed we can calculate the speed at the bottom of the ramp. Taking the final speed and subtracting the initial speed (which was zero at the top of the ramp) and dividing by t we get the acceleration. It should only take about 10-15 minutes to get the information to solve this problem. This will really give the students

a chance to apply what they have done in this experiment.]

B. Can they extend F=ma to a slightly different setting?

1. Place a student on roller skates. The skater must hold a spring balance by its hook.
2. A second student must grasp the other end of the spring balance and exert a constant pulling force on the skater . The puller must maintain a constant force throughout the distance over which the skater is pulled. Do not pull harder to get going.
3. What is the acceleration experienced by the student on the skates?
4. If a student who weighed more than the first student put on the skates, what would his acceleration be, if the puller pulled with the same force?
5. Just out of curiosity, now that the acceleration for a skater has been found using F=ma, would you get the same value if you measured off on the floor distances similar to those you marked off on the ramp and measured the time it took for the skater to reach these marks. To make it easier to time use 900 cm, 400 cm, and 100 cm instead of 90 cm, 40 cm, and 10 cm. The calculations could be done the same way that they were done in the experiment named Acceleration (Inclined Plane).