SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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Student Materials

Learning Sequence Item:

917

Law of Conservation of Momentum

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Adapted by: Stephen Druger

Contents

Lab Activities

Readings

This micro-unit was adapted by **Stephen Druger** (Northwestern University, Evanston, Ill.)

Science as Inquiry

Who's Pushing?

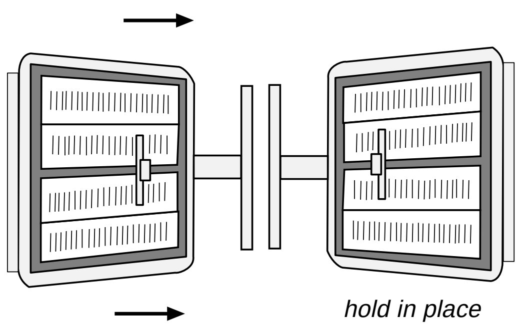
What is the effect on an object when you apply a force?

Overview:

In this activity we examine what an object does in response when you push or pull on it.

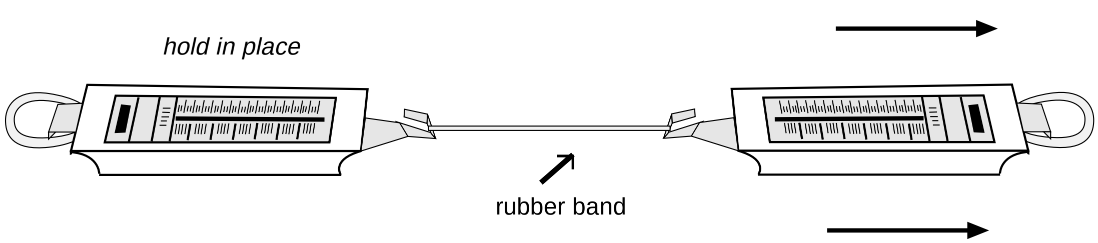
Procedure:

First, carefully adjust two mail scales so that they both read zero when held horizontally. Now press the tops of the two scales against each other. Apply a force on one while holding the other in the same position. How do the readings compare for each applied force?



Now carefully adjust two identical spring scales so that they both read zero when held horizontally. Be careful!—the weight of the hook makes the scale read differently when held horizontally instead of vertically. Tie the bottom hooks (i.e., the bottom hook when vertical) of the spring scales to opposite ends of a long string. Pull on one scale while holding the other in place, with both held on top of a table. Try this for different applied forces, record the results, and observe what relation there is between the measured force on one and the measured force on the other.

Now repeat the exercise by connecting the spring scales with a long rubber band instead of a string. How do you expect the results to change? Note what relation you observe between the force experienced by the first scale and the force experienced by the second scale.



Choose one of these two experiments and see if you can find a way to make the force one object exerts on the second a lot larger than the force the second exerts on the first.

Questions:

1. In the case of the two mail scales, what conclusions can you reach about how the force an object exerted on a second was related to the force the second exerted on the first?

2. Similarly, what conclusions did you reach in the case of the spring balances connected by string?

3. How did you expect the results to differ when you connected them with a rubber band instead of a string, and why? Did the experiment confirm that expectation or lead to a different result, and how?

4. Were you able to make the force one object exerts on a second object much greater than the force the second object exerts on it? If so, how? If not, what conclusion does this suggest?

5. Now let's consider the forces acting on the movable hook of the spring balance. You'll notice, of course, that the scale works precisely because there is a spring included within it. When the string exerts a force on the hook to the right, what does the spring inside do in terms of how its shape changes, and what does it do in terms of the force it exerts?

6. What would happen if there were no spring inside to pull back when the hook on the bottom is subjected to a force (by being pulled)?

7. When the string attached to the hook of the scale pulls the hook to the right and the spring inside the scale pulls it to the left, so it settles in a position with both forces acting at the same time, how do the directions and the sizes of the two forces compare with each other?

8. The previous question dealt with two forces acting on the same hook. How does that differ from the two forces you compared in this activity using the rubber band connecting two spring scales?

9. Consider your answers to questions seven and eight, and especially question six, in answering this: Do the results obtained here demonstrate that two forces acting on the same object are always equal and opposite? Do the results demonstrate that one object exerting a force on another experiences in return an equal and opposite force on itself? Justify your answer in terms of what was observed—be sure in answering to explain the difference between the two cases described.

Science as Inquiry

Pushing and Pulling

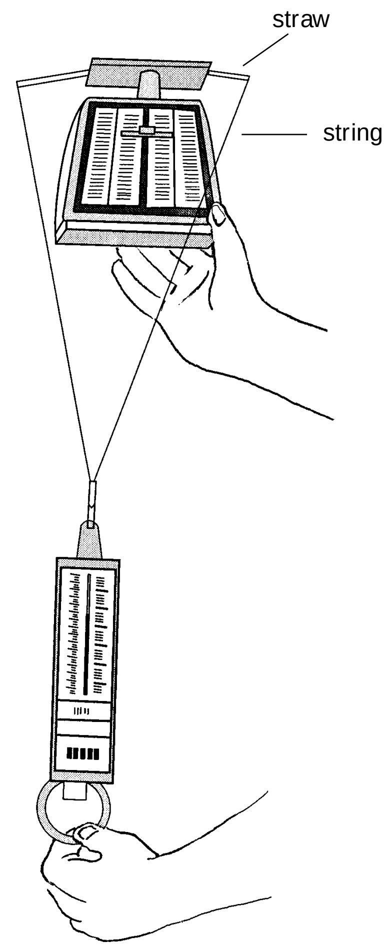
Does the direction of an applied force matter?

Overview:

Applying a force on an object by pushing it might seem different in many ways than applying a force by pulling it. But suppose one object exerts a force on another in such a way that we would regard one object as being pulled and the other as being pushed. We might well ask whether there is a relation between the strength of the two forces, and what the direction of one force is compared with the other. This activity examines that relation for a specific case.

Procedure:

First, tape down a straw or plastic tube with a string (or fishing line) in it to the top of a mail scale and carefully adjust the mail scale to read zero with the small extra weight on it. Similarly, adjust the spring balance so it reads zero when held upside down. Couple the two scales as shown so that the plastic tube and string inside it are pushing down on the mail scale when the string pulls up on the spring scale. Now try exerting different forces on the spring scale while holding the mail scale in position and for each force applied compare the readings of the two scales.



Questions:

1. How do the readings of the spring scale and the mail scale compare, and what can you conclude about the relationship between the size of the forces?

2. What can you conclude about the direction of the force that is exerted by the spring scale and that of the force exerted on it? How about the mail scale?

3. Consider the two scales and the piece of string or fishing line all to be exerting forces on each other. Identify the forces exerted on the fishing line, the direction of each force, and what exerts the force. Do the same for the spring scale, and then do the same for the mail scale.

Science as Inquiry

Point of Application

Does it matter where its pushed?

Overview:

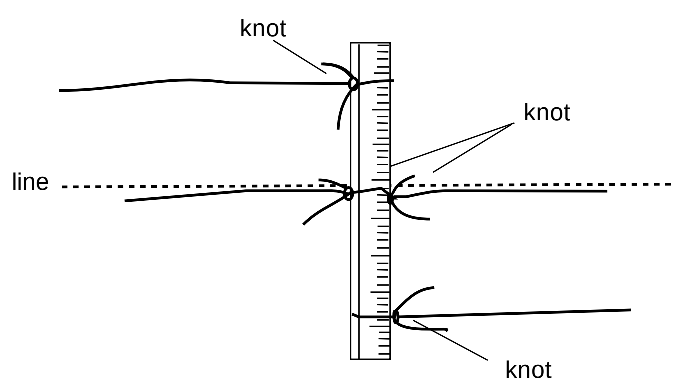
Forces can change how an object moves, for example, making an object at rest start moving. But most everyday objects are large enough that two forces could be applied to the object at different locations. We need to know how that affects the response of an object to the force applied. This activity gives some experience with that.

Procedure:

Tape a large piece of paper to the table top and using a ruler or meter stick draw a line parallel to its edge. Tie lengths of string to a ruler 2.5 cm (one inch) in from each end, then two strings right at the middle of the ruler. The knots at the midpoint should rest on opposite sides of the ruler, as shown, as should the knots at each end. Tape the strings securely in position on the ruler with tape, especially near the knots.

Arrange the ruler perpendicular to the line on the paper as shown. Note what happens when you pull with equal force to the right on one string near the end and to the left on the other, pulling parallel to the line. Rearrange the ruler perpendicular to the line, and note this time what happens when you pull with equal force to the right and to the left at the midpoint of the ruler. Again, pull right along the line on the paper.

Now pull the string to the right at one end and with an equal force to the left pull the other end, so that the ruler readjusts into position. Another student can then line up a ruler or a meter stick so that it goes from one knot being pulled to the other. What do you notice about the direction of the meter stick marking the line from one knot to the other compared with the directions of the strings being pulled? See if you can state under what the conditions an object will not be moved when two equal forces in opposite directions are applied to different points.



Questions:

1. In which cases was no motion produced?

2. What conclusions can you reach about whether the place where the force is applied matters?

3. Under what conditions do you think it would be possible to apply equal forces in opposite directions and have them not cause the stationary object to move? Justify your answer.

4. In the previous question, you compared forces acting at the same time in opposite directions on the same object. When these forces are unequal what happens?

5. When the string pulls on the block (exerting a force), what do the previous activities in this micro-unit tell you about the relation between that force and the force of the block on the string?

6. Questions four and five both deal with two forces that are of equal strength but in opposite directions. In what way are the equal but opposite forces in question five different from the pair of forces in question four? Consider especially what object or objects they act on.

Science as Inquiry

Exploding Carts

How are rockets propelled?

Overview:

When you pull on a spring, it pulls back on you. The forces, as you previously observed, are equal in size and opposite in direction, as are the forces exerted by the two mail scales pushing on each other. This was different from the case of two forces, equal but pointing in opposite directions, acting on the same object at the same time.

But thus far we have been looking at situations in which the forces have not been allowed to set things in motion. By examining a case where the forces cause objects to move, we can see more clearly that the two situations described above really are very different.

Procedure:

First weigh the carts to check to see that they have the same mass. Compress the spring between the two carts and tie them together with string. Then cut the string with a sharp pair of scissors so that the scissors themselves do not push on the carts in the direction they can move. (Some carts may have a built-in spring mechanism that accomplishes the same effect as tying them together with the spring compressed between them.)

Try this with carts that are empty and then with an extra 1-kg mass added as cargo in one of the two carts. Pay careful attention to how the carts move and notice how the motion changes when there is an extra 1-kg mass in one of the carts.

Now repeat the exercise with a very small cart and a much more massive one. Observe what happens when the string is cut.

Questions:

1. What did you observe in the case where the two carts had the same mass? Did one cart move or both? How did their motions compare?

2. When one cart pushes the other to the right with a certain force, what force, if any, is the second cart exerting on the first? What evidence have you seen for this in previous activities?

3. How can your observations about the motion for two carts of equal mass be explained in terms of your answer to the previous question?

4. Now let’s consider the case where the total mass of one cart is much larger than the other. How do the forces that each exerts on the other compare? And what did you observe in comparing the observed motion for each of the two carts?

5. Based on your answer to the previous question, and on what you observed in this activity, what can you conclude about how resistance to being set into motion by a force depends on mass, and why?

6. Based on what you observed, what conclusions can you reach about how ejecting a mass backward should affect the motion of an object that is free to move, and why does this happen in terms of forces that act?

7. When one cart pushes the other, the other experiences an equal force in the opposite direction. Suppose someone tells you that the total force is therefore zero, because the two equal and opposite forces cancel, and therefore nothing should move. Clearly that is not what you saw, so what is wrong with that argument?

8. A rocket emits gas rapidly in a backward direction. Suppose the rocket is floating in space far from the earth when it starts doing this. What would you expect to happen, and why, in terms of what you observed in this activity?

Student Sheet

Science as Inquiry

Push 'em Back!

How is a rocket propelled?

Overview:

When you pull on a spring, it pulls back on you. The forces, as you previously observed, are equal in size and opposite in direction, as are the forces exerted by the two mail scales pushing on each other. This was different from the case of two forces, equal but pointing in opposite directions, acting on the same object at the same time.

But thus far we have been looking at situations in which the forces have not been allowed to set things in motion. By examining a case where the forces cause objects to move, we can see more clearly that the two situations just described above really are very different.

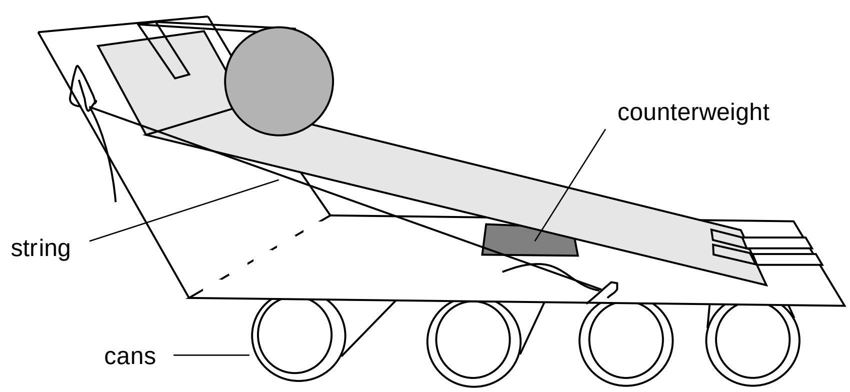
Procedure:

Cut out the cardboard as shown. Use a cutting edge and a ruler to etch a line partly into the cardboard so that you can fold up a flap at the end, and using some paper clips and string secure the flap so it is at about a 45° angle with the horizontal. Use some tape to hold the rubber ball in position at the top edge of the flap.

Place empty aluminum soda cans under the cardboard to allow it to roll. You will probably first find it necessary to add the counterweight to the cardboard to keep it from tipping over when placed on the soda-can support.

When ready, carefully snip the tape with a pair of sharp scissors to allow the ball to roll down the incline. Be careful that the scissors themselves do not apply any significant force in the any direction along which the cardboard can roll. Observe what moves in which way when the ball is allowed to roll.

Repeat the exercise with about 0.5 kg more mass as the counterweight. Observe the motion now compared with the previous case.



Questions:

1. What did you observe with the less massive counterweight? Did the cardboard also move, and if so, in what direction, or did it stay still?

2. Let's now consider just the forces along a horizontal direction. If the cardboard pushes the ball to the right as it rolls down the incline, what horizontal force, if any, does the ball in turn exert on the cardboard, and is it to the left or to the right?

3. What evidence have you seen for this in previous activities in this micro-unit?

4. How can what you observed for the experiment with the less massive counterweight be explained in terms of your answer to the previous question?

5. Now let's consider the case where the extra mass has been added. How did the motion you observed differ for this case?

6. Based on your answer to the previous question, and on what you observed in this activity, what can you conclude about how resistance to being set into motion by a force depends on mass, and why?

7. What conclusions can you reach based on what you observed about how ejecting a mass backward should affect the motion of an object that is free to move?

8. When the ball is pushed by the cardboard, the ball exerts a force just as strong in the opposite direction. Suppose someone tells you that the total force is therefore zero, because the two equal and opposite forces cancel, and therefore nothing should move. Clearly that is not what you saw, so what is wrong with that argument?

9. A rocket emits gas rapidly in a backward direction. Suppose the rocket is floating in space far from the earth when it starts doing this. What would you expect to happen, and why, in terms of the forces acting and what you observed in this activity?