Force, Work and Energy

Reference Guide

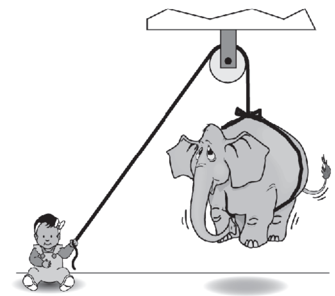
Equipment Setup

Investigation Guides

A-1 Ropes and Pulleys

Key Question: How can you use the ropes and pulleys to lift large weights with small forces?

In this Investigation, students learn to define force and identify input and output force in a simple machine. They gain quantitative experience working with force through the use of spring scales. Next, students build a block and tackle machine and discover how this simple machine can be used to multiply force. The students will develop a mathematical relationship between the number of supporting strands of rope and the force needed to lift the block.



Preparation

You may wish to practice setting up the ropes and pulleys set before class. It is helpful to have one set assembled to use as a demonstration. Students may be confused by the terms "ropes and pulleys" and "block and tackle." They refer to the same materials.

Setup and Materials

Students work in groups of four at tables.

Each group should have:

- One physics stand
- One ropes and pulleys set
- One spring scale calibrated to measure 0 -10 newtons
- One calculator

Each student should have:

- Copy of the Investigation and answer sheet

The Investigation

Time

One class period

Leading Questions

- What is force?
- How is force measured?
- How can ropes and pulleys make it possible to lift large weights with small forces?

Learning Goals

In this Investigation, students will:

- Define and measure force.
- Identify input and output force on a simple machine.
- Describe how input force changes as the string is arranged to pass over more pulleys.

Key Vocabulary

force, weight, input force, output force, newton

1

1a. Sample student answers:
Someone stepping on the accelerator of a car
Someone pedaling faster on a bicycle
Someone throwing a baseball

1b. Sample student answers:
Someone stepping on the brakes of a car
A goalie stopping a hockey puck

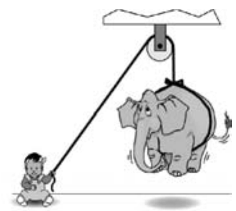
1c. Sample student answers:
Someone turning the steering wheel of a car to change its direction
Someone returning a serve in tennis

A-1 Ropes and Pulleys

Question: How can you use the ropes and pulleys to lift large weights with small forces?

In this Investigation, you will:

1. Learn to build machines that allow you to lift large weights with small forces.
2. Discover the relationship between the input force needed to lift a load and the number of pulleys in your machine.



Would you believe that a small child can lift an elephant with just muscle power? It's true! You could make it possible by building a simple machine with some rope and pulleys.

1 What is force?

In this Investigation, you measure the amount of **force** you need to lift a block. To understand what's happening, you need to know about forces.

In science, force is defined as a push, pull, or any action that has the ability to change motion. It takes force to start a soccer ball rolling, and it takes force to change its direction or to stop its motion.

This definition doesn't mean that forces *always* change motion. If you were to push down on a table, for example, it probably wouldn't move. However, if the legs were to break, the table *could* move.

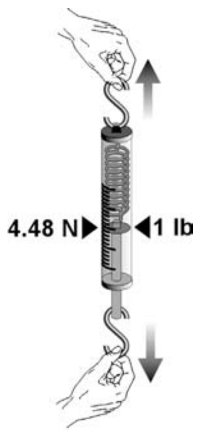
Name some examples of forces you observed today. Include one of each:

a. A force that increased motion.
b. A force that decreased motion.
c. A force that changed the direction of motion.

1

2 How is force measured?

A-1



1 lb = 4.48 N

Force is usually measured in **pounds (lbs)** or **newtons (N)**. You are probably familiar with using pounds to measure weight but not force. However, when you measure weight, you are actually measuring force.

Weight describes the force of gravity acting on an object. This is easy to see when you use a spring scale to measure weight. If you hang a one-pound weight on the end of a spring scale, the force of gravity between the object and Earth *pulls* the spring scale. The spring scale measures one pound (or 4.48 newtons) of pull. If you remove the weight and pull down on the spring scale with your hand, your muscles, rather than gravity, provide the force. You can measure the force of your pull in pounds or newtons, just like you measured the pull of gravity.

Scientists commonly use newtons to measure force. A newton is smaller than a pound. There are 4.48 newtons in a pound. A person weighing 100 pounds weighs 448 newtons.

a. Name two units used to measure force.

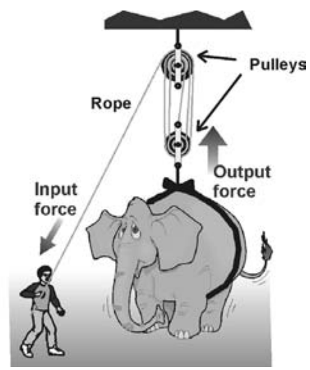
b. A dog weighs 50 pounds. How much does the dog weigh in newtons?

3 Ropes and pulleys

A rope with some pulleys can be used to change the size and direction of forces, allowing someone to lift a heavy load with a smaller amount of force. One person could easily lift an elephant with a properly designed set of ropes and pulleys!

You can think of a set of rope and pulleys as having an **input force** and an **output force**. The input force is the force you apply to the rope. The output force is the force applied to the load you are trying to lift.

In this Investigation, you will measure the amount of input force needed to lift a certain amount of weight (the output force). You will change the number of pulleys the rope passes through for each trial.



a. How do you think adding more pulleys affects the amount of input force needed to lift a certain amount of weight?

2

2

Teaching Notes

Be sure students have read and understand the introductory material before they begin the activity. You can have them practice making measurements using the spring scales. If students are confused by the fact that weight is a force, it may be helpful to explain to them that common “bathroom scales” work on the same principle as the spring scales used in the lab. When you step on a bathroom scale, a spring inside is compressed. The scale measures how hard you push on the spring.

You can also bring in other examples of simple machines so that your students can practice identifying input and output forces. Here are a few suggestions:

A broom. The input force is our push on the broom, and the output force moves dirt along the floor.
A bottle opener. The input force is our lifting motion on the opener, and the output force opens the bottle.
A set of two gears. The input force is our turning of the first gear, and the output force is the resulting turn of the second gear.
A wrench. The input force is our turning of the wrench. The output force loosens the nut.

2a. Two units used to measure force are newtons and pounds.

2b. The dog weighs 224 newtons.

3

3a. Sample student answer:
We think the amount of input force increases as pulleys are added because there is more friction.

4

Teaching Notes

Most spring scales have a small lever which allows adjusting the zero reading on the scale. It is very important that students "zero" their spring scales before making measurements. Note that the zero position must be adjusted when the spring scale is used upside-down. Otherwise, the weight of the scale itself will cause an error of approximately 0.2 newtons.

Another source of spring scale measurement error can be avoided by pulling slowly and steadily *downward*, keeping constant tension on the string. Please note that the frictional binding in most spring scales causes significant errors in force measurement when the scale is held fixed or moved slowly upward.

When measuring input force, be sure that the students use the cord stops to attach the spring scales. This eliminates the need to tie knots in the string—they can be difficult to untie.

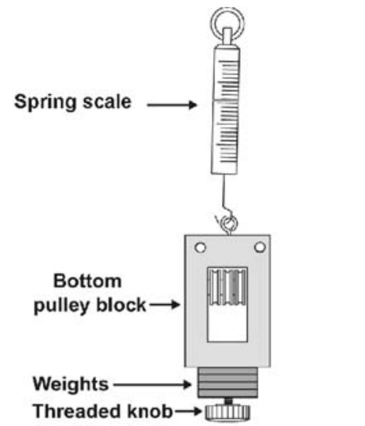
Students will find that the bottom pulley block weighs between 9 and 10 newtons.

4 Setting up the experiment A-1

1. Attach four weights to the bottom block. Use a spring scale to weigh the bottom block after you attach the weights.

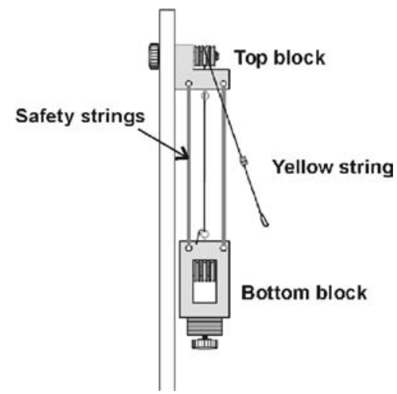
   The weight of the bottom block is equal to the **output force** used to lift the block.

   Record the weight of the bottom block in newtons.



2. Attach the top block near the top of the physics stand. Clip the yellow string to the bottom block.
3. The yellow string (pull string) will be used to move the bottom block with the weights up and down. You will pull on the end of the yellow string.

   The yellow string can be clipped to either the top or bottom block. It will pass around one or more pulleys.



4. The pink string is the *safety string*. It holds up the bottom block while you rearrange the yellow string.
5. Attach the spring scale to the yellow string as shown. You will use the spring scale to measure the **input force**.

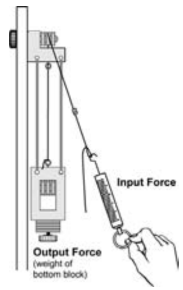
SAFETY TIP: Pull the rope downward. Don't pull the rope horizontally, or you could tip the stand over.

3

5 Doing the experiment

A-1

1. Record the output force (the weight of the bottom block) in the last column of the table below. This will be the same for each trial of the experiment.
2. Clip the end of the yellow string to the bottom block and pass the string over the middle pulley of the top block. In this arrangement, the yellow string passes over one pulley.
3. Use the spring scale to measure the force it takes to slowly lift the bottom block. This is the input force.
4. Record the input force in the table. Use the row corresponding to one pulley.



5. Take the yellow string off, and clip the end to the top block. Pass the string around the middle pulley on the bottom block and back over the middle pulley on the top block.
6. Measure the force it takes to slowly lift the bottom block (input force).
7. Record the input force in the row for two pulleys.
8. Rearrange the yellow string so that it passes over three pulleys. Then try arrangements that pass over four, five, and six pulleys.
9. Measure and record the input force it takes to lift the bottom block for each new setup.

In this arrangement, yellow string passes over one pulley.

In this arrangement, yellow string passes over two pulleys.

Number of pulleys	Input force (newtons)	Output force (newtons)
1		
2		
3		
4		
5		
6		

6 Thinking about the data

a. As the yellow string passes over more pulleys, what happens to the force used to lift the bottom block? Does this agree or disagree with your original idea about adding pulleys?

b. Write a rule that describes how the input force changes as more pulleys are used to lift the block.

4

5

For arrangements using 1,3, and 5 pulleys, the students should clip the string to the bottom block. For 2, 4, and 6 pulleys, they should clip the string to the top block.

No. of pulleys	Input force (newtons)	Output force (newtons)
1	9.0	9.0
2	4.5	9.0
3	3.0	9.0
4	2.3	9.0
5	1.8	9.0
6	1.5	9.0

The table above provides typical results for input force when 1-6 pulleys are used. A force spring scale was used to take all the measurements. It should be apparent to the students that the force needed to lift the lower block decreases as the number of pulleys increases.

6

6a. The force needed to lift the lower block decreases as the number of pulleys in the arrangement increases. This disagrees with our original idea.

6b. The number of pulleys multiplied by the input force equals the output force.

Another way to express this relationship is that the ratio of output force to input force is equal to the number of pulleys over which the yellow string passes. To teach students more about this ratio, see the section on mechanical advantage in Investigation *B-1*.

1. Answers are:
   a. The input force is the smaller child's weight—35 pounds.
   b. The output force is the older child's weight—50 pounds.
2. The string must pass over 5 pulleys because the rule developed in this lesson says that the number of pulleys (5) multiplied by the input force (2 newtons) equals the output force (10 newtons).
3. The input force must be 2.5 newtons. The rule developed in this Investigation says that the number of pulleys (4) multiplied by the input force (2.5 newtons) equals the output force (10 newtons).
4. The rope must pass over at least 40 pulleys to make sure the piano doesn't lift the baby into the air.
   Note: in practice, rope passed around this many pulleys would have a great deal of friction, so even more force would be necessary to lift the piano.

Curriculum Resource Guide: Ropes and Pulleys

Credits

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