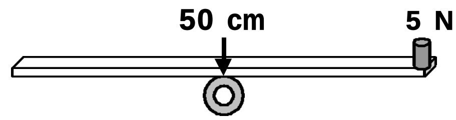
Per 7 Activity Sheet Solutions: Simple Machines

7.1 How do Levers Work? – Fulcrums and Forces

a) Place a meter stick on the plastic tube with the 50 cm mark directly above the tube. Place a 5 newton weight at the 100 cm mark of the meter stick.



Raise the weight by pressing down on the other end of the meter stick with your finger. Now move your finger closer to the center of the meter stick and press down again. What happens to the amount of force needed to raise the weight as your finger moves closer to the 50 cm mark? ? _ **The amount of force you must apply increases as you press closer to the center of the lever.**_

b) Your instructor will demonstrate the force and fulcrum board.

1) Describe what happens when the fulcrum is placed under the center of mass of the board and one weight is placed on each end.

The two ends of the board are approximately level.

2) What happens when two weights are placed at one end and one weight is placed at the other end?

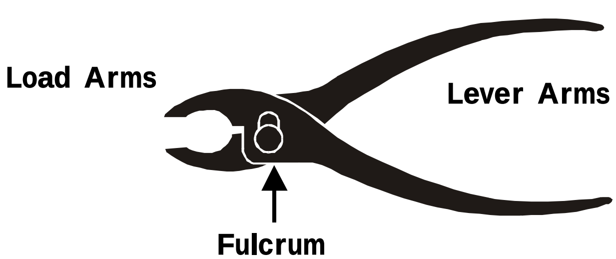
The end of the lever with one weight is raised and the end with two weights is lowered.

3) What should be done to the fulcrum so that one weight on one end can lift two weights on the other end?

The fulcrum must be placed near the end with two weights so that the lever arm is longer than the load arm.

7.2 How Do We Use Levers?

a) Examine the examples of levers (scissors, hammer, grass clippers, pliers, nutcracker, can opener, etc.). Make a rough sketch of one of these tools and label the fulcrum, lever arm, and load arm.



b) Explain how this tool uses levers to trade force for distance.

Tools with long lever arms and short load arms, such as pliers, trade a small force in over long lever arms for a large force out over short load arms. Tools with short lever arms and long load arms, such as grass clippers, trade a large force in over short lever arms for a small force out over long load arms.

c) The red hinged board represents a human arm. The hinge represents the elbow, and the spring scale represents a muscle.

1) Record the amount of force that the board exerts on the scale. This is the force the "muscle" must exert to hold up the "arm." _________

2) Hang a 5 newton weight from the bottom of the board. (This represents holding 5 newtons in your hand. The scale measures the force exerted on the muscles of your arm by the 5 N weight.) How much **additional** force does the scale measure after adding the 5 N weight? _________

3) Is the force your muscles exert to lift 5 newtons more, less, or the same as the force the 5 newton weight exerts on your hand? _ **Your arm muscle exerts more force than the 5 N weight exerts on your hand.**_

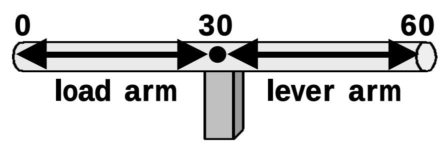
4) Explain your answer in terms of force and distance in the human arm.

Your elbow is a fulcrum, and your arm below the elbow forms both the lever arm and the load arm. Your bicep muscles attach just below the elbow, forming a short lever arm. The distance from your elbow to your hand is a long load arm. A large force from your muscles over the short lever arm provides a small force out over a long load arm. Therefore, your muscles must exert more force than the weight your hand holds.

7.3 How do Levers Work? – Lever Arm Length and Distance Moved

A dowel can be used to find the relationship between the lengths of the lever and load arms and the distances the ends of the arms move.

a) Attach the dowel to the vertical arm so that the fulcrum is at 30 cm.



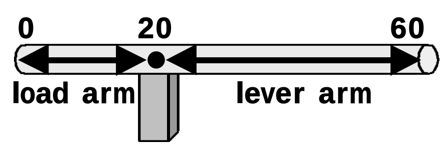
1) Write as a ratio the length of the lever arm (L_{lever}) to the length of the load arm (L_{load}).

_L_{lever}/L_{load} = 30 cm/30 cm = 1 _

2) Move the end of the lever arm a distance of 10 cm. How far does the load end of the dowel move? **__10 cm __**

3) Write as a ratio of the distance the end of the lever arm moved (D_{in}) to the distance the end of the load arm moved (D_{out}).

_D_{in}/D_{out} = 10 cm/10 cm = 1 _



b) Move the dowel to the 20 cm mark.

1) Write as a ratio the length of the lever arm to the length of the load arm.

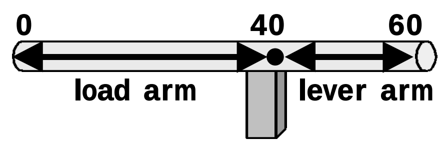
_L_{lever}/L_{load} = 40 cm/20 cm = 2 _

2) Move the end of the lever arm a distance of 10 cm. How far does the load end of the dowel move? **__5 cm __**

3) Write as a ratio of the distance the end of the lever arm moved (D_{in}) to the distance the end of the load arm moved (D_{out}).

_D_{in}/D_{out} = 10 cm/5 cm = 2 _

c) Move the dowel to the 40 cm mark. Move the end of the lever arm a distance of 10 cm.



1) Write as a ratio the length of the lever arm to the length of the load arm.

_L_{lever}/L_{load} = 20 cm/40 cm = 0.5 _

2) Move the end of the lever arm a distance of 10 cm. How far does the load end of the dowel move? **__20 cm __**

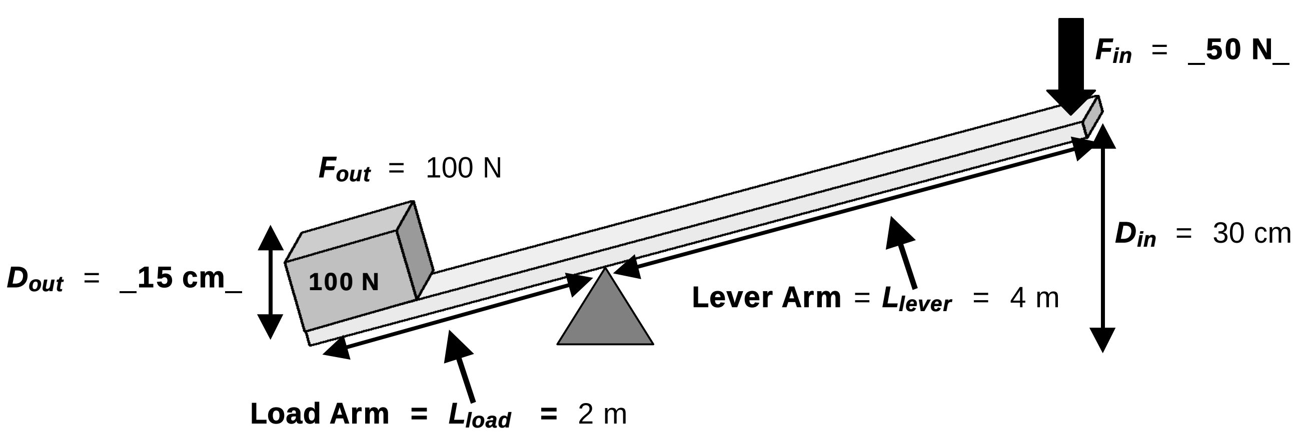
3) Write as a ratio of the distance the end of the lever arm moved (D_{in}) to the distance the end of the load arm moved (D_{out}).

_D_{in}/D_{out} = 10 cm/20 cm = 0.5 _

d) For a lever, how do the lengths of the lever and load arms relate to the distance in and the distance out that the arms move? Write an equation using ratios that expresses this relationship.

$$\frac{L_{lever}}{L_{load}} = \frac{D_{in}}{D_{out}}$$

7.4 How Do Levers Work? – Another Way to Describe Levers



a) If the end of the lever arm in the diagram above moves a distance of 30 cm, how far does the end of the load arm move? Write your answer for D_{out} on the diagram.

$$D_{out} = \frac{D_{in} \times L_{load}}{L_{lever}} = \frac{30\ \text{cm} \times 2\ \cancel{\text{m}}}{4\ \cancel{\text{m}}} = 15\ \text{cm}$$

b) Assuming that the lever has no friction, the work done on either side of the fulcrum is equal ($W_{in} = W_{out}$). Use this principle and the fact that $W = F \times D$ to find the amount of applied force needed to lift the 100 N load. Write your answer for F_{in} on the diagram.

$$F_{in} = \frac{F_{out} \times D_{out}}{D_{in}} = \frac{100\ \text{N} \times 15\ \cancel{\text{cm}}}{30\ \cancel{\text{cm}}} = 50\ \text{N}$$

c) In part b), you found F_{in} using the equation: $F_{in} \times D_{in} = F_{out} \times D_{out}$
You can also find F_{in} using the equation: $F_{in} \times L_{lever} = F_{out} \times L_{load}$
Using the numbers given and inserted in the diagram above, find F_{in} from the equation: $F_{in} \times L_{lever} = F_{out} \times L_{load}$ Do you get the same result as in part b)?

$$F_{in} = \frac{F_{out} \times L_{load}}{L_{lever}} = \frac{100\ \text{N} \times 2\ \cancel{\text{m}}}{4\ \cancel{\text{m}}} = 50\ \text{N}$$

d) Group Discussion Question: As we consider tools made with levers, why is it easier to use the equation: $F_{in} \times L_{lever} = F_{out} \times L_{load}$ than the equation $F_{in} \times D_{in} = F_{out} \times D_{out}$?

When examining a tool, it is usually easier to measure the lengths of the load and lever arms, which are fixed lengths, than to measure the distances in and out that the ends of the arms move, which are different each time the tool is used.

7.5 What is the Theoretical Mechanical Advantage of a Simple Machine?

Your instructor will discuss mechanical advantage.

a) Examine the pulley system on your table. Hang a weight from the bottom of the moveable pulley. Raise the weight a distance of 20 cm by pulling the string. Using the meter stick attached to the ring stand, measure the distance you pulled the string to raise the weight. __________

b) Calculate the theoretical mechanical advantage of this pulley system.

$$MA_{theoretical} = \frac{\text{Distance in}}{\text{Distance out}} = \frac{\text{distance you pull string}}{\text{distance load moves}}$$

c) Explain how you could have determined the theoretical mechanical advantage of this system without making any measurements of the distances involved.

You can determine the theoretical mechanical advantage of a pulley system by counting the number of rope segments supporting the load.

7.6 What is the Actual Mechanical Advantage of a Simple Machine?

Your instructor will demonstrate lifting a cement block with a block and tackle.

a) Calculate the actual mechanical advantage of the block and tackle.

1) How much weight did the block and tackle lift? _______________

2) How much force was needed to lift it? ________________

3) Using these data, calculate the actual mechanical advantage of the block and tackle.

$$MA_{actual} = \frac{\textit{Force out}}{\textit{Force in}} = \frac{\text{weight of blocks}}{\text{force of pull on rope}}$$

b) Find the theoretical mechanical advantage of the block and tackle.

1) How high off the floor were the cement blocks lifted? _________________

2) Through what distance was the rope pulled to lift them? ________________

3) Using these data, calculate the theoretical mechanical advantage.

$$MA_{theoretical} = \frac{\textit{Distance in}}{\textit{Distance out}} = \frac{\text{length of rope pulled}}{\text{height blocks were raised}}$$

4) How well does your calculation agree with the theoretical mechanical advantage found from counting supporting rope segments? _ **Since the block and tackle has 6 supporting rope segments, it has a theoretical MA = 6**_

5) How well does your calculation agree with the theoretical mechanical advantage found from counting supporting rope segments? _________________________

c) Compare your calculations of the actual mechanical advantage and the theoretical mechanical advantage. Why would one value be larger than the other?

The actual mechanical advantage is less than the theoretical mechanical advantage because some of the energy put into the system is wasted overcoming frictional forces in the block and tackle.