Chapter: Work and Simple Machines

What is work?

- **Work** is done when a force causes an object to move in the same direction that the force is applied.

- Maybe it would help to know that you do work when you lift your books, turn a doorknob, raise window blinds, or write with a pen or pencil.

Work and Motion

- In order for you to do work, two things must occur.
- First, you must apply a force to an object.
- Second, the object must move in the same direction as your applied force.

1

Work and Motion

- You do work on an object only when the object moves as a result of the force you exert.

1

Applying Force and Doing Work

- To do work, an object must move in the direction a force is applied.
- The boy's arms do work when they exert an upward force on the basket and the basket moves upward.

1

Applying Force and Doing Work

- The boy's arms still exert an upward force on the basket.
- But when the boy walks forward, no work is done by his arms.

1

Force in Two Directions

- Sometimes only part of the force you exert moves an object.
- Think about what happens when you push a lawn mower.
- You push at an angle to the ground.

1

Force in Two Directions

- Part of the force is to the right and part of the force is downward.
- Only part of the force that is in the same direction as the motion of the mower—to the right—does work.

Calculating Work

- Work can be calculated using the work equation below.

Work Equation

work (in joules) = **force** (in newtons) X **distance** (in meters)

$$W = Fd$$

- In SI units, the unit for work is the joule, named for the nineteenth-century scientist James Prescott Joule.

Work and Distance

- Suppose you give a book a push and it slides across a table.
- To calculate the work you did, the distance in the above equation is not the distance the book moved.

Work and Distance

- The distance in the work equation is the distance an object moves while the force is being applied.
- So the distance in the work equation is the distance the book moved while you were pushing.

What is power?

- What does it mean to be powerful? Imagine two weightlifters lifting the same amount of weight the same vertical distance.

- They both do the same amount of work. However, the amount of power they use depends on how long it took to do the work.

What is power?

- **Power** is how quickly work is done.
- The weightlifter who lifted the weight in less time is more powerful.

1

Calculating Power

- Power can be calculated by dividing the amount of work done by the time needed to do the work.

Power Equation

$$\text{power (in watts)} = \frac{\text{work (in joules)}}{\text{time (in seconds)}}$$

$$P = \frac{W}{t}$$

1

Calculating Power

- In SI units, the unit of power is the watt, in honor of James Watt, a nineteenth-century British scientist, who invented a practical version of the steam engine.

Work and Energy

- If you push a chair and make it move, you do work on the chair and change its energy.

- Recall that when something is moving it has energy of motion, or kinetic energy.

- By making the chair move, you increase its kinetic energy.

Work and Energy

- You also change the energy of an object when you do work and lift it higher.
- By lifting an object, you do work and increase its potential energy.

1

Power and Energy

- Because energy can never be created or destroyed, if the object gains energy then you must lose energy.
- When you do work on an object you transfer energy to the object, and your energy decreases.

1

Power and Energy

- The amount of work done is the amount of energy transferred.

- So power is also equal to the amount of energy transferred in a certain amount of time.

Power and Energy

- Sometimes energy can be transferred even when no work is done, such as when heat flows from a warm to a cold object.

- Power is always the rate at which energy is transferred, or the amount of energy transferred divided by the time needed.

Question 1

When a force causes motion to occur in the same direction in which the force has been applied, we say that ________ has been done.

Answer

Work is done when an object moves in the same direction a force is applied.

Question 2

Suppose you are waiting for a train. While you are standing on the platform, your arms are becoming more and more tired from holding your heavy suitcases. Are you doing work?

1

Answer

No, when you lifted the suitcases you were doing work because you applied a force and moved an object. Holding the bags, although tiring, isn't considered work.

Question 3

In SI, the unit for work is the ________.

A. Ampere
B. Joule
C. Newton
D. Watt

1

Answer

The correct answer is B. The unit for work is the joule.

2

What is a machine?

- When you think of a machine you might think of a device, such as a car, with many moving parts powered by an engine or an electric motor.

2

What is a machine?

- A machine is simply a device that makes doing work easier.
- Even a sloping surface can be a machine.

Mechanical Advantage

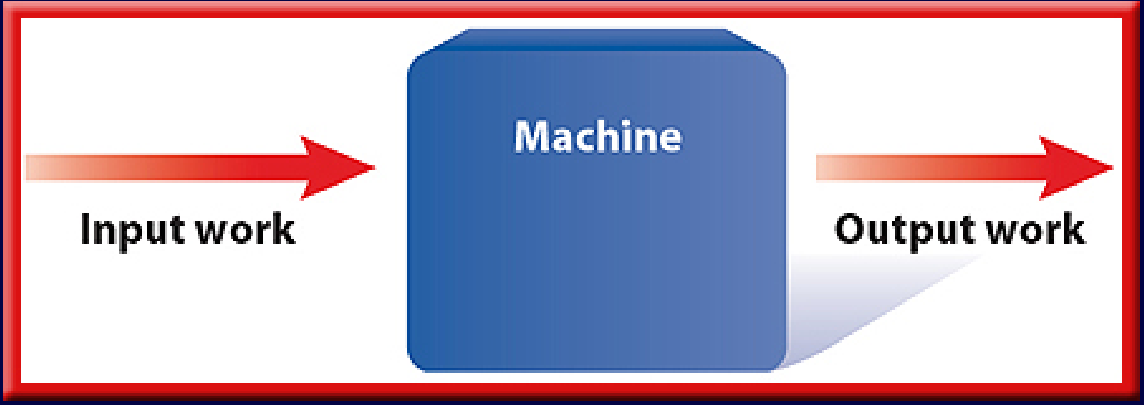
- Even though machines make work easier, they don't decrease the amount of work you need to do.
- Instead, a machine changes the way in which you do work.

Mechanical Advantage

- The force that you apply on a machine is the **input force**.
- The work you do on the machine is equal to the input force times the distance over which your force moves the machine.
- The work that you do on the machine is the input work.

Mechanical Advantage

- The force that the machine applies is the **output force**.
- The work that the machine does is the output work.
- When you use a machine, the output work can never be greater than the input work.



Mechanical Advantage

- What is the advantage of using a machine?

- A machine makes work easier by changing the amount of force you need to exert, the distance over which the force is exerted, or the direction in which you exert your force.

2

Changing Force

- Some machines make doing work easier by reducing the force you have to apply to do work.
- This type of machine increases the input force, so that the output force is greater than the input force.

Changing Force

- The number of times a machine increases the input force is the **mechanical advantage** of the machine.

Changing Force

- The mechanical advantage of a machine is the ratio of the output force to the input force and can be calculated from this equation:

Mechanical Advantage Equation

$$\text{mechanical advantage} = \frac{\text{output force (in newtons)}}{\text{input force (in newtons)}}$$

$$MA = \frac{F_{\text{out}}}{F_{\text{in}}}$$

2

Changing Distance

- Some machines allow you to exert your force over a shorter distance.
- In these machines, the output force is less than the input force.

2

Changing Distance

- The mechanical advantage of this type of machine is less than one because the output force is less than the input force.

Changing Direction

- Sometimes it is easier to apply a force in a certain direction.
- For example, it is easier to pull down on a rope than to pull up on it.
- Some machines enable you to change the direction of the input force.

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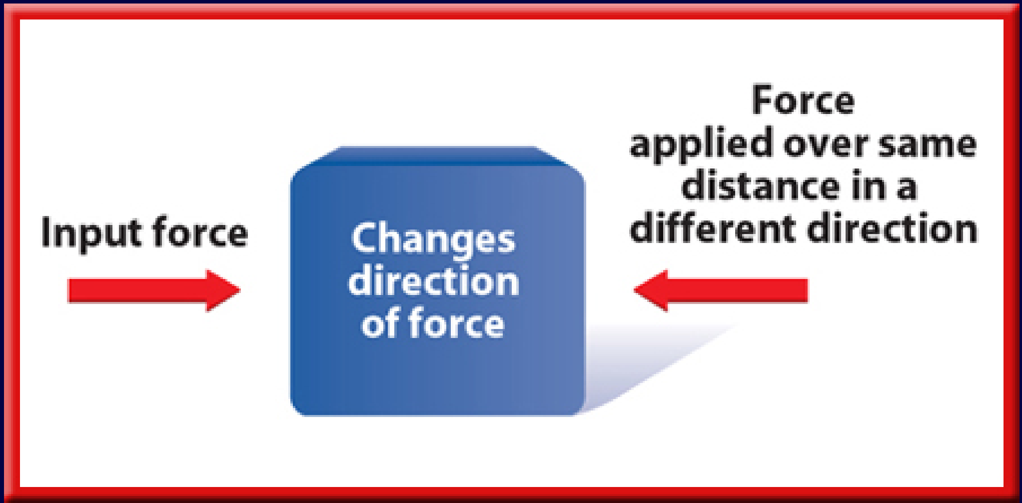
Changing Direction

- In these machines neither the force nor the distance is changed.
- The mechanical advantage of this type of machine is equal to one because the output force is equal to the input force.



Efficiency

- For a real machine, the output work done by the machine is always less than the input work that is done on the machine.
- In a real machine, there is friction as parts of the machine move.

Efficiency

- Friction converts some of the input work into heat, so that the output work is reduced.

- The **efficiency** of a machine is the ratio of the output work to the input work.

2

Efficiency

- If the amount of friction in the machine is reduced, the efficiency of the machine increases.

Efficiency Equation

$$\textbf{efficiency} \text{ (in percent)} = \frac{\textbf{output work} \text{ (in joules)}}{\textbf{input work} \text{ (in joules)}} \times 100\%$$

$$eff = \frac{W_{out}}{W_{in}}$$

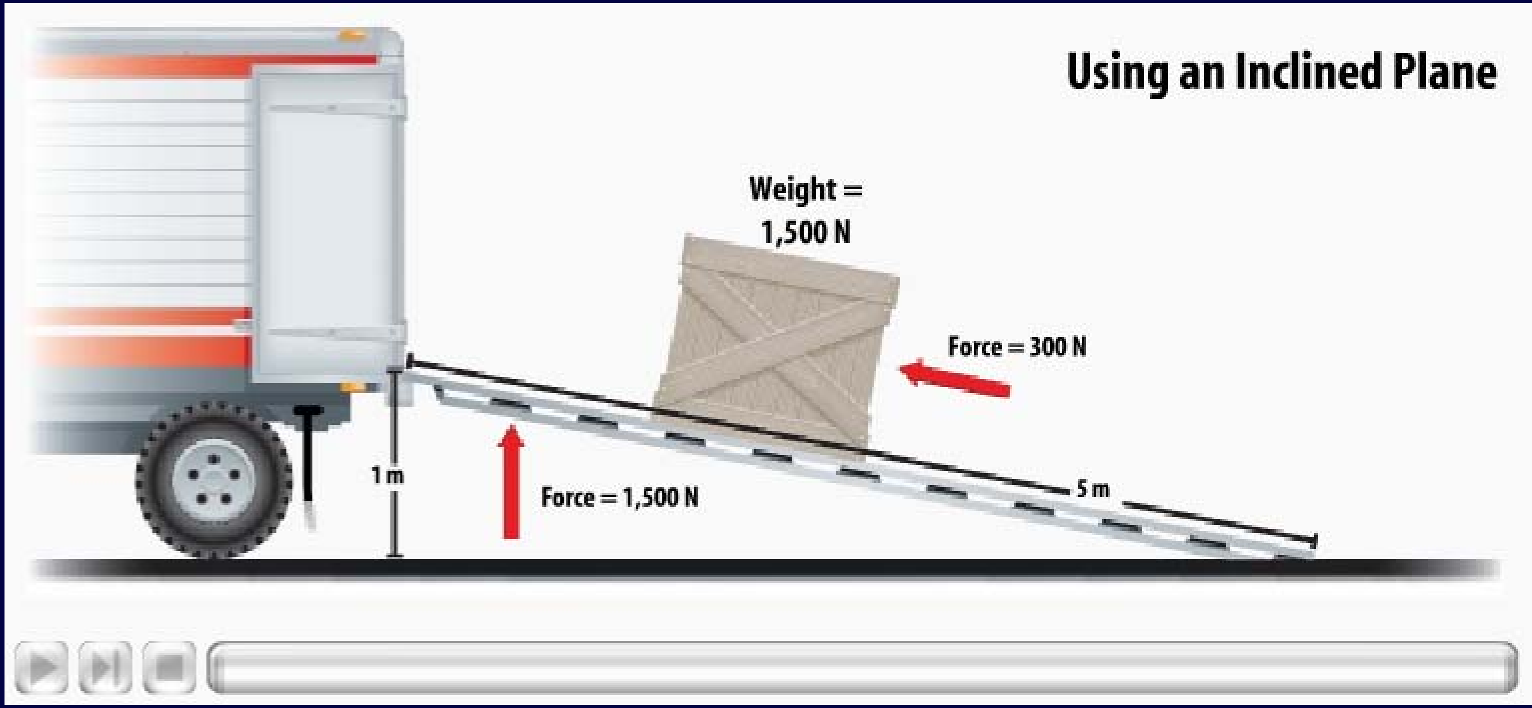
Friction

- To help understand friction, imagine pushing a heavy box up a ramp.
- As the box begins to move, the bottom surface of the box slides across the top surface of the ramp.
- Neither surface is perfectly smooth—each has high spots and low spots.

2

Friction

MAC OSX users click here to view.



Friction

- As the two surfaces slide past each other, high spots on the two surfaces come in contact.
- At these contact points, atoms and molecules can bond together.
- This makes the contact points stick together.

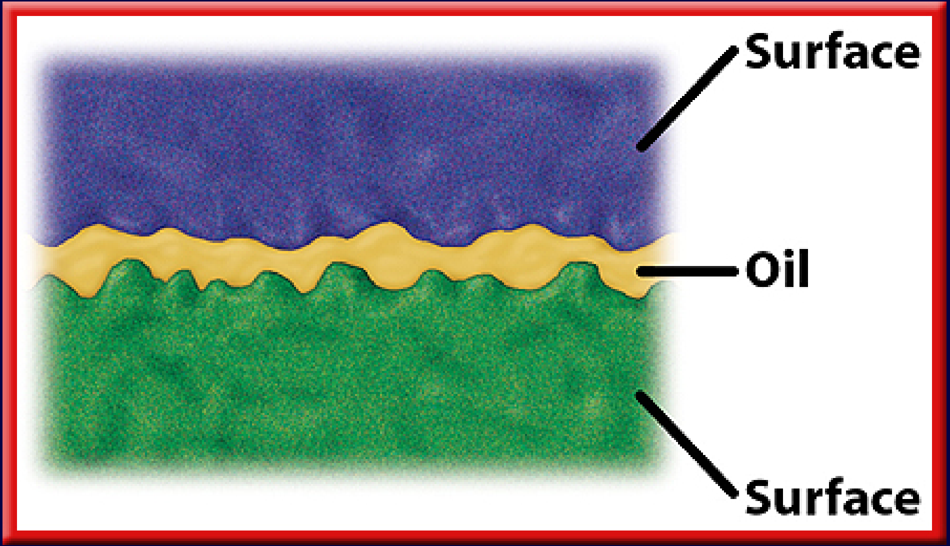
2

Friction

- To keep the box moving, a force must be applied to break the bonds between the contact points.
- Even after these bonds are broken and the box moves, new bonds form as different parts of the two surfaces come into contact.

Friction and Efficiency

- One way to reduce friction between two surfaces is to add oil.
- Oil fills the gaps between the surfaces, and keeps many of the high spots from making contact.
- More of the input work then is converted to output work by the machine.



Question 1

The force that you apply on a machine is known as the ________.

2

Answer

The force that you apply is the input force. The force the machine applies is the output force.

2

Question 2

There are three main advantages to using a machine. In what three ways does a machine make work easier?

Answer

A machine makes work easier by changing the amount of force you need to exert, changing the distance over which the force is exerted, and changing the direction in which you exert the force.

2

Question 3

If the input force is 1000 N and the output force is 10,000 N, what is the mechanical advantage?

A. 1
B. 10
C. 100
D. 1,000

Answer

The answer is B. MA = F out/ F in, therefore, the answer is 10.

What is a simple machine?

- A **simple machine** is a machine that does work with only one movement.

- The six simple machines are the inclined plane, lever, wheel and axle, screw, wedge, and pulley.

What is a simple machine?

- A machine made up of a combination of simple machines is called a **compound machine**.

- A can opener is a compound machine.

Inclined Plane

- To move limestone blocks weighing more than 1,000 kg each, archaeologists hypothesize that the Egyptians built enormous ramps.
- A ramp is a simple machine known as an inclined plane.

Inclined Plane

- An **inclined plane** is a flat, sloped surface.
- Less force is needed to move an object from one height to another using an inclined plane than is needed to lift the object.
- As the inclined plane becomes longer, the force needed to move the object becomes smaller.

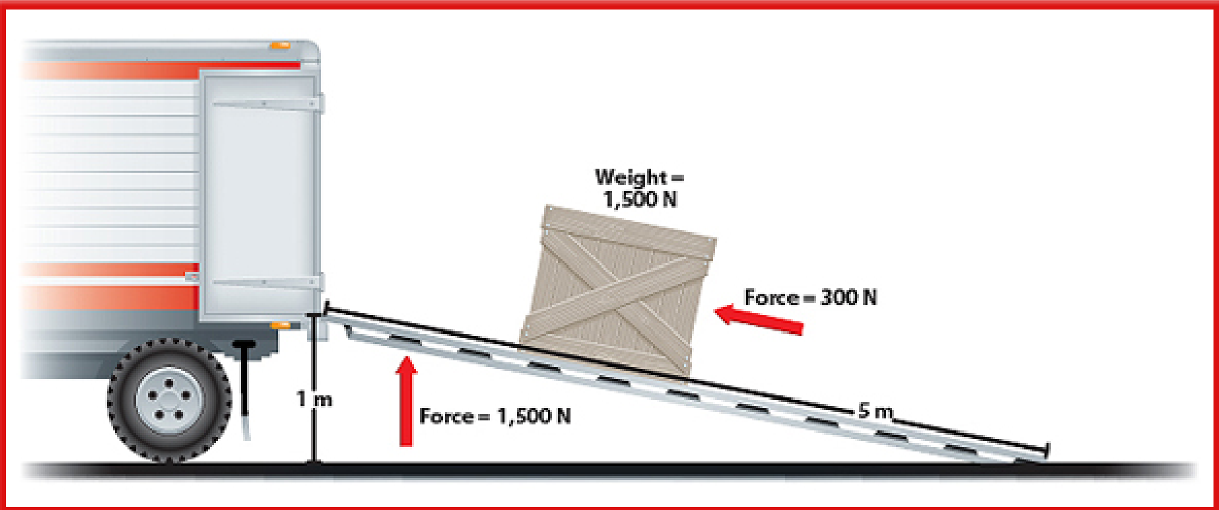
Using Inclined Planes

- Imagine having to lift a box weighing 1,500 N to the back of a truck that is 1 m off the ground.
- You would have to exert a force of 1,500 N, the weight of the box, over a distance of 1 m, which equals 1,500 J of work.

3

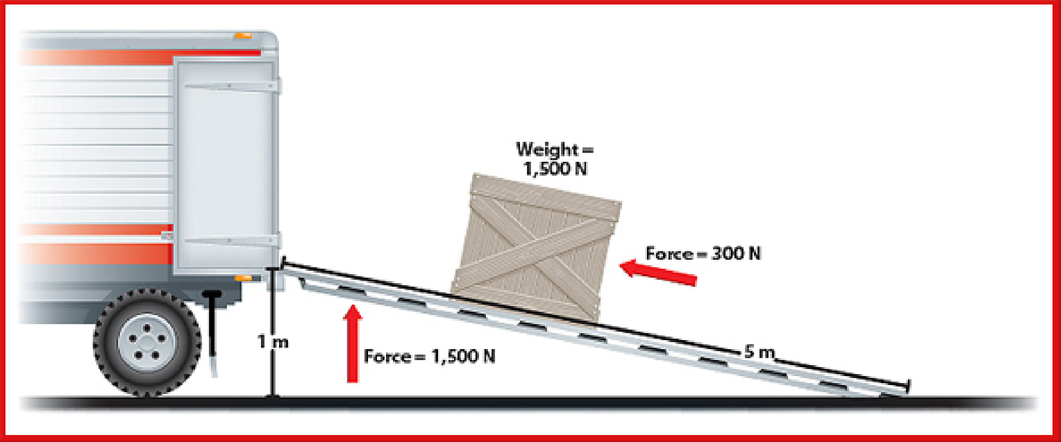
Using Inclined Planes

- Now suppose that instead you use a 5-m-long ramp.
- The amount of work you need to do does not change.



Using Inclined Planes

- You still need to do 1,500 J of work. However, the distance over which you exert your force becomes 5 m.



$$\text{Force} = \frac{\text{work}}{\text{distance}}$$

Using Inclined Planes

- If you do 1,500 J of work by exerting a force over 5 m, the force is only 300 N.

- Because you exert the input force over a distance that is five times as long, you can exert a force that is five times less.

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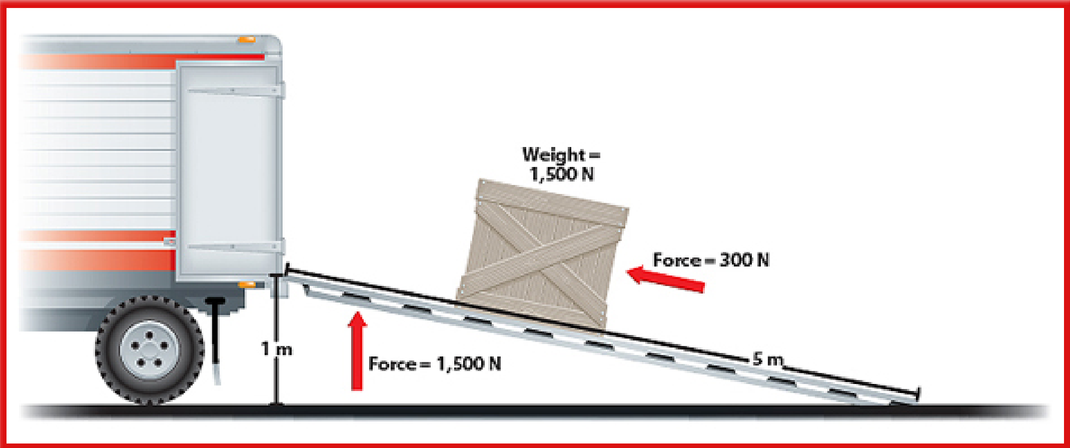
Using Inclined Planes

- The mechanical advantage of an inclined plane is the length of the inclined plane divided by its height.
- In this example, the ramp has a mechanical advantage of 5.



Wedge

- An inclined plane that moves is called a **wedge**.
- A wedge can have one or two sloping sides.

- An axe and certain types of doorstops are wedges.
- Just as for an inclined plane, the mechanical advantage of a wedge increases as it becomes longer and thinner.

Wedges in Your Body

- You have wedges in your body.
- Your front teeth are wedge shaped.
- A wedge changes the direction of the applied effort force.

3

Wedges in Your Body

- The teeth of meat eaters, or carnivores, are more wedge shaped than the teeth of plant eaters, or herbivores.

- The teeth of carnivores are used to cut and rip meat, while herbivores' teeth are used for grinding plant material.

3

The Screw

- A **screw** is an inclined plane wrapped around a cylinder or post.
- The inclined plane on a screw forms the screw threads.
- Just like a wedge changes the direction of the effort force applied to it, a screw also changes the direction of the applied force.

The Screw

- When you turn a screw, the force applied is changed by the threads to a force that pulls the screw into the material.
- The mechanical advantage of the screw is the length of the inclined plane wrapped around the screw divided by the length of the screw.

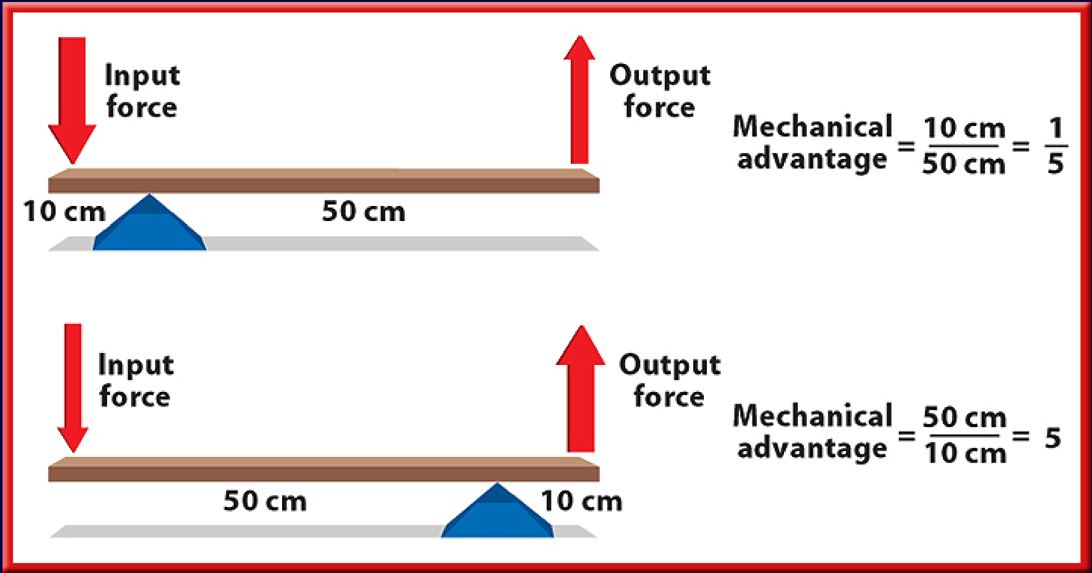
Lever

- A **lever** is any rigid rod or plank that pivots, or rotates, about a point.
- The point about which the lever pivots is called a fulcrum.

3

Lever

- The mechanical advantage of a lever is found by dividing the distance from the fulcrum to the input force by the distance from the fulcrum to the output force.



Lever

- When the fulcrum is closer to the output force than the input force, the mechanical advantage is greater than one.
- Levers are divided into three classes according to the position of the fulcrum with respect to the input force and output force.

Lever

- In a first-class lever, the fulcrum is between the input force and the output force.
- First-class levers multiply force or distance depending on where the fulcrum is placed.

Lever

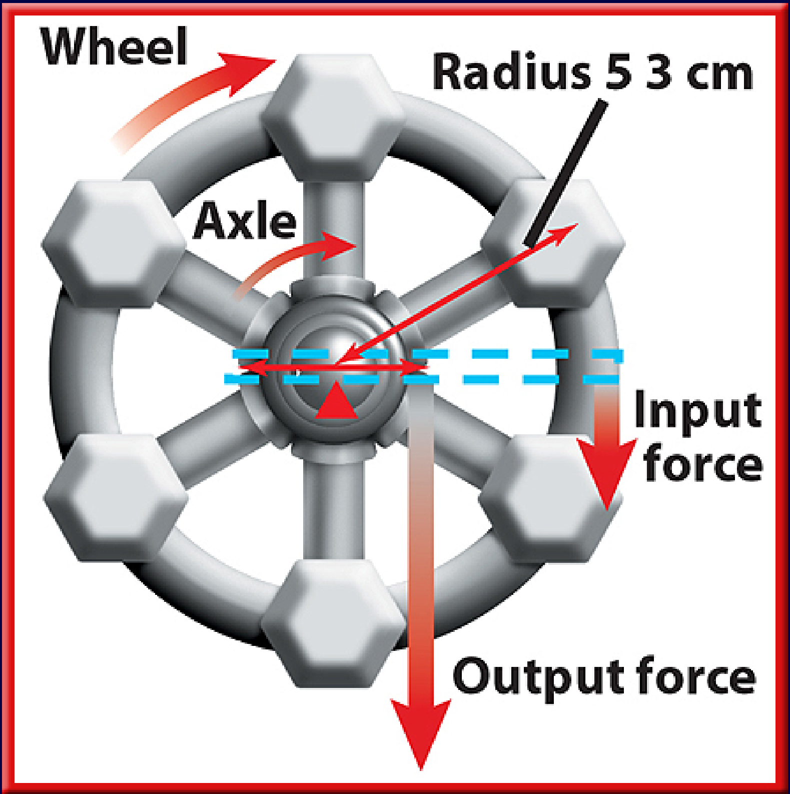
- In a second-class lever, the output force is between the input force and the fulcrum.
- Second-class levers always multiply the input force but don't change its direction.

3

Lever

- In a third-class lever, the input force is between the output force and the fulcrum.
- For a third-class lever, the output force is less than the input force, but is in the same direction.

Wheel and Axle



- A **wheel and axle** consists of two circular objects of different sizes that are attached in such a way that they rotate together.
- As you can see, the larger object is the wheel and the smaller object is the axle.

Wheel and Axle

- The mechanical advantage of a wheel and axle is usually greater than one.

- It is found by dividing the radius of the wheel by the radius of the axle.

Using Wheels and Axles

- In some devices, the input force is used to turn the wheel and the output force is exerted by the axle.
- Because the wheel is larger than the axle, the mechanical advantage is greater than one.
- So the output force is greater than the input force.

Using Wheels and Axles

- In other devices, the input force is applied to turn the axle and the output force is exerted by the wheel.
- Then the mechanical advantage is less than one and the output force is less than the input force.
- A fan and a ferris wheel are examples of this type of wheel and axle.

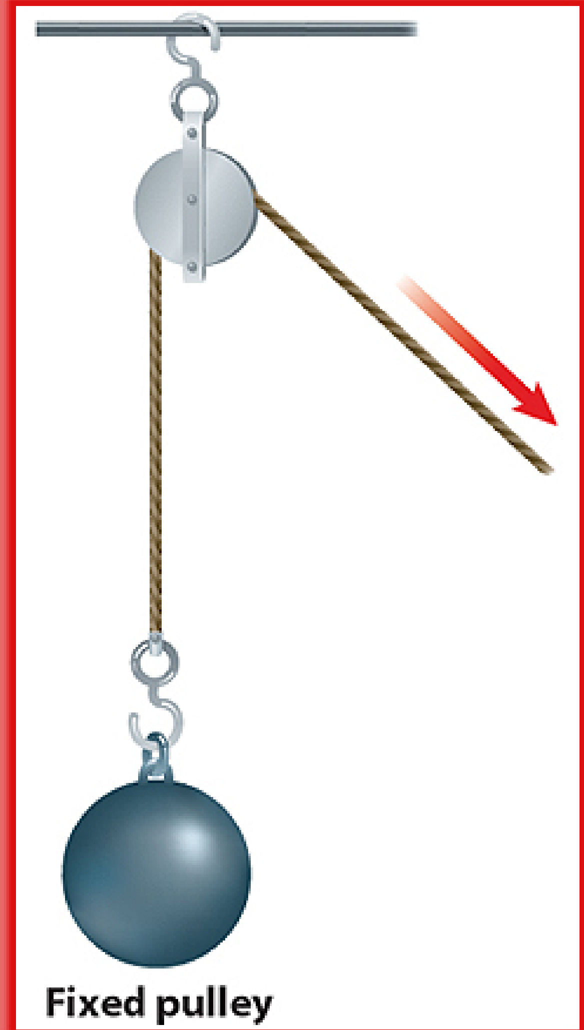
Pulley

- To raise a sail, a sailor pulls down on a rope.
- The rope uses a simple machine called a pulley to change the direction of the force needed.
- A **pulley** consists of a grooved wheel with a rope or cable wrapped over it.

3

Fixed Pulleys

- Some pulleys are attached to a structure above your head.
- When you pull down on the rope, you pull something up.

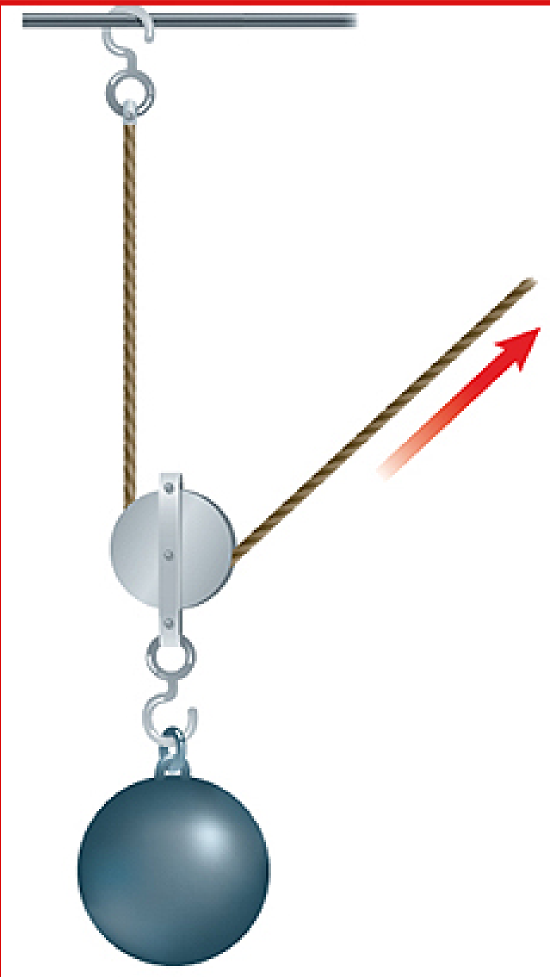


Fixed Pulleys

- This type of pulley, called a fixed pulley, does not change the force you exert or the distance over which you exert it.
- Instead, it changes the direction in which you exert your force.
- The mechanical advantage of a fixed pulley is 1.

Movable Pulleys

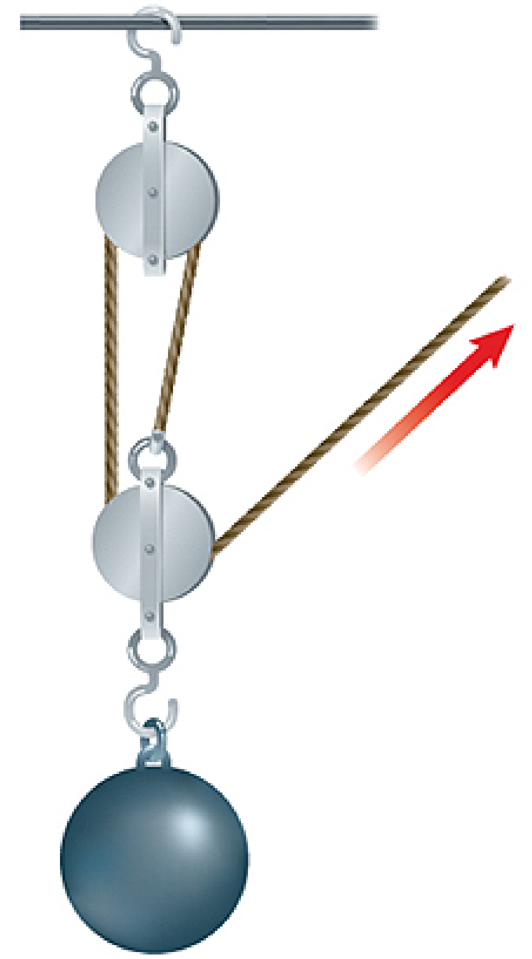
- Another way to use a pulley is to attach it to the object you are lifting.
- This type of pulley, called a movable pulley, allows you to exert a smaller force to lift the object.
- The mechanical advantage of a movable pulley is always 2.



Movable pulley

Movable Pulleys

- More often you will see combinations of fixed and movable pulleys. Such a combination is called a pulley system.
- The mechanical advantage of a pulley system is equal to the number of sections of rope pulling up on the object.


Pulley system

Question 1

A machine that does work with only one movement is known as a ________.

Answer

Simple machines do work with only one movement. A pulley is an example of a simple machine.

3

Question 2

Name the six simple machines.

Answer

The inclined plane, lever, wheel and axle, screw, wedge, and pulley are simple machines.

3

Question 3

As an inclined plane becomes longer, the force needed to move an object over it becomes

_________.

?

CHAPTER RESOURCES

END

Answer

The force needed becomes smaller. This is the advantage of using a ramp, which is an inclined plane, instead of lifting objects.

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