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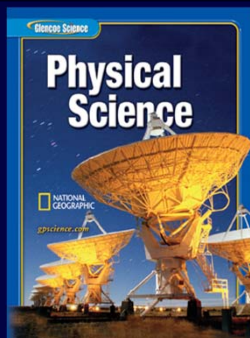


Table of Contents

5

Unit 1: Energy and Motion

Chapter 5: Work and Machines

Work

5.1

What is work?

- To many people, the word *work* means something they do to earn money.
- The word *work* also means exerting a force with your muscles.

Work

5.1

What is work?

- Someone might say they have done work when they push as hard as they can against a wall that doesn't move.
- However, in science the word *work* is used in a different way.

Work

5.1

Work Makes Something Move

- Remember that a force is a push or a pull. In order for work to be done, a force must make something move.
- **Work** is the transfer of energy that occurs when a force makes an object move.
- If you push against the desk and nothing moves, then you haven't done any work.

Work

5.1

Doing work

- There are two conditions that have to be satisfied for work to be done on an object.
- One is that the applied force must make the object move, and the other is that the movement must be in the same direction as the applied force.

Work

5.1

Doing work

- For example, when you lift a stack of books, your arms apply a force upward and the books move upward. Because the force and distance are in the same direction, your arms have done work on the books.

CHAPTER RESOURCES END

Work

5.1

Force and Direction of Motion

- When you carry books while walking, you might think that your arms are doing work.
- However, in this case, the force exerted by your arms does no work on the books.

CHAPTER RESOURCES END

Work

5.1

Force and Direction of Motion

- The force exerted by your arms on the books is upward, but the books are moving horizontally.
- The force you exert is at right angles to the direction the books are moving.

CHAPTER RESOURCES END

Work

5.1

Work and Energy

- When work is done, a transfer of energy always occurs.
- This is easy to understand when you think about how you feel after carrying a heavy box up a flight of stairs.
- You transferred energy from your moving muscles to the box and increased its potential energy by increasing its height.

CHAPTER RESOURCES END

Work

5.1

Work and Energy

- You may recall that energy is the ability to cause change.
- Another way to think of energy is that energy is the ability to do work.
- If something has energy, it can transfer energy to another object by doing work on that object.

CHAPTER RESOURCES END

Work

5.1

Work and Energy

- When you do work on an object, you increase its energy.
- The student carrying the box transfers chemical energy in his muscles to the box.

CHAPTER RESOURCES END

Work

5.1 Work and Energy

- Energy is always transferred from the object that is doing the work to the object on which the work is done.

Work

5.1 Calculating Work

- The amount of work done depends on the amount of force exerted and the distance over which the force is applied.
- When a force is exerted and an object moves in the direction of the force, the amount of work done can be calculated as follows.

Work Equation

work (in joules) = **applied force** (in newtons) × **distance** (in meters)

$$W = Fd$$

Work

5.1 Calculating Work

- In this equation, force is measured in newtons and distance is measured in meters.
- Work, like energy, is measured in joules.
- One joule is about the amount of work required to lift a baseball a vertical distance of 0.7 m.

Work

5.1 When is work done?

- Suppose you give a book a push and it slides along a table for a distance of 1 m before it comes to a stop.
- Even though the book moved 1 m, you do work on the book only while your hand is in contact with it.

Work

5.1 Power

- Suppose you and another student are pushing boxes of books up a ramp and load them into a truck.
- To make the job more fun, you make a game of it, racing to see who can push a box up the ramp faster.

Work

5.1 Power

- **Power** is the amount of work done in one second. It is a rate—the rate at which work is done.

Work

5.1

Calculating Power

- To calculate power, divide the work done by the time that is required to do the work.

Power Equation

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

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

- The SI unit for power is the watt (W). One watt equals one joule of work done in one second.

Work

5.1

Calculating Power

- Because the watt is a small unit, power often is expressed in kilowatts.
- One kilowatt (kW) equals 1,000 W.

Work

5.1

Power and Energy

- Just as power is the rate at which work is done, power is also the rate at which energy is transferred.
- When energy is transferred, the power involved can be calculated by dividing the energy transferred by the time needed for the transfer to occur.

Power Equation for Energy Transfer

$$\textbf{power} \text{ (in watts)} = \frac{\textbf{energy transferred} \text{ (in joules)}}{\textbf{time} \text{ (in seconds)}}$$

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

Section Check

5.1

Question 1

__________ is the transfer of energy that occurs when a force makes an object move.

A. Conversion
B. Energization
C. Power
D. Work

Section Check

5.1

Answer

The answer is D. In order for work to be done, the applied force must make the object move in the same direction as the applied force.

Section Check

5.1

Question 2

The amount of work done depends on what two things?

Answer

The amount of work done depends on the amount of force exerted and the distance over which the force is applied.

Section Check

5.1

Question 3

Which of the following equations can be used to calculate power?

A. W = F/d
B. P =Wt
C. t = W/P
D. P = t/W

CHAPTER RESOURCES END

Section Check

5.1

Answer

The answer is C. This is a rearrangement of the equation for calculating power, P = W/t.

CHAPTER RESOURCES END

Using Machines

5.2

What is a machine?

- A **machine** is a device that makes doing work easier.
- Machines can be simple.
- Some, like knives, scissors, and doorknobs, are used everyday to make doing work easier.

CHAPTER RESOURCES END

Using Machines

5.2

Making Work Easier

- Machines can make work easier by increasing the force that can be applied to an object.
- A second way that machines can make work easier is by increasing the distance over which a force can be applied.
- Machines can also make work easier by changing the direction of an applied force.

CHAPTER RESOURCES END

Using Machines

5.2

Increasing Force

- A car jack is an example of a machine that increases an applied force.
- The upward force exerted by the jack is greater than the downward force you exert on the handle.

CHAPTER RESOURCES END

Using Machines

5.2

Increasing Force

- However, the distance you push the handle downward is greater than the distance the car is pushed upward.
- The jack increases the applied force, but doesn't increase the work done.

CHAPTER RESOURCES END

Using Machines

5.2

Force and Distance

- The work done in lifting an object depends on the change in height of the object.
- The same amount of work is done whether the mover pushed the furniture up the long ramp or lifts it straight up.
- If work stays the same and the distance is increased, then less force will be needed to do the work.

Using Machines

5.2

Changing Direction

- Some machines change the direction of the force you apply.
- The wedge-shaped blade of an ax is one example.

Using Machines

5.2

The Work Done by Machines

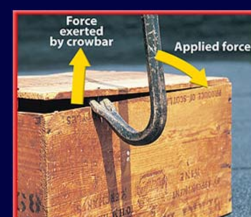
- When you use an ax to split wood, you exert a downward force as you swing the ax toward the wood.
- The blade changes the downward force into a horizontal force that splits the wood apart.

Using Machines

5.2

The Work Done by Machines

- When you use a machine such as a crowbar, you are trying to move something that resists being moved.
- If you use a crowbar to pry the lid off a crate, you are working against the friction between the nails in the lid and the crate.



Using Machines

5.2

The Work Done by Machines

- You also could use a crowbar to move a large rock.
- In this case, you would be working against gravity—the weight of the rock.

Using Machines

5.2

Input and Output Forces

- Two forces are involved when a machine is used to do work.
- The force that is applied to the machine is called the **input force**.
- F_{in} stands for the effort force.
- The force applied by the machine is called the **output force**, symbolized by F_{out}.

Using Machines

5.2

Input and Output Forces

- Two kinds of work need to be considered when you use a machine—the work done by you on the machine and the work done by the machine.
- The work done by you on a machine is called the input work and is symbolized by W_{in}.
- The work done by the machine is called the output work and is abbreviated W_{out}.

CHAPTER RESOURCES END

Using Machines

5.2

Conserving Energy

- When you do work on the machine, you transfer energy to the machine.
- When the machine does work on an object, energy is transferred from the machine to the object.

CHAPTER RESOURCES END

Using Machines

5.2

Conserving Energy

- The amount of energy the machine transfers to the object cannot be greater than the amount of energy you transfer to the machine.
- A machine cannot create energy, so W_{out} is never greater than W_{in}.

CHAPTER RESOURCES END

Using Machines

5.2

Conserving Energy

- When a machine is used, some of the energy transferred changes to heat due to friction.
- The energy that changes to heat cannot be used to do work, so W_{out} is always smaller than W_{in}.

CHAPTER RESOURCES END

Using Machines

5.2

Ideal Machines

- Suppose a perfect machine could be built in which there was no friction.
- None of the input work or output work would be converted to heat.
- For such an ideal machine, the input work equals the output work.

$$W_{in} = W_{out}$$

CHAPTER RESOURCES END

Using Machines

5.2

Ideal Machines

- Suppose the ideal machine increases the force applied to it.
- This means that the output force, F_{out}, is greater than the input force, F_{in}.
- Recall that work is equal to force times distance.

CHAPTER RESOURCES END

Using Machines

5.2

Ideal Machines

- If F_{out} is greater than F_{in}, then W_{in} and W_{out} can be equal only if the input force is applied over a greater distance than the output force is exerted over.

CHAPTER RESOURCES END

Using Machines

5.2

Mechanical Advantage

- The ratio of the output force to the input force is the **mechanical advantage** of a machine.
- The mechanical advantage of a machine can be calculated from the following equation.

Mechanical Advantage Equation

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

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

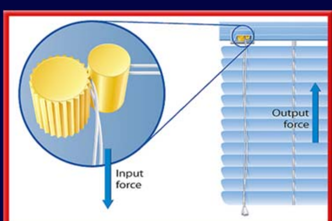
CHAPTER RESOURCES END

Using Machines

5.2

Mechanical Advantage

- Window blinds are a machine that changes the direction of an input force.



- A downward pull on the cord is changed to an upward force on the blinds.

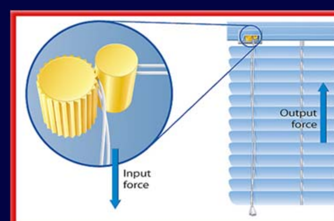
CHAPTER RESOURCES END

Using Machines

5.2

Mechanical Advantage

- The input and output forces are equal, so the MA is 1.



CHAPTER RESOURCES END

Using Machines

5.2

Ideal Mechanical Advantage

- The mechanical advantage of a machine without friction is called the ideal mechanical advantage, or IMA.
- The IMA can be calculated by dividing the input distance by the output distance.

CHAPTER RESOURCES END

Using Machines

5.2

Efficiency

- **Efficiency** is a measure of how much of the work put into a machine is changed into useful output work by the machine.
- A machine with high efficiency produces less heat from friction so more of the input work is changed to useful output work.

CHAPTER RESOURCES END

Using Machines

5.2

Calculating Efficiency

- To calculate the efficiency of a machine, the output work is divided by the input work.
- Efficiency is usually expressed as a percentage by this equation:

Efficiency Equation

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

$$efficiency = \frac{W_{out}}{W_{in}} \times 100\%$$

Using Machines

5.2

Calculating Efficiency

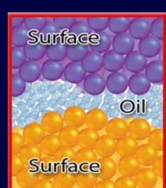
- In an ideal machine there is no friction and the output work equals the input work. So the efficiency of an ideal machine is 100 percent.
- The efficiency of a real machine is always less than 100 percent.

Using Machines

5.2

Increasing Efficiency

- Machines can be made more efficient by reducing friction. This usually is done by adding a lubricant, such as oil or grease, to surfaces that rub together.
- A lubricant fills in the gaps between the surfaces, enabling the surfaces to slide past each other more easily.



Section Check

5.2

Question 1

What do a knife, a doorknob, and a car jack have in common?

Answer

These are all machines, because they are devices that make doing work easier.

Section Check

5.2

Question 2

When a machine is used to do work, the force that is applied to the machine is the __________.

A. Fulcrum
B. input force
C. mechanical advantage
D. output force

Section Check

5.2

Answer

The answer is B. The input force is applied to the machine

Section Check

5.2

Question 3

What is the effect of increasing a machine's efficiency?

Answer

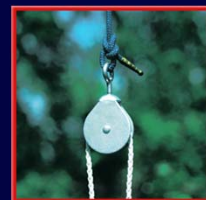
Increasing efficiency increases the amount of input energy converted to useful output.

Simple Machines

5.3

Types of Simple Machines

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



- There are six types of simple machines: lever, pulley, wheel and axle, inclined plane, screw and wedge.

Simple Machines

5.3

Levers

- A **lever** is a bar that is free to pivot or turn around a fixed point.
- The fixed point the lever pivots on is called the fulcrum.

Simple Machines

5.3

Levers

- The input arm of the lever is the distance from the fulcrum to the point where the input force is applied.
- The output arm is the distance from the fulcrum to the point where the output force is exerted by the lever.

Simple Machines

5.3

Levers

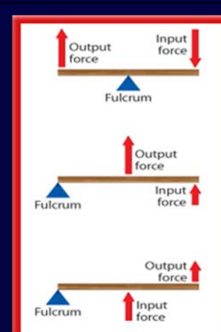
- The output force produced by a lever depends on the lengths of the input arm and the output arm.
- If the output arm is longer than the input arm, the law of conservation of energy requires that the output force be less than the input force.

Simple Machines

5.3

Levers

- If the output arm is shorter than the input arm, then the output force is greater than the input force.
- There are three classes of levers.



Simple Machines

5.3

Ideal Mechanical Advantage of a Lever

- The ideal mechanical advantage, or IMA, can be calculated for any machine by dividing the input distance by the output distance.
- For a lever, the input distance is the length of the input arm and the output distance is the length of the output arm.

Simple Machines

5.3

Ideal Mechanical Advantage of a Lever

- The IMA of a lever can be calculated from this equation:

Ideal Mechanical Advantage of a Lever

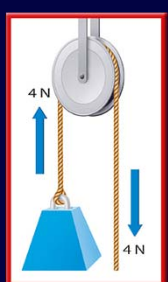
$$\text{ideal mechanical advantage} = \frac{\text{length of input arm (m)}}{\text{length of output arm (m)}}$$

$$IMA = \frac{L_{in}}{L_{out}}$$

Simple Machines

5.3

Pulleys

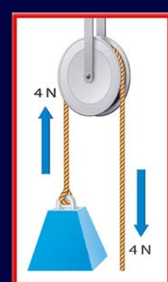


- A **pulley** is a grooved wheel with a rope, chain, or cable running along the groove.
- A fixed pulley is a modified first-class lever.
- The axle of the pulley acts as the fulcrum.

Simple Machines

5.3

Pulleys



- The two sides of the pulley are the input arm and output arm.
- A pulley can change the direction of the input force or increase input force, depending on whether the pulley is fixed or moveable.

Simple Machines

5.3

Fixed Pulleys

- A fixed pulley is attached to something that doesn't move, such as a ceiling or wall.
- Because a fixed pulley changes only the direction of force, the IMA is 1.

Simple Machines

5.3

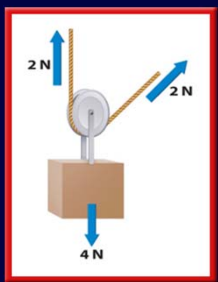
Movable Pulleys

- A pulley in which one end of the rope is fixed and the wheel is free to move is called a movable pulley.
- Unlike a fixed pulley, a movable pulley does multiply force.

Simple Machines

5.3

Movable Pulleys



- With a movable pulley, the attached side of the rope supports half of the 4-N weight.
- You have to apply a 2-N force to lift the weight.

Simple Machines

5.3

Movable Pulleys

- The output force exerted on the weight is 4 N, and the applied input force is 2 N.
- Therefore the IMA of the movable pulley is 2.

Simple Machines

5.3

Movable Pulleys

- For a fixed pulley, the distance you pull the rope downward equals the distance the weight moves upward.
- For a movable pulley, the distance you pull the rope upward is twice the distance the weight moves upward.

Simple Machines

5.3

The Block and Tackle

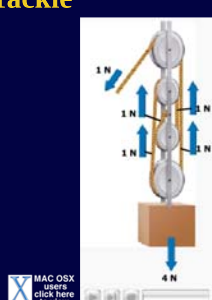
- A system of pulleys consisting of fixed and movable pulleys is called a block and tackle.
- The IMA of a pulley system is equal to the number of rope segments that support the weight.

Simple Machines

5.3

The Block and Tackle

- The block and tackle shown has a IMA of 4.



Simple Machines

5.3

Wheel and Axle

- A **wheel and axle** is a simple machine consisting of a shaft or axle attached to the center of a larger wheel, so that the wheel and axle rotate together.

5.3

Wheel and Axle

- Doorknobs, screwdrivers, and faucet handles are examples of wheel and axles.
- Usually the input force is applied to the wheel, and the output force is exerted by the axle.

5.3

Mechanical Advantage of the Wheel and Axle

- A wheel and axle is another modified lever.
- The center of the axle is the fulcrum.
- The input force is applied at the rim of the wheel.
- So the length of the input arm is the radius of the wheel.

5.3

Mechanical Advantage of the Wheel and Axle

- The output force is exerted at the rim of the axle.
- So the length of the output arm is the radius of the axle.
- The IMA of a wheel and axle is given by this equation:

Ideal Mechanical Advantage of Wheel and Axle

$$\text{ideal mechanical advantage} = \frac{\text{radius of wheel (m)}}{\text{radius of axle (m)}}$$

$$IMA = \frac{r_w}{r_a}$$

5.3

Gears

- A gear is a wheel and axle with the wheel having teeth around its rim.
- When two gears of different sizes are interlocked, they rotate at different rates.
- Each rotation of the larger gear causes the smaller gear to make more than one rotation.

5.3

Gears

- If the input force is applied to the larger gear, the output force exerted by the smaller gear is less than the input force.
- Gears also may change the direction of the force.
- When the larger gear is rotated clockwise, the smaller gear rotates counterclockwise.

5.3

Inclined Planes

- A sloping surface, such as a ramp that reduces the amount of force required to do work, is an **inclined plane**.

Simple Machines

5.3

Mechanical Advantage of an Inclined Plane

- By pushing a box up an inclined plane, the input force is exerted over a longer distance compared to lifting the box straight up.
- The IMA of an inclined plane can be calculated from this equation.

Ideal Mechanical Advantage of Inclined Plane

$$\text{ideal mechanical advantage} = \frac{\text{length of slope (m)}}{\text{height of slope (m)}}$$

$$IMA = \frac{l}{h}$$

CHAPTER RESOURCES END

Simple Machines

5.3

Mechanical Advantage of an Inclined Plane

- The IMA of an inclined plane for a given height is increased by making the plane longer.

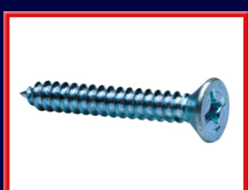
CHAPTER RESOURCES END

Simple Machines

5.3

The Screw

- A **screw** is an inclined plane wrapped in a spiral around a cylindrical post.



- You apply the input force by turning the screw.
- The output force is exerted along the threads of the screw.

CHAPTER RESOURCES END

Simple Machines

5.3

The Screw

- The IMA of a screw is related to the spacing of the threads.
- The IMA is larger if the threads are closer together. However, if the IMA is larger, more turns of the screw are needed to drive it into some material.

CHAPTER RESOURCES END

Simple Machines

5.3

The Wedge

- The wedge is also a simple machine where the inclined plane moves through an object or material.
- A **wedge** is an inclined plane with one or two sloping sides. It changes the direction of the input force.

CHAPTER RESOURCES END

Simple Machines

5.3

Compound Machines

- Two or more simple machines that operate together form a **compound machine**.
- A car is a compound machine.
- Burning fuel in the cylinders of the engine causes the pistons to move up and down.

CHAPTER RESOURCES END

5.3

Compound Machines

- This up-and-down motion makes the crankshaft rotate.

5.3

Compound Machines

- The force exerted by the rotating crankshaft is transmitted to the wheels through other parts of the car, such as the transmission and the differential.
- Both of these parts contain gears, that can change the rate at which the wheels rotate, the force exerted by the wheels, and even reverse the direction of rotation.

5.3

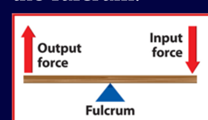
Question 1

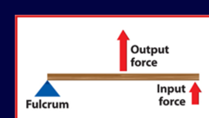
What is the difference between a first-class lever and a second-class lever?

5.3

Answer

In a first-class lever the fulcrum is between the input and output forces; in a second-class lever, the output force is between the input force and the fulcrum.





5.3

Question 2

Which is a third-class lever?

A. baseball bat
B. pulley
C. screwdriver
D. wheelbarrow

5.3

Answer

The answer is A. The output force exerted by a third-class lever is less than the input force, but the distance over which the output force is applied is increased.

Section Check

5.3

Question 3

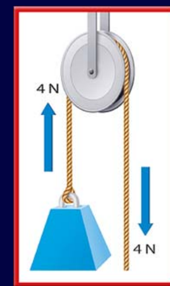
A fixed pulley changes only __________.

Section Check

5.3

Answer

A fixed pulley changes only the direction of force, and the IMA is 1.



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