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Skill Sheet 4-A

Mechanical Advantage



Mechanical advantage (MA) can be defined as the ratio of output force to input force for a machine. In other words, MA tells you how many times a machine multiplies the force put into it. Some machines provide us with more output force than we apply to the machine—this means MA is greater than one. Some machines produce an output force smaller than our effort force, and MA is less than one. We choose the type of machine that will give us the appropriate MA for the work that needs to be performed.

1. What is mechanical advantage?

Mathematically, mechanical advantage may be expressed:

$$MA = \frac{F_o}{F_i}$$

or

$$MA = \frac{\text{output force}}{\text{input force}}$$

If we look at the force unit involved in the calculation, the newton (N), we see that it is present in both the numerator and the denominator of the fraction. Since units behave like numbers in mathematical calculations:

$$\frac{\text{newtons}}{\text{newtons}} = \frac{N}{N} = 1$$

The units cancel each other, leaving the value for mechanical advantage as a unit-less quantity.

2. Calculating mechanical advantage

The following set of problems are designed to provide you with practice using the mechanical advantage formula. The first one is done for you.

1. A force of 200 N is applied to a machine in order to lift a 1,000-newton load. What is the mechanical advantage of the machine?

$$MA = \frac{\text{output force}}{\text{input force}} = \frac{1000 \text{ N}}{200 \text{ N}} = 5$$

2. A machine is required to produce an output force of 600 N. If the machine has a mechanical advantage of 6, what input force must be applied to the machine?
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- An input force of 35 N is applied to a machine with a mechanical advantage of 0.75. What is the size of the load this machine could lift (how large is the output force)?
-
- A machine is designed to push an object with a weight of 12 N. If the input force for the machine is set at 4 N, what is the mechanical advantage of the machine?
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3. Looking ahead

Machines make work easier. Remember that, work is force times distance ($W = F \times d$). The unit for work is the newton-meter, which is often called the joule. Remembering that a joule is the same as a newton-meter will help you cancel units as you work through the problems in this section.

We put work into a machine (work input), and the machine produces work for us in return (work output). The work output is never greater than the work input. In fact, work output is always less than work input because of *friction*. Friction reduces the amount of energy available to the machine. Less energy for the machine means less work done by the machine.

In spite of the loss of work due to friction, the machine still makes work easier because machines can provide mechanical advantage (*MA*).

Machines can multiply your input force (when *MA* is greater than 1) so that you can lift a very heavy object. Machines can also diminish your input force (when *MA* is less than 1). This can be helpful in two ways. First, the object will move farther and faster than the input force; second, you can handle a very delicate object that the force of your fingers might damage. Therefore, knowing a machine's *MA* helps us choose a machine to perform a specific task.

Use the equations for work and mechanical advantage to solve the following problems. The first one is done for you.

- A force of 30 N is applied to a machine to move an object to a height of 2 meters. If the total work output for the machine is 18 joules, what is the mechanical advantage of the machine?

$$\text{input force} = 30 \text{ N} \quad \text{output force} = (\text{work} \div \text{distance}) = (18 \text{ j} \div 2 \text{ m}) = 9 \text{ N}$$

$$MA = \frac{\text{output force}}{\text{input force}} = \frac{9 \text{ N}}{30 \text{ N}} = 0.3$$

- An input force of 50 N is applied to a machine with a mechanical advantage of 3 to move the object 3 meters. If 450 joules of work output is accomplished, what is the output force applied by the machine to the object?
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- 200 joules of work is put into a machine over a distance of 20 meters. The machine does 150 joules of work as it lifts a load 10 meters high. What is the *MA* of the machine?
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Skill Sheet 4-B

Gear Ratios



A gear ratio is used to figure out the number of turns each gear in a pair will make based on the number of teeth each gear has. In this skill sheet you will use gear ratios to solve problems that involve gears.

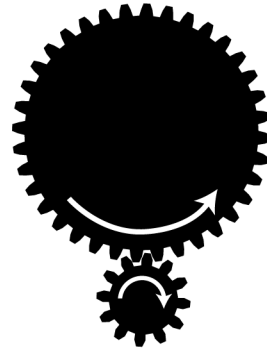
1. What is a gear ratio?

The workings of many machines involve rotating motion. Gears are important for the transfer of rotating motion from one place to another in a machine. For example, rotating engine parts in a car transfers motion to the wheels. The reason that gears are so useful has to do with the teeth around the edges of the gear. The teeth of two neighboring gears can lock together so that rotating motion is transferred from one place to another effectively.

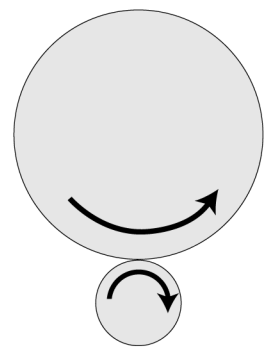
Knowing something about gears allows you to build machines to do specific kinds of work. Clock makers utilize *gear ratios* to figure out how to get the rotating parts of the hour hand and the second hand to work.

To calculate the gear ratio for a pair of gears that are working together, you need to know the number of teeth on each gear. The formula below demonstrates how to calculate a gear ratio. *Notice, that knowing the number of teeth on each gear allows you to figure out how many turns each gear will take.* Why would this be important in figuring out how to design a clock that has a minute and hour hand?

Two gears

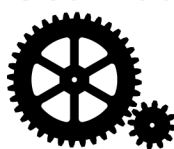


Two wheels



Gears act like touching wheels, but gears have teeth to keep them from slipping as they turn together.

Gear ratio



$$\frac{\text{Turns of output gear} \rightarrow T_o}{\text{Turns of input gear} \rightarrow T_i} = \frac{N_i}{N_o}$$

Number of teeth on input gear (points to N_i)

Number of teeth on output gear (points to N_o)

2. Two-gear problems

Use the gear ratio formula to help you solve these problems. The first one is done for you. Remember that knowing the number of teeth for a pair of gears helps you figure out the number of turns.

1. A gear with 48 teeth is connected to a gear with 12 teeth. If the 48-tooth gear makes one complete turn, how many times will the 12-tooth gear turn?

$$\frac{\text{Turns of output gear?}}{\text{One turn for the input gear}} = \frac{48 \text{ input teeth}}{12 \text{ output teeth}}$$

$$\text{Turns of output gear?} = \frac{48 \text{ teeth} \times 1 \text{ turn}}{12 \text{ teeth}} = 4 \text{ turns}$$

2. A 36-tooth gear turns three times. It is connected to a 12-tooth gear. How many times does the 12-tooth gear turn?

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3. A 12-tooth gear is turned two times. How many times will the 24-tooth gear to which it is connected turn?

-
4. Use the gear ratio formula to help you fill in the table below.

Table 1: Using the gear ratio to calculate number of turns

Input Gear (# of teeth)	Output Gear (# of teeth)	Gear ratio (Input Gear: Output Gear)	How many turns does the output gear make if the input gear turns 3 times?	How many turns does the input gear make if the output gear turns 2 times?
24	24			
36	12			
24	36			
48	36			
24	48			

3. Three-gear problems

The problems in this section involve three gears stacked on top of each other. Once you have filled in Table 2, answer the question that follow. Use the gear ratio formula to help. Remember, knowing the gear ratios allows you to figure out the number of turns for a pair of gears.

Table 2: Set up for three gears

Set up	Gears	Number of teeth	Ratio (top gear: middle gear)	Ratio 2 (middle gear: bottom gear)	Total gear ratio (Ratio 1 x Ratio 2)
1	Top gear	12			
	Middle gear	24			
	Bottom gear	36			
2	Top gear	24			
	Middle gear	36			
	Bottom gear	12			
3	Top gear	12			
	Middle gear	48			
	Bottom gear	24			
4	Top gear	24			
	Middle gear	48			
	Bottom gear	36			

1. As you turn the top gear to the right, what direction does the middle gear turn? What direction will the bottom gear turn?

2. How many times will you need to turn the top gear (input) in set up 1 to get the bottom gear (output) to turn once?

3. If you turn the top gear (input) in set up 2 two times, how many times will the bottom gear (output) turn?

4. How many times will the middle gear (output) in set up 3 turn if you turn the top gear (input) two times?

5. How many times will you need to turn the top gear (input) in set up 4 to get the bottom gear (output) to turn 4 times?

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Skill Sheet 5-A

Work



In science, "work" is defined with an equation. Work is defined as the amount of force applied over distance. By measuring how much force you have used to move something over a certain distance, you can calculate how much work you have accomplished. This skill sheet reviews the work equation and provides problems for you to practice using this equation.

1. What is work?

As you recall, in science work is defined as force acting through a distance. That is, a force acts upon an object to move it a certain distance. However, to do work according to this definition, the force must be applied in the same direction as the movement. For example, if you lift a box off a table, the force applied is up, and the distance is also upward. This means that you have done work. However, if you lift the box off the table and then carry it to a bookshelf, only the lifting is work. Carrying the box is not work because the force on the box is up, and the distance is horizontal. However, you would be doing work if you pushed the box across the floor. Why?

Remember, the only time when work is done is when the force and the distance are in the same direction. So, in scientific terms, work is the force that is applied to an object in the same direction as the motion. The formula for work is:

$$\text{Work (joules)} = \text{Force (newtons)} \times \text{distance (meters)}$$

$$W = F \times d$$

You should note that a *joule* of work is actually a *newton-meter*; both units represent the same thing: work! In fact, one joule of work is defined as a force of one newton that is exerted on an object to move it a distance of one meter.

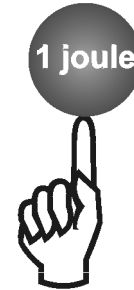
$$1.0 \text{ joule} = 1.0 \text{ N} \times 1.0 \text{ meter} = 1.0 \text{ newton-meter}$$

2. Applying your knowledge

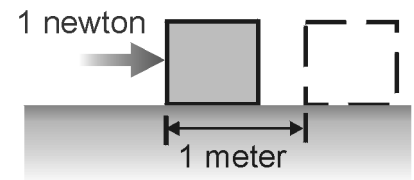
1. In your own words, define work in scientific terms. Be complete in your definition.

2. How are work, force, and distance related?

3. What are two different units that represent work?



is the amount of work done by pushing with a force of 1 newton for a distance of 1 meter.



3. Solving work problems

Solve the following problems using the formula for work. The first problem is done for you.

1. How much work is done on a 10 N block that is lifted 5 meters off the ground by a pulley?

$$\text{work} = F \times d = 10 \text{ N} \times 5 \text{ meters} = 50 \text{ newton-meters} = 50 \text{ joules}$$

2. A woman lifts her 100-newton child up 1 meter and carries her for a distance of 50 meters to her bedroom. How much work does the woman do?

-
3. You pull your sled through the snow a distance of 500 meters with a force of 200 newtons. How much work did you do?

-
4. An ant sits on the back of a mouse. The mouse carries the ant across the floor for a distance of 10 meters. Was there work done by the mouse? Explain.

-
5. You did 170 joules of work lifting a 140 N backpack. How high did you lift the backpack?

-
6. In problem 5, how much did the backpack weigh in pounds? (Hint: there are 4.448 newtons in one pound)

-
7. A crane does 62,500 joules of work to lift a boulder a distance of 25.0 meters. How much did the boulder weigh? (Hint: The weight of an object is considered to be a force.)
-

8. You lift a 45 N bag of mulch 1.2 meters and carry it a distance of 10 meters to the garden. How much work was done?

9. A 455-N gymnast jumps upward a distance of 1.50 meters to reach the uneven parallel bars. How much work did she do before she even began her routine?

10. A 500-newton ballerina did 250 joules of work to lift herself upward through the air. She landed a total of 2.5 meters to the left after completing her jump. How high did she jump?

11. A people-moving conveyor-belt moves a 600-newton person a distance of 100 meters through the airport. How much work was done?

12. A 600 N person lifts his 100 N carry-on bag upward a distance of 1 meter. They travel 100 meters by riding on the “people mover.” How much work was done in this situation?

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Skill Sheet 5-B

Power



In science, work is defined as the force needed to move an object a certain distance. Suppose that you and a friend needed to move two 500-newton piles of potting soil to a garden that was 100 meters away. You accomplished this task in 10 minutes while your friend took 30 minutes. Both of you did the same amount of work (force \times distance), but you did the work in a shorter amount of time. The amount of work done per unit of time is called power. In the example, you had more power than your friend. This skill sheet will give you practice with how to calculate power.

1. What is power?

Suppose you and a friend are helping a neighbor to re-shingle the roof of his home. You each carry 10.0 bundles of shingles weighing 300. newtons apiece up to the roof which is 7.00 meters from the ground. You are able to carry the shingles to the roof in 10.0 minutes but your friend needs 20.0 minutes.

Both of you did the same amount of work (force \times distance) but you did the work in a shorter time.

$$W = F \times d$$

$$W = 10 \text{ bundles of shingles}(300 \text{ N/bundle}) \times 7.00 \text{ m} = 21,000 \text{ joules}$$

However, you had more power than your friend.

$$\text{Power (watts)} = \frac{\text{Work (joules)}}{\text{Time (seconds)}}$$

Let's do the math to see how this is possible.

Step one: Convert minutes to seconds.

$$10 \text{ minutes} \times \frac{60 \text{ seconds}}{\text{minute}} = 600 \text{ seconds (You)}$$

$$20 \text{ minutes} \times \frac{60 \text{ seconds}}{\text{minute}} = 1,200 \text{ seconds (Friend)}$$

Step two: Find power.

$$\frac{21,000 \text{ joules}}{600 \text{ seconds}} = 35 \text{ watts (You)}$$

$$\frac{21,000 \text{ joules}}{1,200 \text{ seconds}} = 17.5 \text{ watts (Friend)}$$

As you can see, the same amount of work that is done in less time produces more power. You are familiar with the word *watt* from a light bulb. Is it now clear to you why a 100-watt bulb is more powerful than a 40-watt bulb?

2. Solving problems

Solve the following problems using the power and work equations. The first problem is done for you.

1. A motor does 5,000 joules of work in 20 seconds. What is the power of the motor?

$$\text{power} = \frac{\text{work}}{\text{time}} = \frac{5000 \text{ joules}}{20 \text{ sec}} = \frac{250 \text{ joules}}{\text{sec}} = 250 \text{ watts}$$

2. A machine does 1,500 joules of work in 30 seconds. What is the power of this machine?
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3. A horse moves a sleigh 1.00 kilometer by applying a 2,000 newton force on its harness for 45 minutes. What is the power of the horse? (Hint: Convert minutes to seconds.)
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4. A wagon is pulled at a speed of 0.40 meters per second by a horse exerting a horizontal force of 1,800 N. What is the power of this horse?
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5. Suppose a force of 100 N is used to push an object a distance of 5.0 meters in 15 seconds. Find the work done and the power for this situation.
-

6. A force of 100 N is used to move an object a distance of 15 meters with a power of 25 watts. Find the work done and the time it takes to do the work.
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7. If a small machine does 2,500 joules of work on an object to move it a distance of 100 meters in 10 seconds, what is the force needed to do the work? What is the power of the machine doing the work?
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8. A machine uses a force of 200 N to do 20,000 joules of work in 20 seconds. Find the distance the object moved and the power of the machine. (Hint: A joule is the same as a Newton-meter.)
-

9. A machine that uses 200 watts of power moves an object a distance of 15.0 meters in 25.0 seconds. Find the force needed and the work done by this machine.
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Skill Sheet 5-C

Potential and Kinetic Energy



In this skill sheet, you will review the forms of energy and formulas for two kinds of mechanical energy—potential and kinetic. After having worked through this skill sheet, calculating the amount of kinetic or potential energy for an object will be easy!

1. Forms of energy

Energy includes radiant energy from the sun, chemical energy from the food you eat, and electrical energy from the outlets in your home. Mechanical energy refers to the energy an object has because of its motion. All forms of energy may be used or stored. Energy that is stored is called *potential energy*. Energy that is being used is called *kinetic energy*. All types of energy are measured in joules or newton-meters.

$$1 \text{ N} = 1 \text{ kg} \cdot \frac{\text{m}}{\text{sec}^2}$$

$$1 \text{ joule} = 1 \text{ kg} \cdot \frac{\text{m}^2}{\text{sec}^2} = 1 \text{ N} \cdot \text{m}$$

2. Potential energy

The word *potential* means that something is capable of becoming active. Potential energy sometimes is referred to as stored energy. This type of energy often comes from the position of an object relative to Earth. A diver on the high diving board has more energy than someone who dives into the pool from the low dive.

The formula to calculate the potential energy of an object is the mass of the object times the acceleration of gravity times the height of the object.

$$E_p = mgh$$

The mass of the object in kilograms times the acceleration of gravity (g) is the same as the weight of the object in newtons. The acceleration of gravity is equal to 9.8 m/sec^2 .

$$\text{mass of the object (kilograms)} \times \frac{9.8 \text{ m}}{\text{sec}^2} = \text{weight of the object (newtons)}$$

3. Kinetic energy

The second category of energy is kinetic energy, the energy of motion. Kinetic energy depends on the mass of the object as well as the speed of that object. Just think of a large object moving at a

very high speed. You would say that the object has a lot of energy. Since the object is moving, it has kinetic energy. The formula for kinetic energy is:

$$E_k = \frac{1}{2}mv^2$$

To do this calculation you need to square the velocity value. Next, multiply by the mass, and then, divide by 2.

4. Solving problems

Now it's time for you to practice calculating potential and kinetic energy. Make sure to show your work with all units present in your calculations as well as your answer. The first two problems have been done for you.

1. A 50 kg boy and his 100 kg father went jogging. Both ran at a rate of 5 m/sec. Who had more kinetic energy? Show your work and explain.

Although the boy and his father were running at the same speed, the father has more kinetic energy because he has more mass.

The kinetic energy of the boy:

$$\frac{1}{2}(50 \text{ kg})\left(\frac{5 \text{ m}}{\text{sec}}\right)^2 = 625 \text{ kg} \cdot \frac{\text{m}^2}{\text{sec}^2} = 625 \text{ joules}$$

The kinetic energy of the father:

$$\frac{1}{2}(100 \text{ kg})\left(\frac{5 \text{ m}}{\text{sec}}\right)^2 = 1,250 \text{ kg} \cdot \frac{\text{m}^2}{\text{sec}^2} = 1,250 \text{ joules}$$

2. What is the potential energy of a 10 N book that is placed on a shelf that is 2.5 meters high?

The book's weight (10 newtons) is equal to its mass times the acceleration of gravity. Therefore, you can easily use this value in the potential energy formula:

$$\text{potential energy} = mgh = (10 \text{ N})(2.5 \text{ m}) = 25 \text{ N} \cdot \text{m} = 25 \text{ joules}$$

3. Determine the amount of potential energy of a 5 N book that is moved to 3 different shelves on a bookcase. The height of each shelf is 1.0 meter, 1.5 meters, and 2.0 meters.

4. Two objects were lifted by a machine. One object had a mass of 2 kg, and was lifted at a speed of 2m/sec. The other had a mass of 4 kg and was lifted at a rate of 3 m/sec. Which object had more kinetic energy while it was being lifted? Show all calculations.

5. In problem 4, which object had more potential energy when it was lifted a distance of 10 meters? Show your calculation. (Remember that gravity = 9.8 m/sec^2)

6. You are on roller blades on top of a hill. Your potential energy is equal to 1,000 joules. The last time you checked your mass was 60 kg.

a. What is your weight in newtons?

b. What is the height of the hill?

c. If you start skating down this hill, your potential energy will be converted to kinetic energy. At the bottom of the hill, your kinetic energy will be equal to your potential energy at the top. What will be your speed at the bottom of the hill?

7. Answer the following:

a. A 1.0-kilogram ball is thrown into the air with an initial velocity of 30 m/sec. How much kinetic energy does the ball have?

b. How much potential energy does the ball have when it reaches the top of its ascent?

c. How high into the air did the ball travel?

8. What is the potential energy of a 3 kg-ball that is on the ground?

9. What is the kinetic energy of a 2,000 kg boat moving at 5 m/sec?

10. What is the velocity of an 500 kg elevator that has 4000 joules of energy?

11. What is the mass of an object that creates 33, 750 joules of energy by traveling at 30 m/sec?
