Name:

Skill Sheet 10.1 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 applied 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 using either of the following equations:

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

or

$$MA = \frac{\text{input lever arm}}{\text{output lever arm}} = \frac{L_i}{L_o}$$

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. Units behave like numbers in mathematical calculations. They can cancel each other, leaving the value for mechanical advantage as a unit-less quantity.

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

2. Calculating mechanical advantage

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

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

$$MA = \frac{\text{output force}}{\text{input force}} = \frac{1{,}000\ \text{N}}{200\ \text{N}} = 5$$

2. A machine is required to produce an output force of 600 newtons. If the machine has a mechanical advantage of 6, what input force must be applied to the machine?

3. An input force of 35 newtons is applied to a machine with a mechanical advantage of 0.75. What is the size of the load this machine could lift, or how large is the output force?

4. A machine is designed to push an object with a weight of 12 newtons. If the input force for the machine is set at 4 N, what is the machine's mechanical advantage?

5. A lever has an input arm of 1.5 meters, an output arm of 0.5 meters. What is the mechanical advantage?

6. A person with a mass of 80 kilograms wants to lift a stone with a mass of 600 kilograms. The person wants to use a steel bar 2 meters long. Calculate the minimum ratio of the input to the output arm and the maximum output lever arm.

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, or 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) so that you can handle a very delicate object that the force of your fingers could damage. Therefore, knowing a machine's mechanical advantage 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.

1. A force of 30 newtons is applied to a machine through a distance of 10 meters. The machine is designed to lift 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?

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

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

2. An input force of 50 newtons is applied through a distance of 10 meters to a machine with a mechanical advantage of 3. If the work output for the machine is 450 joules and this work is applied through a distance of 3 meters, what is the output force of the machine?

3. Two hundred 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 machine's mechanical advantage (*MA*)?

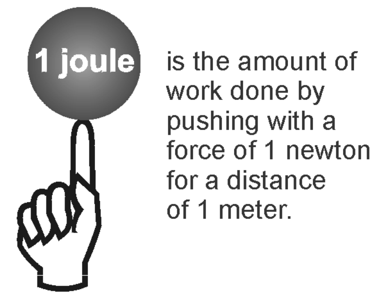
Name: ______________________

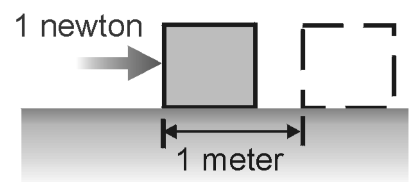
Skill Sheet 10.2 Work

In science, "work" is defined with an equation. Work is defined as force times 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 over 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 upward 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 shelf, only the lifting is work. Carrying the box is not work because the force on the box is upward but the distance is horizontal. However, you would be doing work if you pushed the box across the floor. Why?





Remember, the only time that 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 and remember that a *joule* of work is a *newton-meter*; both units represent the same thing: WORK. In fact, one joule of work is defined as a force of one newton 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?

____

3. Solving work problems

Solve the following problems using the formula for work. The first problem is done for you. Write your answers in joules.

1. How much work is done on a 10-newton 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 daughter up 1 meter and carries her a distance of 50 meters to her bedroom. How much work does the woman do?

3. You pulled 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 a distance of 10 meters across the floor. Was there any work done by the mouse? Explain.

5. You did 170 joules of work lifting your140-newton backpack. How high did you lift your 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-newton bag of mulch 1.2 meters and carry it a distance of 10 meters to your garden. How much work was done?

9. A 455-newton 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?

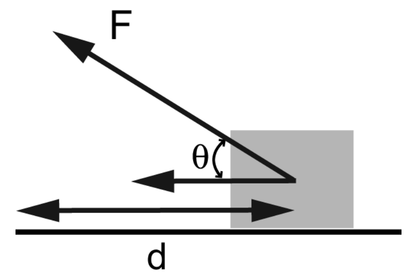
10. It took a 500-newton ballerina a force of 250 joules to lift herself upward through the air. She landed a total of 2.5 meters to the left after completing her jump. How high did she jump?

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-newton passenger at the airport lifts his 100-newton carry-on bag upward a distance of 1 meter. They ride for 100 meters on the "people mover." How much work was done in this situation?

4. Solving work problems that involve angles

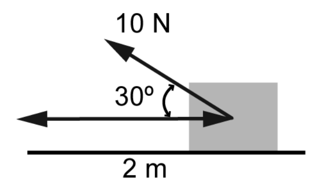
Sometimes work problems involve angles. When the applied force is at an angle to the direction of motion, the only component of the force that contributes to the work is that which is along the direction of motion. As shown on the schematic below, when a force (F) is applied at an angle θ to the direction of motion, the work done by the force (F) as the object moves a distance (d) as indicated is:



$$W = Fd\cos\theta$$

Note that as the angle θ increases, the work done by the force (F) along (d) is decreasing. When θ becomes 90°, the work done by the force (F) along d is zero. Use this information to answer the following questions.

A 10-kilogram box is pulled along the floor by a force of 10 newtons that is at an angle of 30 degrees from horizontal. The box is pulled over a horizontal distance of 2 meters.



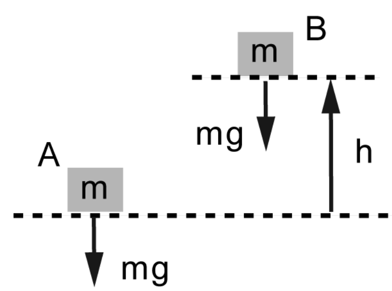
1. How much work is done by the force on the box?

2. What is the work done by the force when the angle increases to 80 degrees?

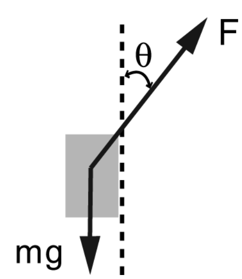
5. Solving work problems using the potential energy equation

When objects of mass (m) are moved vertically, the work done by the force of gravity (mg) is $W = mgh$, where h is the vertical distance in meters that the mass has been moved.

For example, the work done against the force of gravity by moving the mass (m) from position A to position B is $W = mgh$. Note that this work is now stored in the system as energy. If the energy at position A is zero, when the object moves to position B it has potential energy (E) so that $E = mgh$. Use this information to answer the following questions.



An 10-kilogram object is pulled up a vertical wall by a force of 500 newton which acts at an angle 45 degrees.
m = 10 kilograms; θ = 45°; g = 9.8 m/sec^2.



1. What is the work done by the force F on the object as it moves up a distance of 5 meters?

2. What is the work done against the force of gravity as the object is pulled up 5 meters?

Name: ______________________________

Skill Sheet 10.3 Potential and Kinetic Energy

In this skill sheet, you will review the forms of energy and formulas for two kinds of 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 can be used or stored. When talking about motion, energy that is stored is called *potential energy.* Energy that is used when an object is moving is called *kinetic energy.* Other forms of energy include radiant energy from the sun, chemical energy from the food you eat, and electrical energy from the outlets in your home. Energy is measured in joules or newton-meters.

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

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

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 board has more potential energy than someone who dives into the pool from the low board.

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 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 imagine 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 you can practice calculating potential and kinetic energy. Make sure to show your work with all units present in your calculations as well as in your answer. Write your answers in joules. The first two problems have been done for you.

1. A 50-kilogram boy and his 100-kilogram 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:

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

   The kinetic energy of the father:

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

2. What is the potential energy of a 10-newton book sitting on a shelf 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:

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

3. Determine the amount of potential energy of a 5-newton book that is moved to three different shelves on a bookcase. The height of the shelves 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 kilograms, and was lifted at a speed of 2 m/sec. The other had a mass of 4 kilograms and was lifted at 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 standing in your in-line skates at the top of a large hill. Your potential energy is equal to 1,000 joules. The last time you checked, your mass was 60 kilograms.
   a. What is your weight in newtons?

   b. What is the height of the hill?

   c. If you start skating downhill, 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-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?

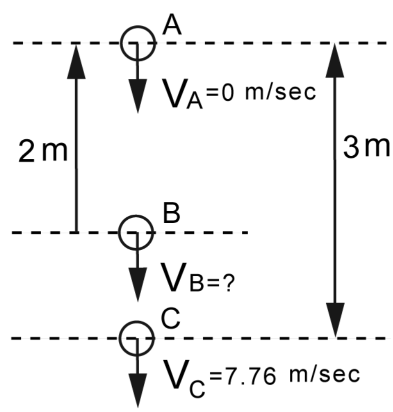
8. What is the potential energy of a 3-kilogram ball lying on the ground?

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

10. What is the velocity of an 500-kilogram elevator that has 4,000 joules of energy?

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

12. **Challenge problem:** In the diagram at right, the potential energy of the ball at position A equals its kinetic energy at position C. At position A, the ball has zero velocity so its kinetic energy equals zero. At position C, the ball does not have potential energy because its height is zero. The mass of the ball is 1 kilogram. Use this information to find the velocity of the ball at position B.



a. Write an equation that shows how the energy of the ball at position B relates to its potential energy at position A.

b. What is the velocity of the ball at position B?

Name: ____________________

Skill Sheet 11.2 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 × 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 this example, you had more power than your friend. This skill sheet will give you practice with how to calculate power.

1. What is power?

Both you and your friend did the same amount of work.

$$W = F \times d$$

$$W = 500 \text{ N} \times 100 \text{ m} = 50{,}000 \text{ N-m} = 50{,}000 \text{ joules}$$

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.

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

$$30 \text{ minutes} \times \frac{60 \text{ seconds}}{\text{minute}} = 1{,}800 \text{ seconds (Friend)}$$

Step two: Find power.

$$\frac{50{,}000 \text{ joules}}{600 \text{ seconds}} = 83.3 \text{ watts (You)}$$

$$\frac{50{,}000 \text{ joules}}{1{,}800 \text{ seconds}} = 27.8 \text{ watts (Friend)}$$

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. Now you see why a 100-watt bulb is more powerful than a 40-watt bulb. Time for you to practice solving some problems involving work and power.

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?

3. A sleigh weighing 2,000 newtons is pulled by a horse a distance of 1.0 kilometer (or 1,000 meters) in 45 minutes. What is the power of the horse? (HINT: Convert time to seconds.)

4. A wagon weighing 1,800 newtons is pulled by a horse at a speed of 0.40 m/sec. What is the power of this horse?

5. Suppose a force of 100 newtons is used to push an object a distance of 5 meters in 15 seconds. Find the work done and the power for this situation.

6. A force of 100 newtons 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.

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?

8. A machine uses a force of 200 newtons 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 meters in 25 seconds. Find the force needed and the work done by this machine.

Name:

Skill Sheet 12.1 Momentum

This exercise will help you solve problems that involve momentum. The momentum of an object is equal to its mass times its velocity. When two objects collide, their momentum before the collision is equal to their momentum after the collision. This statement is called the law of conservation of momentum.

1. What is momentum?

A baseball bat and a ball are a pair of objects that collide with each other. Because of Newton's third law of motion, we know that the force the bat has on the baseball is equal, but opposite in direction, to the force of the ball on the bat. The bat and the baseball illustrate that action and reaction forces come in pairs.

Similarly, the momentum of the bat before it hits the ball will affect how much momentum the ball has after it and the bat collide. Likewise, the momentum of the ball coming toward the bat determines how much force you must use when swinging the bat if you are to hit a home run. What is *momentum*?

The momentum (kg-m/sec) of an object is its mass (in kilograms) multiplied by its velocity (m/sec). The equation for momentum where p equals momentum, m equals mass, and v equals velocity, is:

$$\vec{p} = m\vec{v}$$

$$\vec{p} = \text{mass in kilograms} \times \text{velocity in m/sec}$$

2. The law of conservation of momentum

The *law of conservation of momentum* states that momentum is conserved. This means that the momentum of the bat and ball before their collision is equal to the momentum of the bat and ball after their collision.

Two colliding objects represent a *system*. The formula below can be used to find the new velocities of objects if both keep moving after the collision.

$$\text{the momentum of a system before a collision} = \text{the momentum of a system after a collision}$$

$$m_1\vec{v}_{1(\text{ initial})} + m_2\vec{v}_{2\text{ (initial)}} = m_1\vec{v}_{3\text{ (final)}} + m_2\vec{v}_{4\text{ (final)}}$$

If two objects are initially at rest, the total momentum of the system is zero. For the final momentum to be zero, the objects must have equal momenta in opposite directions.

For example, if you are standing on ice skates and throw a bowling ball, the ball's forward momentum will be equal to your backward momentum.

$$\text{the momentum of a system before a collision} = 0$$

$$0 = \text{the momentum of a system after a collision}$$

$$0 = m_1\vec{v}_3 + m_2\vec{v}_4$$

$$m_1\vec{v}_3 = -(m_2\vec{v}_4)$$

If a collision is inelastic and the objects stick together, both have the same final velocity.

$$m_1\vec{v}_{1(\text{inital})} + m_2\vec{v}_{2(\text{intial})} = (m_1 + m_2)\vec{v}_{3(\text{final})}$$

3. Solving momentum problems

Find the momentum of the following objects. The first two problems have been done for you.

1. A 0.2-kilogram steel ball that is rolling at a velocity of 3.0 m/sec.

$$\text{momentum} = m \times \vec{v} = 0.2\ \text{kg} \times \frac{3\ \text{m}}{\text{sec}} = 0.6\ \text{kg} \cdot \frac{m}{\text{sec}}$$

2. A 0.005-kilogram bullet with a velocity of 500 m/sec.

$$\text{momentum} = m \times \vec{v} = 0.005\ \text{kg} \times \frac{500\ \text{m}}{\text{sec}} = 2.5\ \text{kg} \cdot \frac{m}{\text{sec}}$$

3. A 100-kilogram fullback carrying a football on a play at a velocity of 3.5 m/sec.

4. A 75-kilogram defensive back chasing the fullback at a velocity of 5 m/sec.

5. In questions 3 and 4 above, if the fullback collided with the defensive back, who would get thrown backward? Explain your answer.

6. If a ball is rolling at a velocity of 1.5 m/sec and has a momentum of 10.0 kg-m/sec, what is the mass of the ball?

7. What is the velocity of an object that has a mass of 2.5 kilogram and a momentum of 1,000 kg-m/sec?

4. Problems involving the law of conservation of momentum

Use the law of conservation of momentum formulas to answer the following problems. The first problem has been done for you.

1. You and a friend stand facing each other on ice skates. Your mass is 50 kilograms and your friend's mass is 60 kilograms. As the two of you push off each other, you move with a velocity of 4 m/sec to the right. What is your friend's velocity?

$$m_1\vec{v}_3 = -(m_2\vec{v}_4)$$
$$(50\text{ kg})(4\text{ m/sec}) = -(60\text{ kg})(v_4)$$

   The answer is: v_4 = - 3.33 m/sec or 3.33 m/sec to the left.

2. A 400-kilogram cannon fires a 10-kilogram cannonball at 20 m/sec. If the cannon is on wheels, at what velocity does it move backward? (This backward motion is called recoil velocity.)

3. You stand on a skateboard at rest and throw a rock at 5 m/sec. You move back at 0.5 m/sec. What is the combined mass of you and the skateboard?

4. A 2,000-kilogram railroad car moving at 5 m/sec collides with a 6,000-kilogram railroad car at rest. If the cars coupled together, what is their velocity after the collision?

5. A 2,000-kilogram railroad car moving at 5 m/sec to the east collides with a 6,000-kilogram railroad car moving at 3 m/sec to the west. If the cars couple together, what is their velocity after the collision?

6. A 4-kilogram ball moving at 8 m/sec to the right collides with a 1-kilogram ball at rest. After the collision, the 4-kilogram ball moves at 4.8 m/sec to the right. What is the velocity of the 1-kilogram ball?

Name: ______________________________

Skill Sheet 12.2 Rate of Change of Momentum

Momentum is given by the expression $p = mv$ where p is the momentum of an object of mass m moving with velocity v. The units of momentum are *kg-m/sec*. Change of momentum (represented Δp) over a time interval (represented Δt) is also called the rate of change of momentum. In this skill sheet, you will practice solving problems that involve rate of change of momentum.

1. Rate of change of momentum equations

Since, momentum is $p = mv$, if the mass remains constant during the time Δt, then:

$$\frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t}$$

The expression, $\frac{\Delta v}{\Delta t}$, represents change in velocity over change in time also known as acceleration. From Newton's second law, we know that acceleration equals force divided by mass ($a = F/m$). Rearranging the equation, we see that force equals mass times acceleration ($F = ma$). Similarly, force (F) equals change in momentum over change in time.

$$F = ma = m\frac{\Delta v}{\Delta t} = \frac{\Delta p}{\Delta t}$$

A mass, m, moving with velocity, v, has momentum mv. If this momentum becomes zero over some change in time (Δt), then there is a force, $F = (mv - 0)/\Delta t$.

- mv is the initial momentum.
- 0 is the momentum after a change in time Δt.

When a car accelerates or decelerates, we feel a force that pushes back during acceleration and pushes us forward during deceleration. When the car brakes slowly, the force is small. However, when the car brakes quickly, the force increases considerably.

2. Example problems

Example: A person having a weight of 80 kilograms is a passenger in a car going 90 km/hour. The driver puts on the brakes and the car comes to a stop in 2 seconds. What is the average force felt by the passenger?

First, convert the velocity to a value that is in meter per second: 90 km/hour = 25 m/second. Next, use the equation that relates force and momentum:

$$\text{Force} = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t} = 80\text{ kg}\frac{(25 - 0)\text{ m/sec}}{2\text{ sec}} = 1{,}000\text{ N}$$

This is a large force, and for the person to stay in his seat, he must be strapped in with a seat belt.

When the stopping time decreases from 2 seconds to 1 second, the force increases to 2,000 newtons. When the car is involved in a crash, the change in momentum happens over a much shorter period of time, thereby creating very large forces on the passenger. Air bags and seat belts help by slowing down the person's momentum change, resulting in smaller forces and a reduced chance for injury. Let's look at some numbers.

The car travels at 90 km/hour, crashes, and comes to a stop in 0.1 sec. The air bag inflates and cushions the person for 1.5 seconds. Let's calculate the force experienced by the passenger in an automobile without air bags and in one case with air bags.

- Without the air bag, the momentum change happens over 0.1 seconds. This results in a force:

$$\text{Force} = 80\ \text{kg}\frac{25\ \text{m/sec}}{0.1\ \text{sec}} = 2{,}000\ \text{N}$$

  Chances are the passenger is killed.

- With the air bag, the force created is:

$$\text{Force} = 80\ \text{kg}\frac{25\ \text{m/sec}}{1.5\ \text{sec}} = 1{,}333\ \text{N}$$

  The chances for survival are much higher.

Example: A pile is driven into the ground by hitting it repeatedly. If the pile is hit by the driver mass at a rate of 100 kg/sec and with a speed of 10 m/sec, calculate the resulting average force on the pile.

We are told that the driver mass hits the pile at a rate of 100 kg/sec. What does this mean exactly? We can have a 100-kilogram mass hitting the pile every second, or a 50-kilogram mass hitting the pile every half-second, or a 200-kilogram mass hitting the pile every 2 seconds. You get the idea.

The speed (v) with which the mass hits the pile is 10 m/sec. The mass (m) is 100 kilograms. Time changes occur at 1 second intervals. The force on the pile is:

$$\text{Force} = m\frac{\Delta v}{\Delta t} = 100\ \frac{\text{kg}}{\text{sec}}\ 10\ \frac{\text{m}}{\text{sec}} = 1{,}000\ \frac{\text{kg m}}{\text{sec}^2} = 1{,}000\ \text{N}$$

3. Problems

1. A wrecking ball weighing 1,000 kilograms hits a wall with a speed of 2 m/sec and comes to a stop in 1/100 second. Calculate the force experienced by the wall.

2. A soccer ball weighing 0.15 kilogram is rolling with a speed of 10 m/sec and is stopped by the frictional force between it and the grass. If the average friction force is 0.5 N, how long would this take?

3. Water comes out of a fire hose at a rate of 5 kg/sec and with a speed of 50 m/sec. Calculate the force on the hose. (This is the force that the firefighter has to provide in order to hold the hose.)

4. Water from a fire hose is hitting a wall straight on. The water comes out with a flow rate of 25 kg/sec and hits the wall with a speed of 30 m/sec. What is the resulting force exerted on the wall by the water?

5. The water at Niagara Falls flows at a rate of 3 million kilograms per second. The water hits the bottom of the falls at a speed of 25 m/sec. What is the force generated by the change in momentum of the falling water?

6. A 50-g (0.05 kilogram) egg that is dropped from a height of 5 meters will hit the floor with a speed of about 10 m/sec. The hard floor forces the egg to stop very quickly. Let's say that it will stop in 0.001 second.
   a. What is the force created on the egg?

   b. The egg will break at the force you calculated for 6(a). Imagine that a 50-kilogram person fell down on the egg falling under the influence of gravity. What would the force of the person on the egg be?

   c. Do you think the egg will break if the person fell on it? Why or why not?

   d. If we now drop the egg onto a pillow, it will allow the egg to stop over a much longer time compared with the time it takes for it to stop on the hard surface. The weight and the velocity of the egg is still the same, but now the time it takes for the egg to come to rest is much longer, about 0.5 second or about 500 times longer than the time it took to stop on the floor. What would the force on the egg be under these circumstances?

   e. Do you think the egg will break when it drops on the pillow? Why or why not?