

## **STAAR Science Tutorial 24** **TEK 7.7A: Work**

***TEK 7.7A: Contrast situations where work is done with different amounts of force to situations where no work is done such as moving a box with a ramp and without a ramp, or standing still.***

### **Work**

- In science, for “work” to be performed, a force must be used to move an object. No matter how much force is used, if no movement occurs, no work is done. For example, if you push with 200 newtons of force on a solid brick wall, and do not move the wall, no work was done, even though a force was applied.
- For formula used to calculate work is force multiplied by distance:

$$\text{Work} = \text{Force} \bullet \text{Distance}$$

- The units for the work formula are newtons (N) for force, and meters (m) for distance. This means that the unit for work is the newton-meter (N•m), which is also called a **joule (J)**. The heavy dot “•” is here being used as a sign for multiplication, instead of the “x” that you may be used to seeing. (In algebra, the letter “x” is often used to represent an unknown variable.)
- As an example of this formula and its use, suppose that an object is moved 2 meters, by applying a force of 10 newtons. The amount of work done would be  $2 \text{ m} \bullet 10 \text{ N} = 20 \text{ J}$  of work. Notice that the mass of the object is not needed to calculate work, only the force and the distance. If the distance is given in some unit other than meters, it must be converted to meters before the formula can be used. For example, 20 cm would be converted to 0.2 m before solving the formula.

### **Simple Machines**

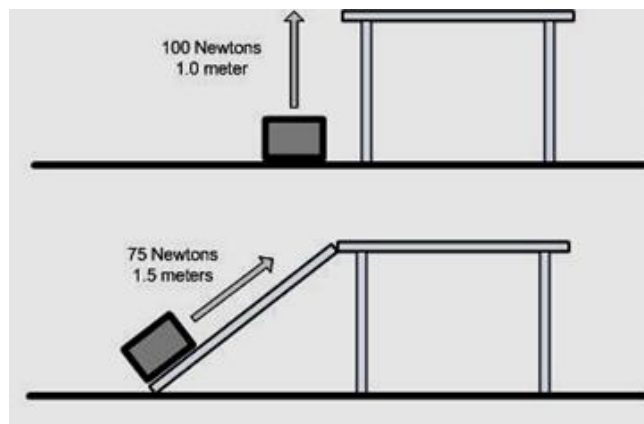
- A **machine** is a device that is used to make it easier to perform work, by changing (1) the amount of input force needed, (2) the amount of input distance moved, or (3) the direction of the input force, all as compared to the output force, distance and direction.
- **Input force** (also called effort force) is the amount of force that is applied to the machine by the user. **Output force** (also called resistance force) is the amount of force that the machine applies to the object being moved. Input distance is the distance that the input force must be applied. Output distance is the distance that the object is being moved by the machine.

- Machines cannot change the total amount of work, however. They simply trade force for distance. If the machine allows less force to be used, the trade-off is that the input force must be applied for a greater distance. In the end, the output work is either the same or less than the input work.
- **Efficiency** in a machine is the measurement of the ratio of the amount of output work to the amount of input work, stated as a percentage (by multiplying by 100). The formula for efficiency is:

$$\text{Efficiency} = \frac{\text{Output Work}}{\text{Input Work}} \bullet 100$$

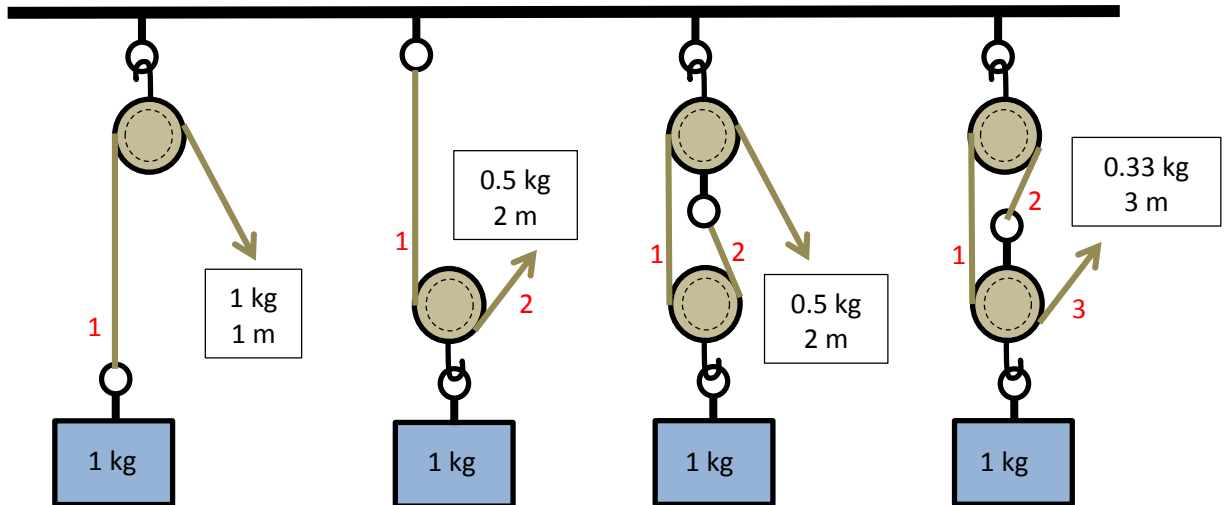
In the real world, no machine can be 100% efficient. All machines lose some of the input work to friction, and thus are less than 100% efficient.

- There are six types of **simple machines**, which can be used separately or in combination to change the amount of input force and movement distance or direction needed to perform work: the inclined plane (ramp), pulley, lever, wheel & axle, screw, and wedge.
- An **inclined plane** or ramp is a flat sloped surface used to spread the work of lifting an object against the force of gravity over a longer distance, thereby requiring less force. For example, all public buildings have a “handicapped ramp” which can be used by people in wheelchairs instead of stairs. Rather than lifting the wheelchair and its occupant up and over the stairs, the work of lifting the wheelchair up the elevation of the stairs is spread over a greater distance, which allows the wheelchair user to do the work themselves. The example below shows a comparison of work done to lift a box versus pushing a box up a ramp:



In this example, it takes 100 newtons of force and 100 Nm of work to lift the box, and 75 newtons of force and 112.5 Nm of work to push the box up the ramp. If the person moving the box has only 80 newtons of strength, he will not be able to lift the box, but will be able to push the box up the ramp. The trade-off is that more work is done to push the box up the ramp, because some work is lost to friction on the ramp.

- The **pulley** is a device that uses a rope or chain passing around one or more grooved wheels to change the direction of the input force, and if more than one wheel is used, to decrease the amount of input force by increasing the amount of input distance. Pulleys are used to raise flags or lift heavy objects. Shown below are examples of four different pulley arrangements, each labeled with the input force and distance needed to lift a 1 kilogram object by 1 meter:

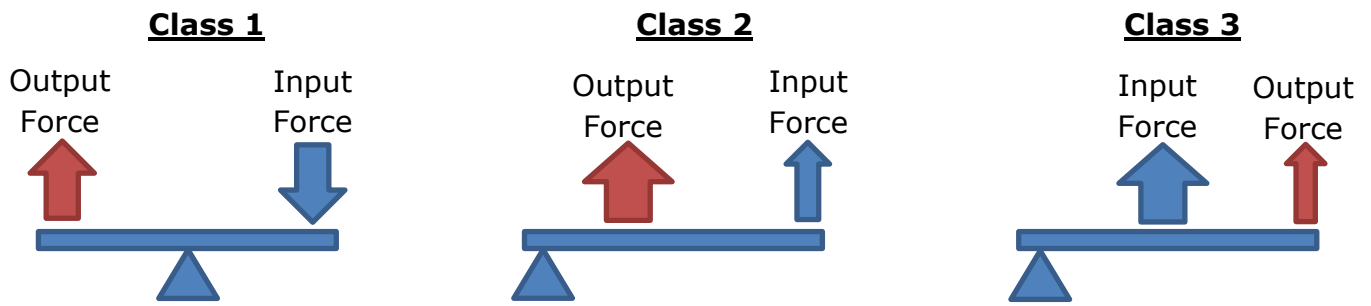


Notice that in each pulley arrangement, the total work performed is the same, about 1 joule ( $N \cdot m$ ), even though the amount of input force and input distance (shown in the box next to the input force arrow) varies. To find the **ideal mechanical advantage** (the magnification factor of the force, disregarding friction) of a pulley, simply count the number of ropes leading away from the weight being lifted (the small red numbers next to the ropes show this count).

- The **lever** is a rigid (unbending) arm that pivots (rotates) around a fixed point called the **fulcrum**. Common examples of levers are listed in the table below:

Lever Example	Lever Arm	Lever Fulcrum	Lever Class	Purpose
See-Saw	Board with two seats	See-saw support at middle	1	Balances weight if fulcrum is centered
Pry Bar	Bar	Bent point of bar	1	Magnifies force if fulcrum is closer to output force end of bar
Wheelbarrow	Handle to wheel support	Wheel	2	Magnifies input force if output force is close to fulcrum at end
Broom, Baseball Bat	Broom Handle or Bat	Hand at end	3	Magnifies movement if input force is close to fulcrum end

- Diagrams of each of the three lever types are shown below:



In each class of lever, the difference between the lengths of the input and output arms determines the mechanical advantage. The further away that the input force is from the fulcrum, as compared to the output force, the greater the magnification of force and mechanical advantage.

- The **wheel & axle** has a large diameter wheel rotating around a smaller diameter axle. Both the wheel and the axle are bound together, so that when the wheel rotates, so does the axle. Because the diameter of the wheel is larger than the diameter of the axle, the distance-measured motion of the axle is magnified when transferred to the wheel. A steering wheel in a car magnifies the force applied to the wheel to help turn the car. The tires of a car magnifies the drive axle's distance turned, helping the car to travel faster.
- The **screw** is like an inclined plane or ramp winding around a center support. Screws usually magnify a small circular force applied over a long distance into a large vertical force. Examples of screws are a car jack, where a small force turning the jack handle is magnified into a large force lifting the car, and a screw-top lid to a jar, where a small turning force on the lid is magnified into a large tightening-down force on the lid.
- The **wedge** is a solid bar which tapers from a thin edge on one end to a thick edge at the other. The edge of a knife, scissors or axe is a wedge designed to split or cut paper, wood or other soft substances. A zipper uses a wedge to force the two sides of the zipper together

### Practice Questions

- What is work? \_\_\_\_\_  
\_\_\_\_\_
- Can work be done if an object does not move when force is applied to it? Why or why not? \_\_\_\_\_  
\_\_\_\_\_
- What is a machine used for? \_\_\_\_\_  
\_\_\_\_\_

4. How is the efficiency of a machine calculated? \_\_\_\_\_  
\_\_\_\_\_.
5. What are the six kinds of simple machines? (1) \_\_\_\_\_;  
(2) \_\_\_\_\_; (3) \_\_\_\_\_;  
(4) \_\_\_\_\_; (5) \_\_\_\_\_; and (6) \_\_\_\_\_.
6. Give two examples of an inclined plane. \_\_\_\_\_  
\_\_\_\_\_.
7. Give two examples of a pulley. \_\_\_\_\_  
\_\_\_\_\_.
8. How is the ideal mechanical advantage of a pulley calculated? \_\_\_\_\_  
\_\_\_\_\_.
9. Give two examples of first-class levers. \_\_\_\_\_  
\_\_\_\_\_.
10. Give two examples of second-class levers. \_\_\_\_\_  
\_\_\_\_\_.
11. Give two examples of third-class levers. \_\_\_\_\_  
\_\_\_\_\_.
12. How is the ideal mechanical advantage of a lever calculated? \_\_\_\_\_  
\_\_\_\_\_.
13. Give two examples of a wheel & axle. \_\_\_\_\_  
\_\_\_\_\_.
14. Give three examples of a screw. \_\_\_\_\_  
\_\_\_\_\_.
15. Give three examples of a wedge. \_\_\_\_\_  
\_\_\_\_\_.