



Force, Speed, and Horsepower

From this lesson, students will gain an understanding of energy, force, work, power, horsepower, and torque. The lesson will use items familiar to students to better explain the concepts listed above. This lesson contains both a hands-on and lecture component.

Primary Learning Outcomes

What are energy, force, work, power, horsepower, and torque and what applications do these have in our everyday lives?

Assessed Georgia Performance Standards

- SPS8. Students will determine relationships between force, mass, and motion.
- Calculate velocity and acceleration
 - Apply Newton's three laws to everyday situations by explaining the following:
 - Inertia
 - Relationship between force, mass, and acceleration
 - Equal and opposite forces
 - Relate falling objects to gravitational force
 - Explain the difference in mass and weight.

Procedures/Activities

Step: 1 Duration: 1 hour 30 minutes

Discussion with students concerning energy, force, work, power, horsepower, and torque. Discussion will also include the concept of the conservation of energy. A brief background of these concepts is included.

Step: 2 Duration: 30 minutes

Review concepts covered in previous days lecture before entering into the lab portion of the discussion.

Step: 3 Duration: 1 hour

Laboratory portion of lesson in which students will measure the amount of force needed to move an object. Objects of different sizes will be used for comparison. The difference in force used to lift an object and to push or pull an object can be demonstrated with a scale and some object to lift or pull. Attach scale to object and lift the object. In effect, you are weighing the object. You are also demonstrating the force required to move the object vertically. Next, tie the scale to the object and pull the object with the scale. You are now demonstrating the force required to move the object in a direction other than vertically. Relate this force difference to the simple machine of an inclined plane.) Can be measured in pounds (lbs.)

Materials and Equipment

Scale that will weigh up to at least 50 lbs

Object weighing 50 lbs or less

10 feet of rope

Meter stick

Total Duration

3 hours

Assessment

Students will be assessed with an exam on the concepts and formulas discussed in the lesson, as well as be graded on a set of questions that accompany the lab exercise.

Discussion of Concepts

1. What is energy?

- A. The resource that *provides the capacity to do work*.
- B. Two forms are potential energy and kinetic energy. Potential energy is stored energy a body has due to its position, chemical state or condition.
 - Examples:
 - Position- water stored behind a dam
 - Chemical - gasoline
 - Condition - a spring compressed
 - Kinetic energy is energy in motion. In effect it is released potential energy. Examples:
 - Water falling over a dam
 - a riding lawn mower moving
 - a spring released.
- C. The law of conservation of energy states that energy cannot be created or used up. The amount of energy is fixed. Energy can be converted from one form to another, but energy is not used up.

2. What is force?

- A. anything that *changes or tends to change the state of rest or motion of a body(mass)*.
- B. Sir Isaac Newton formulated laws, which explain the way objects move. One of his laws states: An object that is moving or at rest does not change its state of motion unless a force acts on it.
- C. Motion is started or stopped by a force.
- D. Once in motion objects tend to stay in motion, and it takes a force to change the direction or speed of an object in motion.
- E. Force is also defined as any push or pull applied to an object. Gravity is a force that pulls down on every object on the earth. The weight of an object is actually how much force of gravity is pulling on the object or how much force is being applied in a vertical position. When a person lifts an object, that person must exert enough force to equal the pull of gravity on the object.
- F. Force is measured in units such as pounds, ounces, grams, etc. For instance, if a person lifts a 60-pound object, the person must exert 60 pounds of force on the object.
- G. Force is also the measurement of a push or pull against an object other than in a vertical direction.
 - If a person pushed or pulled a 60-pound object rather than lifted the object, the amount of force required to move the object may be less (or more) than 60 pounds.
 - For instance, it may take only 40 pounds of force to push the object.
 - If a part of the object is in the ground, it may take more than 60 pounds of force to move the object.

- When determining the force required to move an object in any direction other than vertically, it is not necessary to know the weight of the object. The force required will be determined by how difficult it is to pull or push the load.

3. What is work?

- A. The force applied to an object throughout a distance. In other words, ***when a force is applied to an object and that force causes motion or movement, work has occurred.***
- B. An Example is: moving an object against an opposing force.
- When a lawnmower is pushed, and the force applied is sufficient to start the motion of the lawnmower in opposition to the friction produced by the wheels and thick grass, work is produced.
 - After the mower is moving, it will remain in motion until another force stops it.
- C. Work = Force X Distance. The unit of measure for work is foot-pounds (or Inch-pounds, inch-ounces, etc.).
- Example #1: A person lifts a 60-pound object 2 feet vertically. The work that has been done is: Work = 60 pounds x 2 feet = 120 foot pounds of work.
 - Example #2: A person exerts 40 pounds of force to pull an object 2 feet. The work that has been done is: Work = 40 pounds x 2 feet = 80 foot pounds of work.

Note: If force is applied to an object and the object is not moved, no work is done.

4. What is power?

- A. The rate at which work is done or the time required to do a certain amount of work or work per unit of time.

$$\text{Time} = \text{Work} / \text{Power}$$

$$\text{Power} = \text{Work} / \text{Time}$$

- B. Since work is force x distance, power can also be expressed as:

- Power = $\frac{\text{Force (pounds)} \times \text{Distance (feet)}}{\text{Time (minutes, seconds, etc.)}}$
- Refer to example #2 in item 3. If it takes the person 2 minutes to pull the object 2 feet, the power produced is:

$$\begin{aligned} & \frac{\text{Force (40 pounds)} \times \text{distance (2 feet)}}{\text{Time (2 minutes)}} \\ &= \frac{80 \text{ foot-pounds}}{2 \text{ minutes}} = 40 \text{ foot-pounds per minutes} \end{aligned}$$

- If two people pull the object, and the object is moved 2 feet in 1 minute, the power produced is:
 $80 \text{ foot-pounds}/1 \text{ minute} = 80 \text{ foot-pounds per minute.}$
 If three people pull the object 2 feet in .5 minutes, the power produced is:
 $80 \text{ foot-pounds}/.5 \text{ minute} = 160 \text{ foot-pounds per minute.}$

Note that the work required is the same even with more people pulling the load.

5. What is horsepower?

- The standard unit of measure for measuring power produced.
- Horsepower is based on how much power a single horse can develop, or how much work a single horse can do in one minute.
- James Watt determined that one horse could exert 330 pounds of force in moving a load 100 feet in one minute.

- Using the formula for calculating power, Watt determined that one horsepower = 33,000 foot pounds per minute:

$$\begin{aligned} \text{Power} &= \frac{\text{Force (pounds)} \times \text{Distance (feet)}}{\text{Time (minutes)}} \\ &= 330 \text{ pounds} \times 100 \text{ feet}/1 \text{ minute} \\ &= 33,000 \text{ foot-pounds per minute} \end{aligned}$$

- With this standard of measure, the formula for determining horsepower is:
 - Horsepower = Force x Distance/Time x 33,000. Horsepower may also be expressed as 1 hp = 33,000 foot-pounds/ minute or 1 hp = 550 foot-pounds/second.
 - Refer to the example of one person exerting 40 pounds of force to pull an object 2 feet in 2 minutes. The amount of horsepower produced is:

$$\begin{aligned} &\frac{40 \text{ pounds} \times 2 \text{ feet}}{2 \text{ minutes} \times 33,000} \\ &= \frac{80 \text{ foot-pounds}}{66,000} \\ &= .001 \text{ horsepower.} \end{aligned}$$

6. What is torque?

- A. The force that produces or attempts to produce rotation.
- B. If a door with a doorknob is opened, torque is applied to the doorknob to turn the knob.
- C. Torque must be applied to the pedal of a bicycle to rotate the chain sprocket. If torque produces rotation, work is done. If no rotation is produced, no work is done, but torque can still be measured.
- D. Torque is calculated by multiplying the force applied by the distance from the center of the object being turned. Therefore,
 - $\text{Torque} = \text{Force (pounds, ounces, grams, etc.)} \times \text{radius (feet, inches, meter, etc.)}$
 - Example: 20 pounds of force is applied to the pedal of a bicycle. The pedal is 1 foot from the center of the chain sprocket. How much torque is being applied to the sprocket?
 - $\text{Torque} = 20 \text{ pounds} \times 1 \text{ foot}$. Torque = 20 pound - feet.

Note about radius: Radius is 2 of the diameter of a circle. When determining torque, the radius is 2 the diameter of the circle traveled by the lever to which force is applied. In the example above, the sprocket itself may be only 8 in diameter (4" radius). However, since the pedal lever is 1 foot long, the pedal travels in a circle of 2'. Therefore, the radius used in determining torque is 1'.

- E. Torque and work are both measured in the same units: pounds and feet. However, there is a difference in how the two are determined.
 - $\text{Work} = \text{Force} \times \text{Distance}$
 - $\text{Torque} = \text{Force} \times \text{Radius}$.
 - Using our same example of the person exerting 40 pounds of force to move an object 2 feet, 80 foot-pounds of work is produced. If the person uses a winch with a 1' lever arm to move the object, the same amount of force (80 pounds) is needed to move the object. However, the torque produced in moving the load is calculated as follows:
$$\begin{aligned} \text{Torque} &= \text{Force} \times \text{Radius} \\ &= 40 \text{ pounds} \times 1 \text{ foot} \\ &= 40 \text{ pound-feet} \end{aligned}$$
 - If the lever arm length is increased to 2', the torque will be:
 - $\text{Torque} = \text{Force} \times \text{Radius}$
$$\begin{aligned} &= 40 \text{ pounds} \times 2 \text{ feet} \\ &= 80 \text{ pound-feet} \end{aligned}$$
 - By increasing the length of the lever arm to 2', the length of the arm and the radius of the circle in which the lever arm moves are doubled. The torque produced is also doubled. The force required to move the object remains the same, 40 pounds. If 40 pounds of force is all that is required to move the object, the force applied at the lever will be reduced from 40 pound-feet to 20 pound feet, calculated as follows:

- If $\text{Torque} = \text{Force} \times \text{Radius}$, then $\text{Force} = \text{Torque} / \text{Radius}$
 $\text{Force} = 40 / 2$
 $= 20 \text{ pounds.}$
 - By increasing the length of the lever arm (which increases the radius), the same amount of work can be done with less force (effort) applied.
- F. Even though work and torque are both measured in the same units of feet and pounds, the examples have shown that there is a difference in work and torque. Therefore, to distinguish between the amount of work produced and the amount of torque produced, work is usually expressed as foot-pounds and torque is usually expressed as pound-feet. Other units of measure for torque are pound-inches, ounce-inches, gram-meter, etc.

7. How do you measure engine torque?

- A. Engine torque can be measured by using a device called a Prony brake.
- B. The pressure arm of the Prony brake is attached to the torque wrench and crankshaft of the engine, this will allow the shaft to turn while applying a turning force to the stationary torque wrench. Use the formula to determine torque.
- C. Torque is not constant and changes with engine speed.
- D. The pressure of the burning air-fuel mixture against the piston is transferred to the crankshaft by the connecting rod.
- E. The greater the pressure, the more torque the crankshaft will develop.