1103 Per 11 Solutions: Wheel and Axles, Hydraulics, Gears, and Complex Machines

11.1 How Do Wheels and Axles Work?

1) Winch Your instructor will demonstrate a winch in the front of the classroom.

   a) Suppose you move the handle of the winch in a circle a distance of 40 meters (distance in). When you do, the winch rope moves 2 meters (distance out).

      If you exert a force of 280 newtons on the winch handle (force in), calculate how much work in must you do to move the winch handle a distance of 40 m.

   b) If the force out on the rope is 2,400 newtons, how much work out does the winch do as it pulls the rope a distance of 2 m?

   c) Calculate the efficiency of the winch.

2) Wheels and Axles The plastic bottle illustrates a wheel and axle trading force for distance. The middle of the bottle represents the wheel and the neck of the bottle represents the axle. We will hang a weight from the wheel (the center of the bottle) to do work on a weight attached to the axle (the neck of the bottle).

   a) Measure the circumference of the middle of the bottle. ________

      Take ½ of this length to find the **distance in.** _________________

      (We use ½ of the length because the bottle can move only ½ turn.)

   b) Measure the circumference of the neck of the bottle. ________

      Take ½ of this length to find the **distance out.** _________________

   c) Attach a 5 newton weight to the string around the neck of the bottle (the axle). This is the **force out.**

   d) **Before you hang weights from the second string,** calculate how much force must hang from the string around the middle of the bottle (the wheel) to balance the 5 N force hanging from the bottle neck. This is the **force in.**

      (Hint: Assume that the bottle is frictionless, so that \( W_{\text{out}} \) done on the weight to raise it equals \( W_{\text{in}} \). Then use \( F_{\text{in}} \times D_{\text{in}} = F_{\text{out}} \times D_{\text{out}} \))
e) Check your prediction. With the 5 N weight hanging from the bottle neck, hang weights totaling the force you found in part 4 from the middle of the bottle. If the work in equals the work out, the bottle should balance without rotating. Describe what happens when you attach the weights.

f) Group Discussion Question: Could this system be unbalanced, but the bottle does not rotate? Why or why not?

11.2 How Do Hydraulic Systems Work?
3) Hydraulic Machines The two connected syringes represent a hydraulic machine
  a) Press the plunger of the small syringe in. Using a ruler, measure the distance in the small plunger moves ______ and the distance out the large plunger moves. ______
  b) Calculate the ideal mechanical advantage of the syringe set.

c) Suppose that a force in of 5 newtons on the small plunger (the force in) is required to exert a force of 12 newtons on out on the large plunger (the force out). Calculate the actual mechanical advantage of the syringe system.

d) Calculate the efficiency of the syringe system.

e) List several devices that operate on the same principle as the syringes.
11.3 How Do Gears Work?

4) Gears
   a) Examine the gear toy. To make the edge of the outer gears turn the fastest, should the center gear be smaller or larger than the outer gear? Make a prediction and then experiment to check your guess.
      Prediction: ___________________  Answer: ____________________

   b) Find a combination of 3 or more gears that make the yellow “flipping eyes” gear flip at the fastest rate. (Use 2 or more gears plus the flipping eyes gear. Put the flipping eyes farthest from the center.)

   c) Find a combination of 3 or more gears that make the flipping eyes gear flip at the slowest rate.

   d) Draw a sketch of your gear setups showing which gears you used.
      Eyes Flip Fastest                           Eyes Flip Slowest

11.4 What Are the Efficiency and Mechanical Advantage of Complex Machines?

5) Complex Machines
   a) Examine the toy on your table made from a Capsela set and list the simple machines you see.

   b) If a hydraulic machine with a mechanical advantage of 5 and an efficiency of 60% is connected to a block and tackle with a mechanical advantage of 4 and an efficiency of 50%, what is the overall mechanical advantage of the complex machine?

   c) What is the overall efficiency of the hydraulic machine and the block and tackle combined?

   d) Is it possible to combine simple machines to form a complex machine with a greater overall mechanical advantage than its component machines? __________

   e) Is it possible to combine simple machines to form a complex machine with a greater overall efficiency than its component machines? __________
      Explain why or why not.
6) **Mechanical Advantage of a Bicycle**

The ideal mechanical advantage of a bicycle depends on the ratios of the pedal radius, front and rear sprocket radii, and the rear tire radius.

a) A bicycle’s pedal radius is 14.5 cm and its front sprocket radius is 7.5 cm. What is the ideal mechanical advantage of this front assembly?

b) The bicycle’s chain is on a rear sprocket gear with a radius of 4.0 cm. The rear wheel radius is 28 cm. What is the ideal mechanical advantage of the rear assembly?

c) What is the complex mechanical advantage of the front and rear assemblies?

d) As the pedals turn, they inscribe a circle of radius 14.5 cm. What is the circumference of this circle?

e) Using your calculation of the pedal circumference as the distance in and the complex mechanical advantage from part c), find the distance out that the bicycle moves with each complete turn of the pedals.

f) Using meters sticks on the floor, measure the distance that the bicycle tire moves as you turn the pedals one revolution. _________________

How does this the measured distance, which is based on the actual mechanical advantage, compare to your calculated distance, which is based on the ideal mechanical advantage? ________________________________

What could account for any differences?
Period 11 Exercises: Gears and Complex Machines

Write answers to the questions below. Show your mathematical steps and the units of the quantities. This sheet with your answers should be turned in at the beginning of Period 12.

1. Combining efficiencies:
   In an auto repair shop, a hydraulic lift raises a 2,000 lb vehicle to a height of 6 feet. (A hydraulic lift is a simple machine that is similar in principle to the water-filled syringes used in class.)
   a) What is the work output of this lift?

   b) This hydraulic lift is 67% efficient. What was the work input to the process of lifting this vehicle?

   c) To improve the efficiency of the hydraulic lift, a mechanic suggests attaching an electric motor with an efficiency of 80% to the hydraulic lift. Would this addition improve the overall efficiency? Why or why not?

2. Combining mechanical advantages:
   The mechanical advantage of a complex machine that punches holes in doughnuts at a bakery is 18. The lever that adjusts the hole punch has a mechanical advantage of 2, and the piston that lowers the punch has a mechanical advantage of 3. What is the mechanical advantage of the rest of this machine?

3. Using gears:
   The three gears of different sizes shown in the diagram are meshed. They same the same number of teeth, so when the large gear turns one complete revolution, the medium sized and small gears also turn one revolution.
   a) The large gear’s diameter is 1.6 cm. A point on the large gear’s edge will travel how many centimeters during one revolution?

   b) The small gear’s diameter is 1.2 cm. How far will a point on the small gear’s edge travel during one revolution?

   c) As the gears turn, a point on the edge of which gear (small, medium, or large) will move the fastest? Why?