a large mechanical advantage, it is easy to move a heavy load with a relatively smaller force. The trade-off is that the smaller applied force must be carried over a longer distance compared to the distance the heavy load is moved. This is a result of the *conservation of energy,* in which the total energy in equals the total energy out. A small force will move a large distance while the large load moves a small distance. The mechanical advantage of a hydraulic system can also be determined by comparing the distance the input force moves compared to the output force.

$$MA = d_i/d_o \qquad \textit{Equation 2}$$

d_i = input distance

d_o = output distance

A hydraulic system is not perfectly efficient. There will always be some energy lost due to frictional forces. Equation 2 is considered the *ideal mechanical advantage* (MA_i) because it is based only on dimensions. Equation 1 provides the actual, real-world mechanical advantage (MA_a) because it is a ratio of the total force out (the lifted mass) to the total force in (the force necessary to raise the mass as well as the force necessary to overcome friction). The efficiency of the system can be calculated using Equation 3.

$$\text{Efficiency} = MA_a/MA_i \times 100\% \qquad \textit{Equation 3}$$

Materials

Beaker, 250-mL
Graduated cylinder, 50-mL
Mass, 1000-g
Paper towels
Meter stick
Scissors
Spring scale, 1000-g (10-N)
String, 300-cm and 60-cm piece
Syringe, plastic, 1-mL
Syringes, plastic, 3-mL, 3
Syringes, plastic, 20-mL, 2
Syringe-tip connectors, Luer Lock, 3
Water, 200 mL

Safety Precautions

When pressing on the syringe systems, be sure to press only the input plunger with your thumb and hold the output syringe with your other hand to prevent the syringes from separating. Do not use the syringe as a "squirt gun." Wear safety glasses. Follow all normal laboratory safety rules.

Preparation

1. Obtain three 3-mL, one 1-mL, and two 20-mL syringes, three syringe-tip connectors, and a 250-mL beaker. Fill the beaker three-quarters full with water.
2. Remove the plunger from one of the 3-mL syringes. (Call this Syringe A.)
3. Connect the Luer Lock syringe-tip connector to another 3-mL syringe. (Call this Syringe B.)
4. Place the open end of the syringe-tip connector on Syringe B into the 250-mL beaker of water. Pull back on Syringe B's plunger to draw water into the syringe until it is approximately three-quarters full.
5. Invert the syringe so that the tip is up and the plunger end is down—any air bubbles trapped in the syringe will rise to the tip end. Carefully flick the syringe body with a finger to release any air bubbles clinging to the sides of the syringe.
6. Connect Syringe A to the open end of the Luer Lock syringe-tip connector on Syringe B.

7. Hold the coupled syringes vertically so that Syringe A is above Syringe B. Then, slowly push on Syringe B's plunger to fill Syringe A. See Figure 2a.
8. If Syringe A does not become completely filled, use a 50-mL graduated cylinder to add enough water to Syringe A until it is just overflowing. See Figure 2b.
9. Once Syringe A is overflowing, replace the plunger into Syringe A making sure no air bubbles become trapped in the syringe body. See Figure 2c. Repeat steps 4–9 if air bubbles become trapped.
10. Repeat steps 2–9 for a 20-mL/3-mL system. Refer to the 3-mL syringe as "Syringe A" and the 20-mL syringe as "Syringe B" in the procedure.
11. Repeat steps 2–9 for a 20-mL/1-mL system. Refer to the 1-mL syringe as "Syringe A" and the 20-mL syringe as "Syringe B" in the procedure. *Note:* The 1-mL syringe does not have the Luer Lock tip. It will not lock into the syringe tip connector.

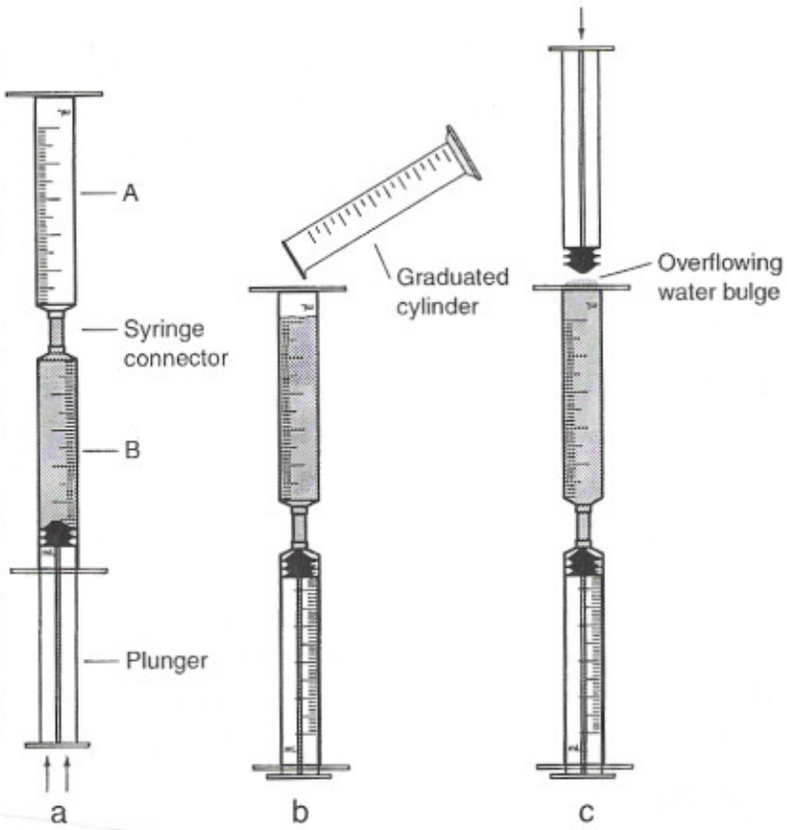

Figure 2.

Procedure

Observations

1. Working one at a time with the three syringe system, press down first on one plunger and watch the movement of the second plunger. Then press on the second plunger and watch the movement of the first plunger. How do the opposing plungers in each system move? Is it easier to push on the smaller or larger plunger in each system? Record all observations in Data Table 1.

   Note: When pressing on the plunger of a syringe, be sure to hold the syringe body of the other syringe to prevent the syringes from coming apart. This is especially important for the 1-mL/20-mL system because the 1-mL syringe does not have a Luer Lock tip. Also, for the 20-mL syringe systems, do not push too hard on the 20-mL plunger since this may cause the 1-mL and 3-mL plungers to "pop out" of their respective syringes.

Mechanical Advantage — Part 1

2. Obtain the 3-mL/3-mL syringe system.
3. Press one plunger all the way down until it can no longer move, thereby moving all water into one of the syringe bodies. The empty syringe (with plunger pushed all the way in) will be the "output" syringe. The water-filled syringe will be the "input" syringe.
4. Measure the initial distance the input plunger is from the end of the syringe body. See Figure 3. Record this distance to the nearest 0.1 cm in Data Table 2.
5. Measure the initial distance the output plunger is from the end of the syringe body. See Figure 3. Record this distance to the nearest 0.1 cm in Data Table 2.

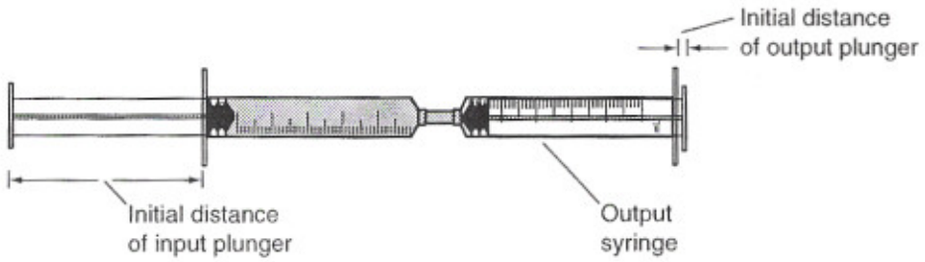

Figure 3.