Fluid and Thermal Systems

Engineering the Future Project 3

Improve a Patented Boat Design

“Reverse Engineering”

- Most problems that engineers encounter involve the improvement of things that already exist. In order to redesign something, the first step is to figure out how it works. This process is called “reverse engineering,” and it usually begins when an engineer takes a very close look at how something operates, makes some good guesses about how it works, then builds a model to test these initial ideas. If the model works, then it’s possible to modify the model to improve its performance. Cars, planes, cell phones, and just about all of the technologies that we depend on daily have been improved again and again through this process.

Putt-Putt Boat

- For this project, you will redesign the “putt-putt boat,” a toy that was invented over a hundred years ago! These boats are still being manufactured today in India, and shipped all over the world for people to buy.
- In order to redesign something, you first have to figure out how it works. Several of the tasks in this project will help you learn how the putt-putt boat transforms heat energy into sound and motion. When you have completed your redesign, you will write a patent application, which will include drawings and a detailed description of how the boat works, and the changes you have made. If you file your patent with the government, you’ll protect your new design so it cannot be copied by one of your competitors.

Outline of Material Gantt Chart

- 3.1 Putt-Putt Boats and Patents
- 3.2 Manufacture a Putt-Putt Boat
- 3.3 Investigate Fluid Systems
- 3.4 Develop a Manufacturing Press
- 3.5 Investigate Heat Engines
- 3.6 The Rocket Effect

Project 3.0: 45-Minute Class Periods	5	10	15	20	25	30	35	40	Text Chapter
Task 3.1: Putt-Putt Boats and Patents Students see a putt-putt boat in action and receive the project assignment.									
Task 3.2: Manufacture a Putt-Putt Boat Students follow instructions and plans to make a replica of a toy boat.									17
Task 3.3: Investigate Fluid Systems Students learn about the basic properties of air and water.									18
Task 3.4: Develop a Manufacturing Press Students consider the properties of hydraulic and pneumatic systems in designing a syringe system that can operate a machine press.									19 20
Task 3.5: Investigate Heat Engines Students learn how heat engines are heated and cooled to produce motion.									21
Task 3.6: The Rocket Effect Students use a model of the boiler engine to understand how pressure difference, resistance, velocity, and volume flow rate are related.									22
Task 3.7: Investigate Resistance in Pipes Students blow through different types of straws of different lengths, areas, and angle bends, in series and parallel, to learn about fluid resistance.									23
Task 3.8: Redesign the Putt-Putt Boat Students design a change to some aspect of the boat, justify the change, and implement it.									
Task 3.9: Present Your Patent Students write a patent application describing how the putt-putt boat works, their changes to the design, and the results. Finally, students present their results to the class.									

3.1 Putt-Putt Boats and Patents

Identify the goals of the project.

Describe what is required in a patent.

Background of the Putt-Putt Boat

- Thomas Piot first patented the putt-putt boat in 1891 in the United Kingdom.
- **Piot Engine** - Because Thomas Piot's boat engine is a unique design, it is called "the Piot Engine."

Piot's Patent

- As you review Piot's original patent for "Improvements in Steam Generators" see if you can match his descriptions in the section called "Complete Specification" with his drawings.

N° 20,081 A.D. 1891

Date of Application, 19th Nov., 1891

Complete Specification Left, 18th Aug., 1892—Accepted, 15th Oct., 1892

PROVISIONAL SPECIFICATION.

Improvements in Steam Generators.

I, Desire Thomas Piot, of No. 71, Bolsover Street, Euston Road, in the County of Middlesex Electrician do hereby declare the nature of this invention to be as follows :—

The object of my invention is to produce a steam generator in which the operation of feeding with water is continuous and depends upon the vaporization of the water in the heating chamber.

In carrying my invention into effect I use two or more tubes, opening into a common chamber so that the orifices thereof, and the ports or slots formed in the sides or circumference may be close to the sides of said chamber. I prefer to charge the tubes and chamber with water, and to generate steam by heating said chamber. The exit of the steam under pressure and consequent condensation by contact with the atmosphere or other surrounding medium causes a reverse current by which the water of condensation or other water may be drawn into the generator.

The chief feature of my said invention is to place a small volume of fluid in direct contact with a source of heat, and to utilise the pressure for producing mechanical work, the volume of liquid under action being always supplied by its own condensation either by using the water thereof or utilising the attenuated pressure to draw in water from other sources and produce a continuous action.

My said invention is especially useful in the case of toy boats, where the propulsion depends upon the pressure of steam acting directly upon the water, and the consequent condensation serves to supply the feed by convection.

Dated this 18th day of November 1891.

FREDK. WALKER,
11, Furnival Street, Holborn, London, E.C., Agent for the Applicant.

COMPLETE SPECIFICATION.

Improvements in Steam Generators.

I Desire Thomas Piot of No 71 Bolsover Street Euston Road in the County of Middlesex, Electrician do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement :—

The object of my invention is to produce a steam generator in which the operation of feeding with water is continuous and depends upon the vaporization of the water in the heating chamber.

In order that my invention may be the better understood I have appended the accompanying sheet of drawings in which

Figure 1 is a side elevational view of a model boat having my improved steam generator adapted thereto.

Figure 2 is a plan of the same and

Figure 3 is a transverse section of my improved generator.

In carrying my invention into effect I employ two or more tubes A A^1 one of said tubes A^1 may be slightly longer than the other, one end of the tubes opening into a chamber B common to the two so that the orifices, ports or slots which may be formed in the sides or circumference may be close to the sides of the above mentioned chamber B, I prefer to charge the tubes and chamber with water and to generate steam by heating said chamber in any suitable manner.

The exit of steam under pressure and consequent condensation by contact with

[Price 8d.]

the atmosphere or other surrounding medium causes a reverse current by which the water of condensation or other water may be drawn into the generator.

The chief feature of my invention is to place a small quantity or volume of fluid in direct contact with a source of heat and to utilise the pressure for producing mechanical work, the volume of liquid under action being always supplied by its own condensation either by using the water thereof or utilising attenuated pressure to draw in water from other sources and produce a continuous action.

Figures 1 and 2, in which the body or hull C of the vessel is utilised as a reservoir for liquid fuel, and has adapted to the deck thereof a suitable burner *b* and wick *c* both wick and burner being shielded from the influences of the external atmosphere by means of a funnel *d*.

The chamber B is supported in any suitable manner inside the aforementioned funnel immediately over the flame *e* and the tubes A A^1 are led therefrom to the stern of the boat as shewn by the dotted lines in Figure 1. Water having been injected by any suitable manner into the chamber B, on lighting the lamp steam is generated, and issuing through the tube A^1 causes a partial vacuum in the said chamber and water is drawn up the tube A when again coming into contact with the heated surface of the chamber is converted into steam thus keeping up a constant flow of water to the chamber B and at the same time propelling the vessel C by the pressure of steam acting upon the water in which the vessel floats. A screwed tap e^1 or other suitable device is provided for the purpose of supplying the oil to the body of the boat.

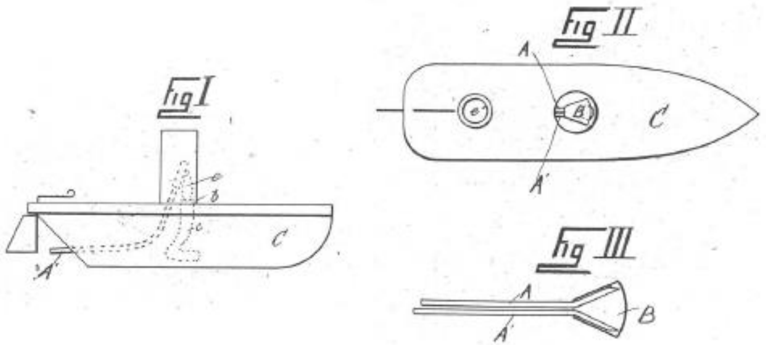
Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is :—

In a steam generator the combination of two pipes or tubes terminating in a chamber heated by a lamp or other source of heat in which steam is generated and a constant supply of water created by convection substantially as herein described with reference to the accompanying drawings.

Dated this 18th day of August 1892.

FREDK. WALKER,
11, Furnival Street, London, E.C., Agent for the Applicant.

London : Printed for Her Majesty's Stationery Office, by Darling & Son, Ltd.—1892



3.2 Construction of the Putt-Putt Boat

Key Manufacturing Processes

- **Forming:** Using pressure or force to shape a material
- **Separating:** Removing unwanted materials
- **Conditioning:** Any process that changes the properties of a material using heat, chemicals, or mechanical force
- **Assembling:** Joining the various parts of a product
- **Finishing:** Any process done to the surface of a product to make the product more attractive to a consumer

3.3 Investigate Fluid Systems

- How do air and water behave differently when pressure is increased?
- How can energy be transferred through hydraulic and pneumatic systems?

Overview of Fluids

- There are many kinds of fluid systems. In the natural world there are open systems like rivers and streams, where the fluid (water) continuously flows in and out. For instance, water evaporates out, and rain water is added in to the system. There are also closed systems like the human circulatory system, in which the fluid (blood) is contained inside veins and arteries. In this task, and the next, you'll explore two kinds of closed systems—hydraulic and pneumatic systems—that can be used to manufacture boat hulls. Later you'll apply these same ideas to how the boiler works in the putt-putt boat.

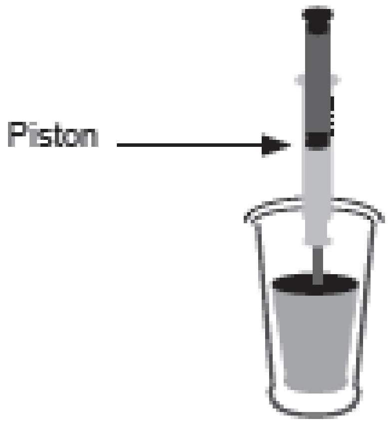
Types of Fluids

- You can use syringes with moveable pistons to make fluids move. You will learn more about this later, when making a machine press move. But what is a fluid?
  - **Fluid:** A material or substance that can flow, including liquids and gases.
- You already know that a liquid like water is a "fluid," but a gas, like air, is also considered a fluid. Both liquids and gases can be used in a system for making things move. A system may be named according to the type of fluid it uses:
  - **Hydraulic System:** Liquid is the fluid that flows in the system.
  - **Pneumatic System:** Gas is the fluid that flows in the system.

Experiment with Fluids

Record your observations in your notebook.

- Try putting air and water in the syringes.
- Push and pull the piston to see how the trapped fluids respond.
- Try to note differences you observe between pneumatics and hydraulics.



Color-Coding Gas Pressure

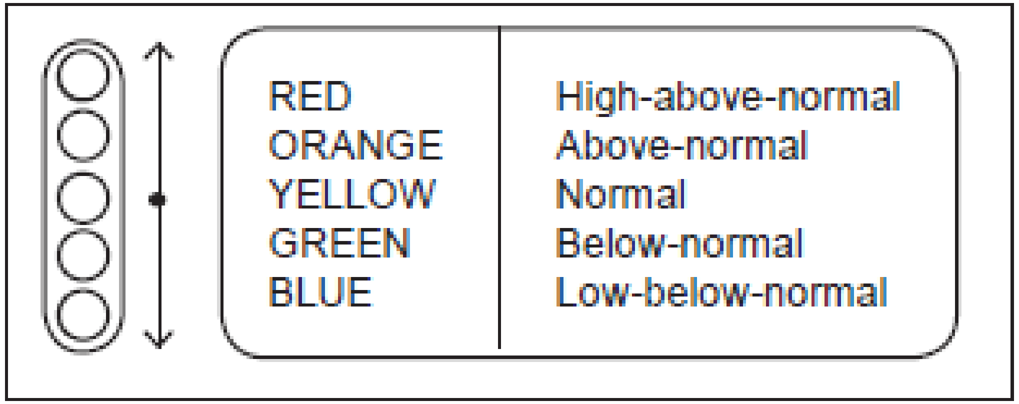
- Gases are difficult to understand because they are impossible to see with the naked eye. Luckily, there are some things you can learn about a gas by experimenting. Using the plunger on a syringe, you can change the amount of space (volume) in the syringe and see what happens. Because the gas can't escape when you push the plunger in, if the cap is on, it is squeezed into a smaller space. Squeezing a gas into a smaller space increases the pressure of the gas. So the volume and the pressure change inside the syringe.

Color-Coding Gas Pressure

- **Pressure:** A measure of what you perceive as the "squeezedness" of a fluid. Pressure is defined as how hard the fluid pushes on the walls of its container. It is similar to how temperature is a measure of what you perceive as an object's "hotness."
- A fluid has a pressure that can be measured, just as it has a temperature that can be measured. As you pull the piston out in a syringe that is full of air, the volume inside the syringe will increase. The gas trapped in the syringe expands to fill the whole syringe. It is even less squeezed than normal. When a gas expands into a larger volume, its pressure decreases.

Color Coding

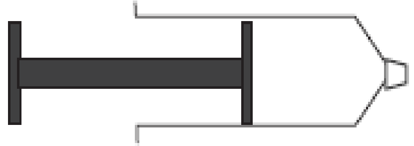
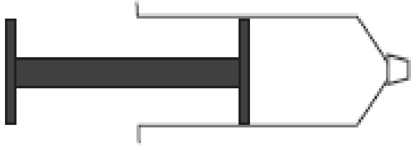
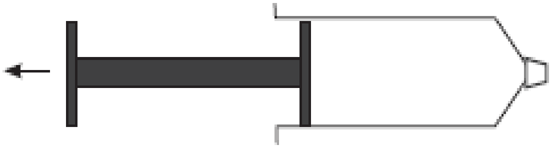
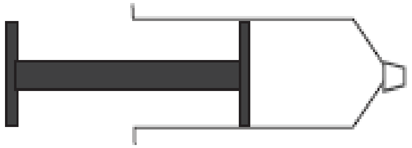
- You can color-code pressure in a way similar to how you color-coded temperature. Just as the air all around you has a “normal” temperature, it also has a “normal” pressure, so you can color it yellow. You can color a “high-above-normal pressure” red and a “low-below-normal pressure” blue.



Color Coding Exercise

Fill a syringe about halfway with air and screw the cap on. Try the actions as indicated in the left column, and observe what happens. In the diagrams below, indicate the pressure inside the syringe with the correct color. Assume that the air around each syringe is always colored yellow.

Explain why, after you push in a piston of a syringe filled with air and then release it, the piston will be pushed back out to its starting point. Use the phrase **"differences drive change"** in your answer.

ACTION	PISTON POSITION	PRESSURE IN THE SYRINGE
Syringe at rest		Normal pressure
Push in piston		High-above-normal pressure
Release piston		Normal pressure
Pull on piston		Low-below-normal pressure
Release piston		Normal pressure

Color Coding Liquid Pressure

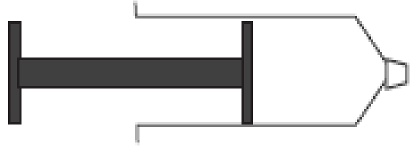
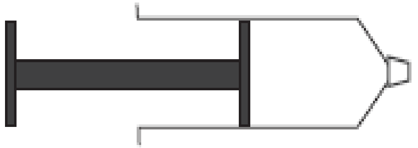
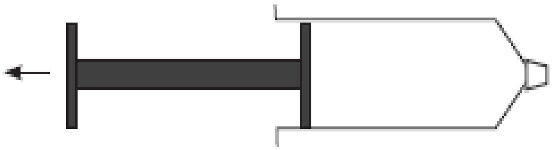
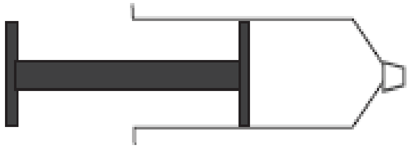
- Fill a syringe about half full with water and try to get all of the air bubbles out. Screw on the cap.
- Push in the piston. What happens? Can you compress water like air? Probably not as much, yet the water is still more squeezed when you're pushing on it than when you're not pushing on it, so the pressure of the liquid does increase. When you stop pushing, the pressure returns to normal, but the piston doesn't move.
- If you pull the piston out, the volume inside the syringe increases, but the volume of the water doesn't change; it just has more room to flow around. The space between the water and the container is filled with very little air, because you tried to get all the air out before. This trapped air has a low-below-normal pressure, which is why the normal air outside pushes the syringe back in.
- How is this different from the air-filled syringes?

Color Coding Exercise

The diagrams show syringes filled with water. Try the actions as indicated in the left column, and observe what happens. In the diagrams below, indicate the pressure inside the syringe with the correct color. Assume that the air around each syringe is always colored yellow.

Fill a syringe about half full with water and try to get all of the air bubbles out. Screw on the cap.

Explain what you see.

ACTION	PISTON POSITION	PRESSURE IN THE SYRINGE
Syringe at rest		Normal pressure
Push in piston		High-above-normal pressure
Release piston		Normal pressure
Pull on piston		Low-below-normal pressure
Release piston		Normal pressure

Comparing Gases and Liquids

Copy the chart in your notebook and circle the correct observation for the liquids and gases.

	Liquids	Gases
Name of system that uses this fluid	Hydraulic Pneumatic	Hydraulic Pneumatic
Mass of trapped fluid	Constant (Stays the same) Variable (May change)	Constant (Stays the same) Variable (May change)
Volume of fluid	Constant (Stays the same) Variable (May change)	Constant (Stays the same) Variable (May change)
Density $Density = \frac{mass}{volume}$	Constant (Stays the same) Variable (May change)	Constant (Stays the same) Variable (May change)
Energy can be stored in fluid	Yes No	Yes No

Comparing Gases and Liquids

Copy the chart in your notebook and circle the correct observation for the liquids and gases.

	Liquid	Gas
Name of system that uses this fluid	hydraulic	pneumatic
Mass of trapped fluid	constant	constant
Volume of fluid	constant	variable (fills container)
Density	constant	variable
Energy can be stored in fluid	no	yes

Benchmark – What do you know?

1. A regular-sized car might have tires that are filled to around 60 pounds per square inch (psi). What characteristic of pneumatic systems makes air a good choice when considering ride comfort in a car? What would it feel like to ride in a car that had liquid-filled tires? Why?
2. Explain what happens when a 4x4 vehicle drives over a big rock in terms of the pressure inside and outside the tire.
3. Is the putt-putt boat a hydraulic system, a pneumatic system, or both? Explain.
4. When transferring energy with a syringe, you pushed on the piston. How is energy transferred in the putt-putt boat to get it moving forward?

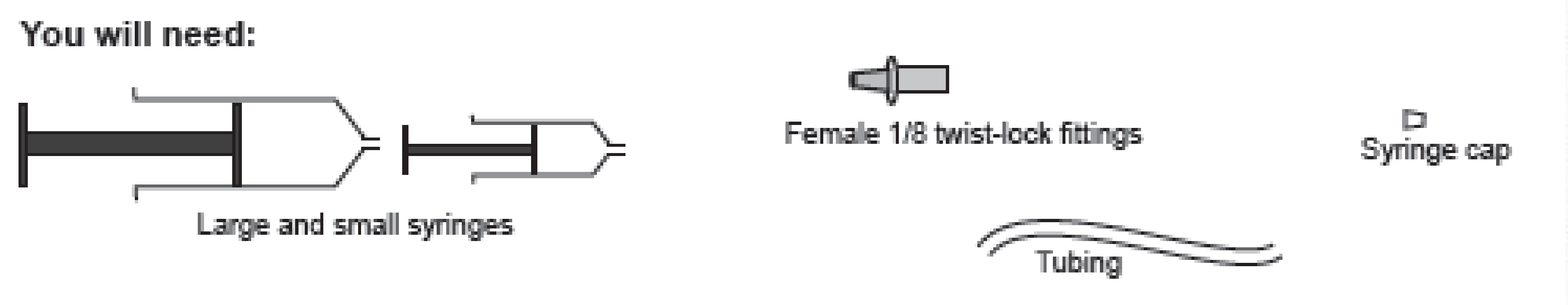
3.4 Develop a Manufacturing Press

How are pneumatic and hydraulic systems used to make things move?

Learn how pressure, volume, force, and area are used for designing fluid systems.

- In this task you will investigate how pneumatic and hydraulic systems transfer energy. Remember that in order for something to happen, such as energy transfer, you must create a difference. In this case you will create a pressure difference using two different fluids: air and water. You will test several combinations of syringes, big to small, filled with water and air, and actually feel these principles in action. Then you will decide which system to use for a machine press for manufacturing boat hulls from thin sheets of metal.

Materials Needed



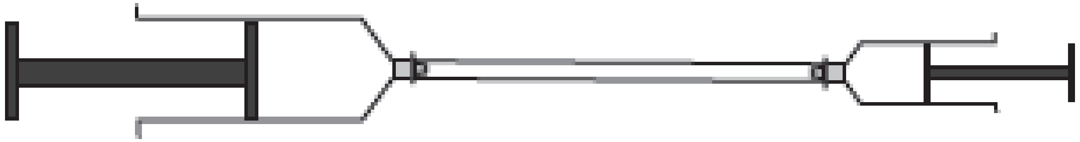
Experimenting with Pneumatic Systems

- Take two syringes and connect them to a section of tubing using twist-lock fittings to create a **pneumatic** system. Different teams should connect different combinations of syringes. Some teams will connect two syringes of the same size, while other teams will connect syringes of different sizes.
- Pull the piston of one of the syringes out nearly all the way, and push the other syringe in nearly all the way. Take turns pushing on each piston so the air moves back and forth through the tube and compare how hard or easy it is to push on each syringe. This is a **closed system** because no fluids enter or leave the syringes and tubing.
- Record your observations, indicating the sizes of the syringes connected together, which one is easier to push, and anything else you notice. Then trade pneumatic systems with another team that has a system with syringes of different sizes. Do this with at least three different sets of syringes, and record your results.

Big-to-big syringes

Small-to-small syringes

Big-to-small syringes



Longer tube with syringes

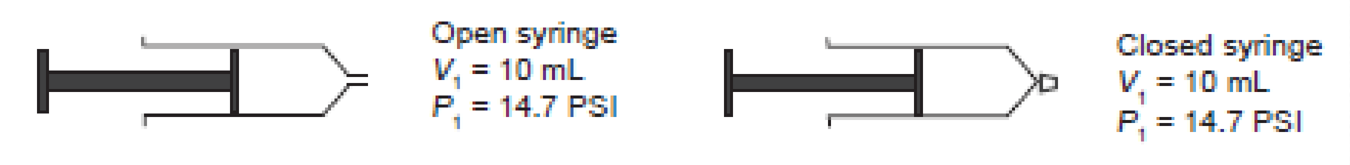
Boyle's Law / Pressure in Gases

- In the 1600's Robert Boyle found that if he kept a gas at constant temperature and compressed it slowly by decreasing the volume of the container, the gas pressure increased. When he increased the volume of the container, its pressure decreased. (That may not be surprising to you, as that is probably what you found in the previous activity involving syringes with traped air.) Expressing this idea with a simple equation can be very useful.
- Expressed as an equation, Boyle's Law states that if you take a trapped gas at a certain pressure ($P1$) and volume ($V1$), and then change the volume ($V2$) by expanding or compressing the container, you can find the new pressure ($P2$). Keep in mind that Boyle's Law is only true if the temperature is kept the same, and it is a closed system, so no gas escapes.

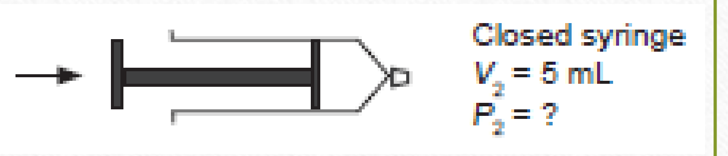
$$\boxed{P_1 V_1 = P_2 V_2}$$

Boyle's Law / Pressure in Gases

- The pressure of air at sea level is 14.7 pounds per square inch (psi). This pressure is due to the weight of the air, and is the weight of the air above one square inch of surface. That is "normal" air pressure. Take an open syringe and move the piston to any measured volume of air—say, 10 mL. The air inside the syringe is the same as the pressure of the air outside—14.7 psi.



- Now put a cap on the syringe and push the piston in so that the volume is just half what it was before. (If it was 10 mL before, it should be just 5 mL now.)



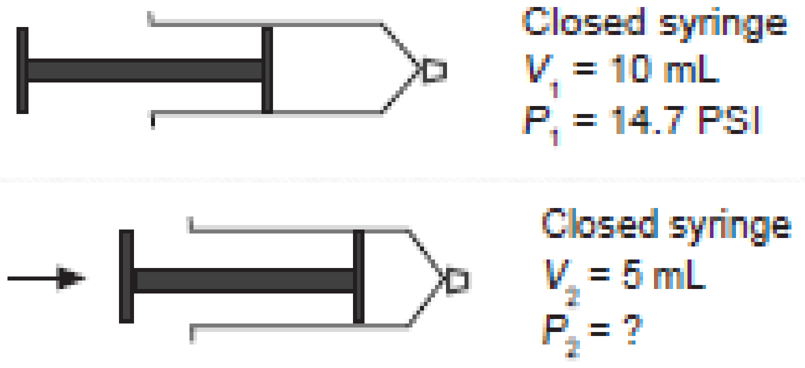
- Use the equation above to calculate the new air pressure in the syringe.

Boyle's Law / Pressure in Gases

Step 1: $P_1V_1 = P_2V_2 \quad or \quad P_2V_2 = P_1V_1$

Step 2: $\dfrac{P_2V_2}{V_2} = \dfrac{P_1V_1}{V_2}$

Step 3: $P_2 = \dfrac{P_1V_1}{V_2} = \dfrac{14.7\ psi\ x\ 10\ ml}{5\ ml} = 29.4\ psi$



Boyle's Law / Pressure in Gases

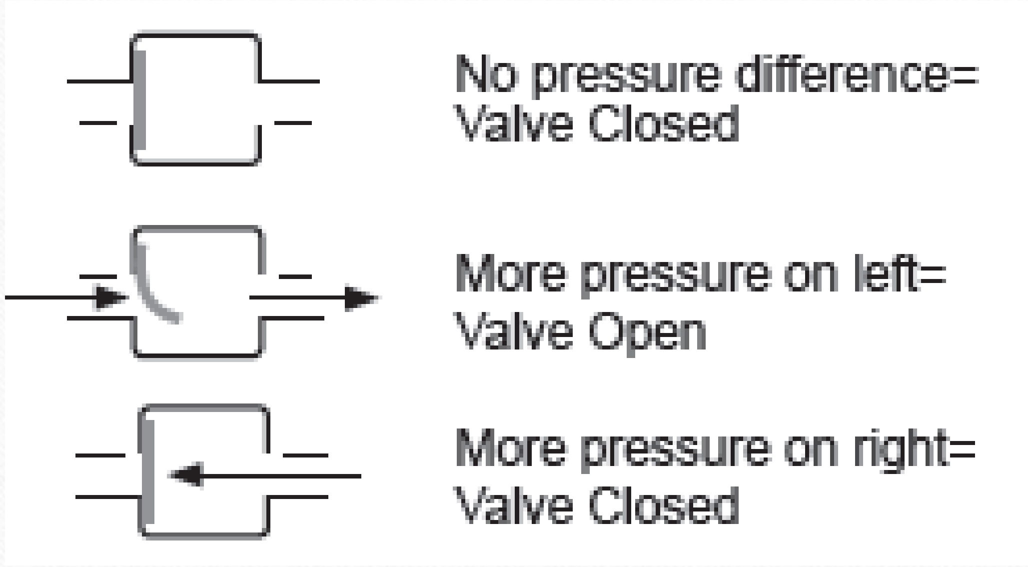
- Would Boyle's Law hold for hydraulic systems? Why or why not?

Build a Pneumatic Pump

- A great many machines work by connecting tubes in various ways to manipulate the pressure of fluids—including both liquids and gases. One of the simplest is the syringe itself used by doctors to inject medicines or extract blood samples.

Build a Pneumatic Pump

- A key component of a pneumatic pump is a one-way valve, which may be as simple as a flap of plastic covering a hole. As air flows from left to right, because of the pressure difference, the flap is pushed open and air can flow through the tube. If the pressure is reversed, the flap is pushed closed.

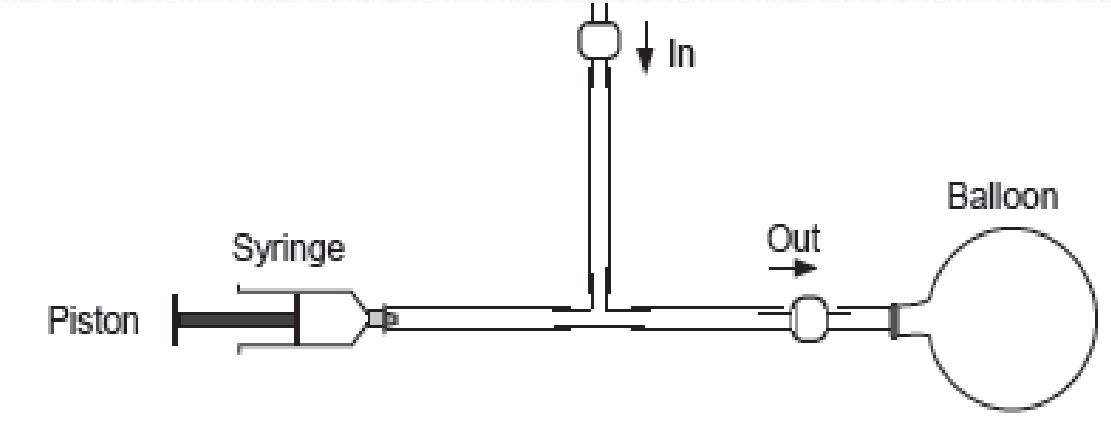


Build a Pneumatic Pump

- Build a pneumatic pump to inflate a balloon by connecting the following parts as shown:
  - 1 syringe
  - 1 balloon
  - 1 plastic "T"
  - 2 one-way valves
  - 3 short lengths of tubing
  - 1 twist-lock fitting for tubing

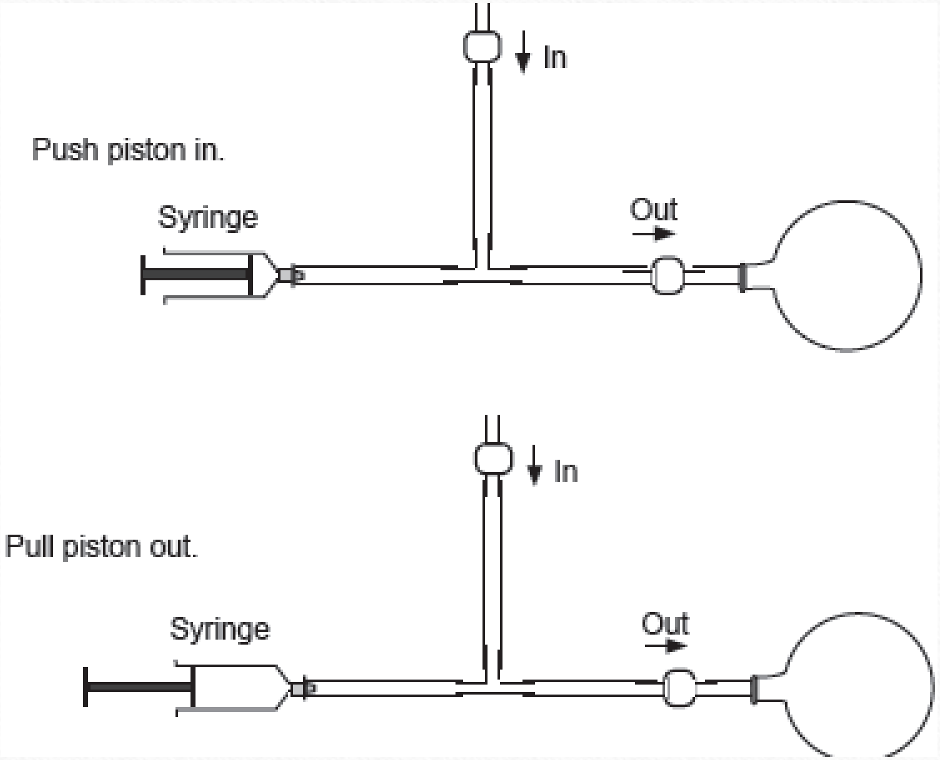
Build a Pneumatic Pump

- How many times do you need to operate the piston in the syringe to inflate the balloon to about four inches in diameter?
- Compare your results with another group who built their pneumatic pump with a different size syringe. What did you find out and what can you conclude about how the size of the piston affects the operation of the pump?
- In your own words, explain how the pump works.



Build a Pneumatic Pump

- Show how the pressure changes in the pneumatic pump by coloring the syringe, tubing, and balloon to show the air pressure while you are pushing the piston into the syringe (top), and when you are pulling it back out (bottom). If necessary, refer back to the color key in Task 3.3 to recall which colors to use for above and below normal pressure. Assume the surrounding air is colored yellow.



Build a Pneumatic Pump

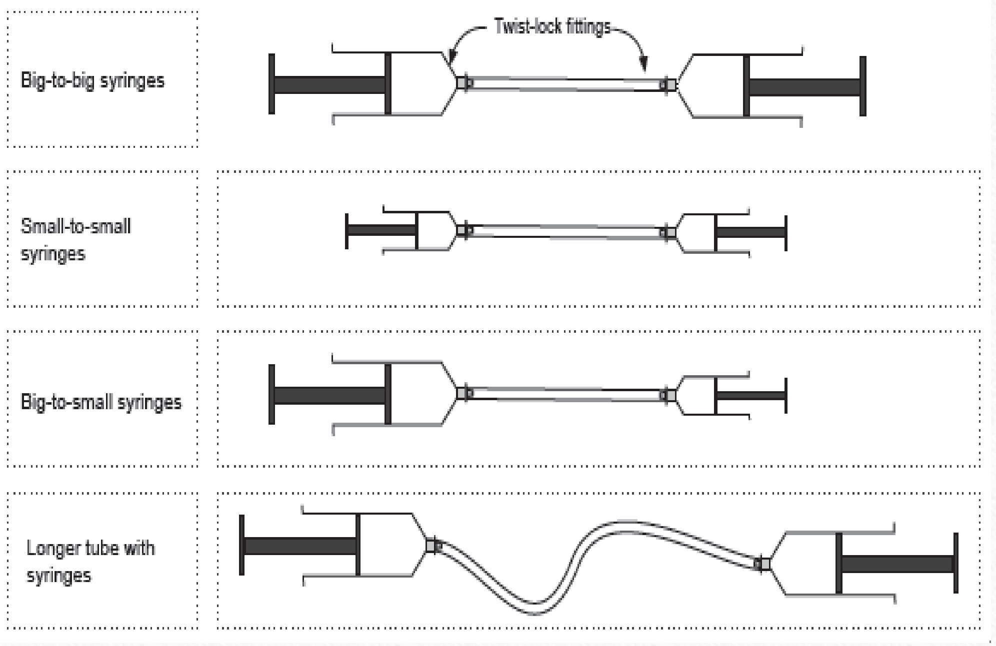
- A pneumatic pump is a kind of air compressor. That is, it creates a volume of air (inside the balloon) that is at a higher pressure than normal air. As you work the pump, you are adding energy to the system. Your body turns chemical energy from the food you have eaten into **mechanical energy**— energy of motion. The balloon stores that energy in the form of pressurized air. What can you do to release the stored energy and turn it back into mechanical energy?
- The pneumatic pump demonstrates an important concept about pressure and energy in fluids: **A difference in pressure drives the flow of energy. When the pressure is equalized, energy stops flowing.** List some examples you can think of in the everyday world where a difference in pressure drives the flow of energy.

Experimenting with Hydraulic Systems

Experimenting with Hydraulic Systems

- Connect two syringes with a tube as before. Different teams should connect different combinations of syringes. This time you will fill your syringes with water, so they will be hydraulic systems. Take care to fill the system completely with water, eliminating bubbles. You may need to submerge the system in a pan of water to get all of the bubbles out. As before, you will want each syringe to be about half full with water so you can push the water back and forth between the two syringes.
- Take turns pushing on each piston so the water moves back and forth through the tube and compare how hard or easy it is to push on each syringe. Record your observations below. Then trade with another team that has a system with syringes of sizes that are different from yours. Do this with at least three different sets of syringes, and record your results.

Experimenting with Hydraulic Systems



- If you can, state a general rule that will allow someone to predict how a hydraulic system would behave based on the relative sizes of the two syringes.
- It takes a difference in pressure for energy to flow from one place to another. You can change the pressure in both pneumatic and hydraulic systems by pushing in a piston, which reduces the volume. Pneumatic systems are better than hydraulic systems for storing energy. Which system is better at immediately transferring energy from one place to another? How do you know?

Pascal's Law / Pressure in Liquids

- Blaise Pascal invented the syringe. He also helped to develop some of the first equipment to help divers breathe under water and, as a result, he became very interested in how fluids behave. One of Pascal's most useful discoveries is now known as **Pascal's Law:**
  - **When a force is applied to a liquid in a container, the pressure will increase equally throughout the liquid.**
- This is different from applying a force to a solid, which acts in just one direction, or to a gas, which can be compressed.

$$\boxed{P = \frac{F}{A}}$$

Pascal's Law / Pressure in Liquids

- You may have noticed in the previous activity that if a small and large syringe are connected in a hydraulic system, the force needed to push the small syringe is less than the force needed to push the large syringe. If the pressure is the same throughout the system, consider why the force is different.
- Remember that pressure and force are not the same thing. **Pressure** (*P*) is the force (*F*) applied to a given area (*A*) as shown. In the case of two syringes, the area is the part of the piston in contact with the liquid. If these areas are different, the force that must be applied to push the liquid back and forth is different, even though the pressure is the same.

$$\boxed{P = \frac{F}{A}}$$

Pascal's Law / Pressure in Liquids

- Select one of the hydraulic systems from your experiments recorded on the previous page, in which the syringes were different sizes. Your task in this problem is to figure out how much harder it is to push the piston in the large syringe than in the small syringe.
- Because the two syringes are part of the same hydraulic system, the pressure exerted on both pistons is the same. So if you use a subscript to indicate the large piston and the small piston, the equation above implies that:

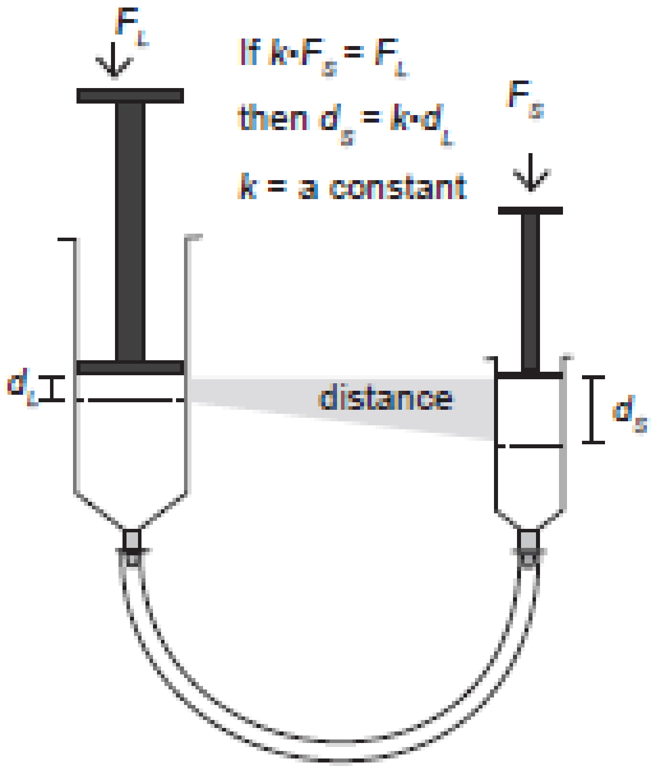
$$\frac{F_{Large}}{A_{Large}} = P = \frac{F_{Small}}{A_{Small}} \qquad \text{It's also true that:} \qquad \frac{F_{Large}}{F_{Small}} = \frac{A_{Large}}{A_{Small}}$$

- In other words, the ratio of forces on two pistons is the same as the ratio of the areas of the two pistons. Suppose, for example, that you had to exert a force of 5 pounds on the small piston. Determine the area of the ends of the pistons and find out how much more force you need to exert on a connected large piston to get the water to move back.

Distance-Force Trade Off

Distance-Force Trade Off

- A hydraulic system can multiply force when you have pistons of different sizes, but the additional force is not free. You have to pay for less force used by pushing the smaller piston farther. The additional distance is proportional to the force multiplier. If the increase in force from the small piston to the large is ten times greater, then the small piston must be pushed ten times farther than the large piston.
- The system also works in reverse. Pushing the small piston ten inches will move the large piston one inch, and the force to move the small piston ten inches is 1/10 the force needed to move the large piston 1 inch. In other words, a hydraulic system allows you to trade off force for distance, or distance for force.

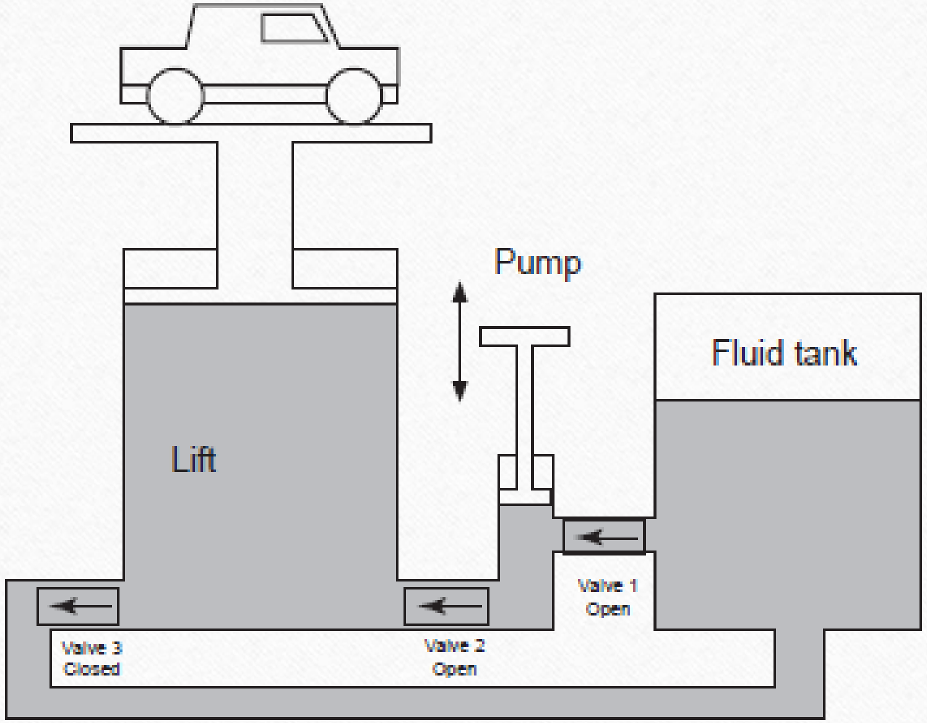


Hydraulic Lift

- The hydraulic press, based on Pascal's Law, was invented by British engineer Joseph Bramah in 1795. The same principle applies to the hydraulic lift, which can be found in just about every garage where cars are repaired. If you pay attention to just the pump (small piston) and the lift (large piston), you'll see that it is like the hydraulic system you have already experimented with.
- In addition to the simple hydraulic system, you'll see that the hydraulic lift includes three one-way valves and a tank for extra fluid. The one-way valves only allow fluid to pass in the direction of the arrows. The fluid used for these systems is almost always oil, but it works the same way as the water hydraulic system. From your experience, you should be able to figure out how it works. Remember, fluid can only move in the direction of the arrows in the system.

Hydraulic Lift

- Step 1: Valves one and two are open and valve three is closed. What happens to the fluid and lift when you push down on the pump?
- Step 2: What happens when you pull up on the pump?
- Step 3: What happens when you close valves one and two and open valve three?



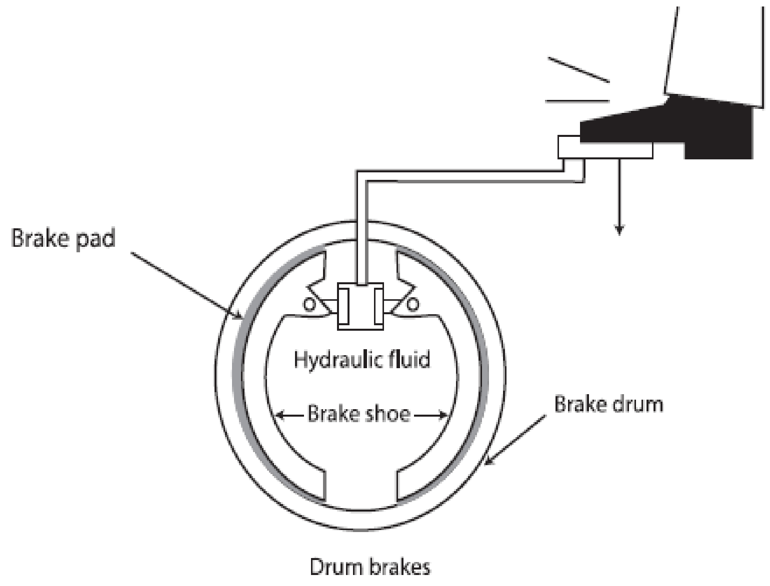
Benchmark – What do you know?

- Which type of system do you think robotic arms use—pneumatic or hydraulic? Why?
- Following are some pneumatic and hydraulic systems. For each one circle "closed" or "open" to indicate if it is a closed or open system:

Pneumatic Systems		Hydraulic Systems	
Bicycle pump	(closed or open)	City water system	(closed or open)
Hot air balloon	(closed or open)	Human circulatory system	(closed or open)
Auto tire	(closed or open)	Auto brake system	(closed or open)

Benchmark – What do you know?

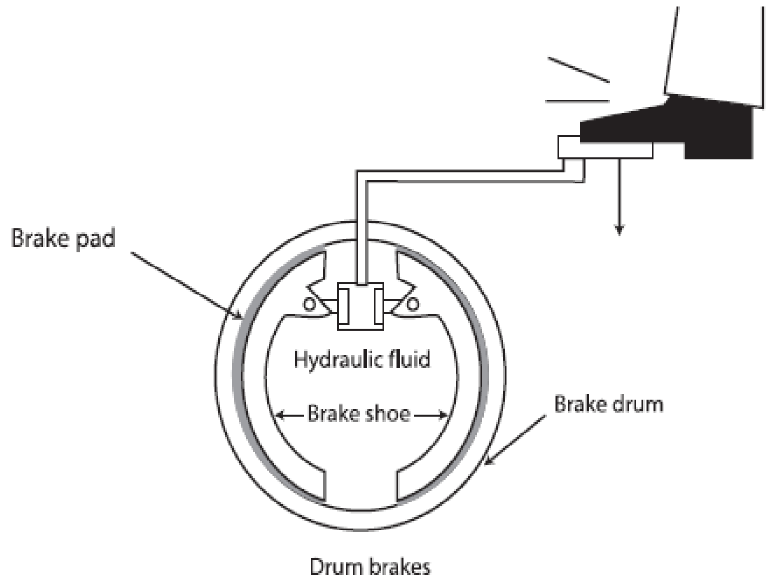
- The brakes in a car consist of brake drums that are attached to all four wheels. Inside the drums are brake shoes that are attached to the axle. In order for the car to stop, the brake shoes in all four wheels must push outward against the brake drums. Look at the simplified diagram for the hydraulic system of drum brakes below and explain how stepping on the brake pedal causes the brake shoes to push outward.



Benchmark – What do you know?

- When new brake fluid is put into the brake system, it’s usually necessary to “bleed” the system, which means to remove all of the air bubbles. What do you think would happen if that were not done?

- Describe the pros and cons of pneumatic and hydraulic systems.



Pneumatics Versus Hydaulics

Pneumatic Pros

- Air is free and abundant.
- Air is easily compressed and can be stored in tanks.
- Pneumatic systems can be built easily with moderate pressure hoses, pipes, or tubing.
- Pneumatic systems can produce large linear movement.
- Air can be returned to the atmosphere; a return line is not needed.
- Compressed air is relatively environmentally friendly.

Pneumatic Cons

- Compressed air systems must be kept clean and dry.
- Using air at high pressure requires safety precautions.
- Pneumatic systems sometimes atomize small amounts of lubricating oil into the air.
- Pneumatics cannot produce as high a force as hydraulics.

Pneumatics Versus Hydraulics

Hydraulic Pros

- Hydraulics are usually simpler in design.
- Most hydraulics are closed systems, so there is no fluid exhaust.
- Flexible pipes and hoses virtually eliminate location problems.
- Hydraulic systems are smooth and quiet in operation.
- Vibration is minimized.
- Control of a wide range of speed and forces is possible.
- High efficiency occurs with minimum friction loss.
- Automatic valves guard against a breakdown from overloading.

Hydraulic Cons

- It’s hard to maintain precision parts against rust, corrosion, dirt, and oil.
- Hydraulic liquids and high-pressure hoses are expensive.
- Hydraulic fluids (usually oils) can be hazardous to one’s health in the event of leakage.

3.5 Investigate Heat Engines

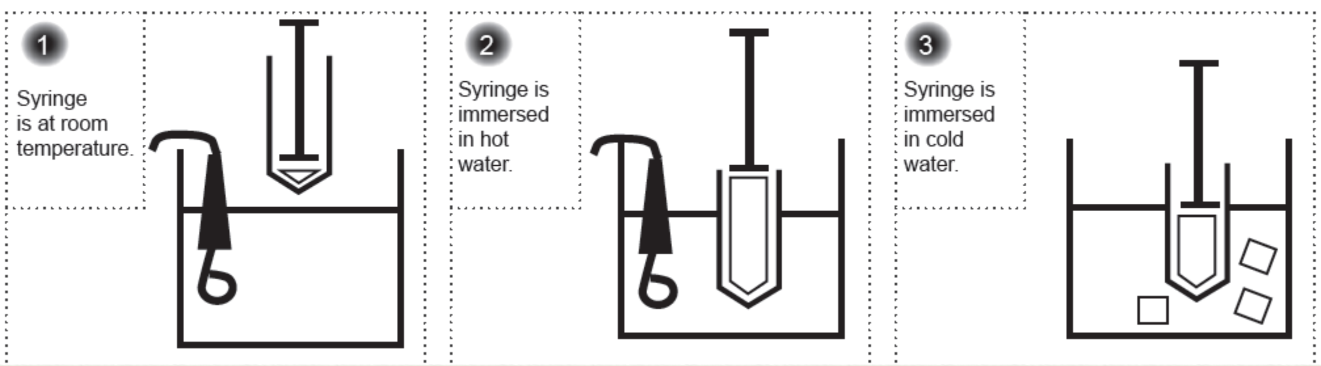
- Explain the relationship between temperature, pressure, and volume in an engine.
- Compare different types of engines.
- What is a heat engine?
- What is an engine cycle?
- What are the pressure changes that take place in the putt-putt boat?

Investigate Heat Engines

- It’s not an exaggeration to say that heat engines are one of the most important technologies of the modern world. Increase the temperature of a gas in a confined space and the pressure goes up dramatically. In engine design this relationship between temperature, pressure, and volume is key. By examining how various engines work, you’ll have a better understanding of the putt-putt boat engine as well as the fundamental principles that underlie all engines.

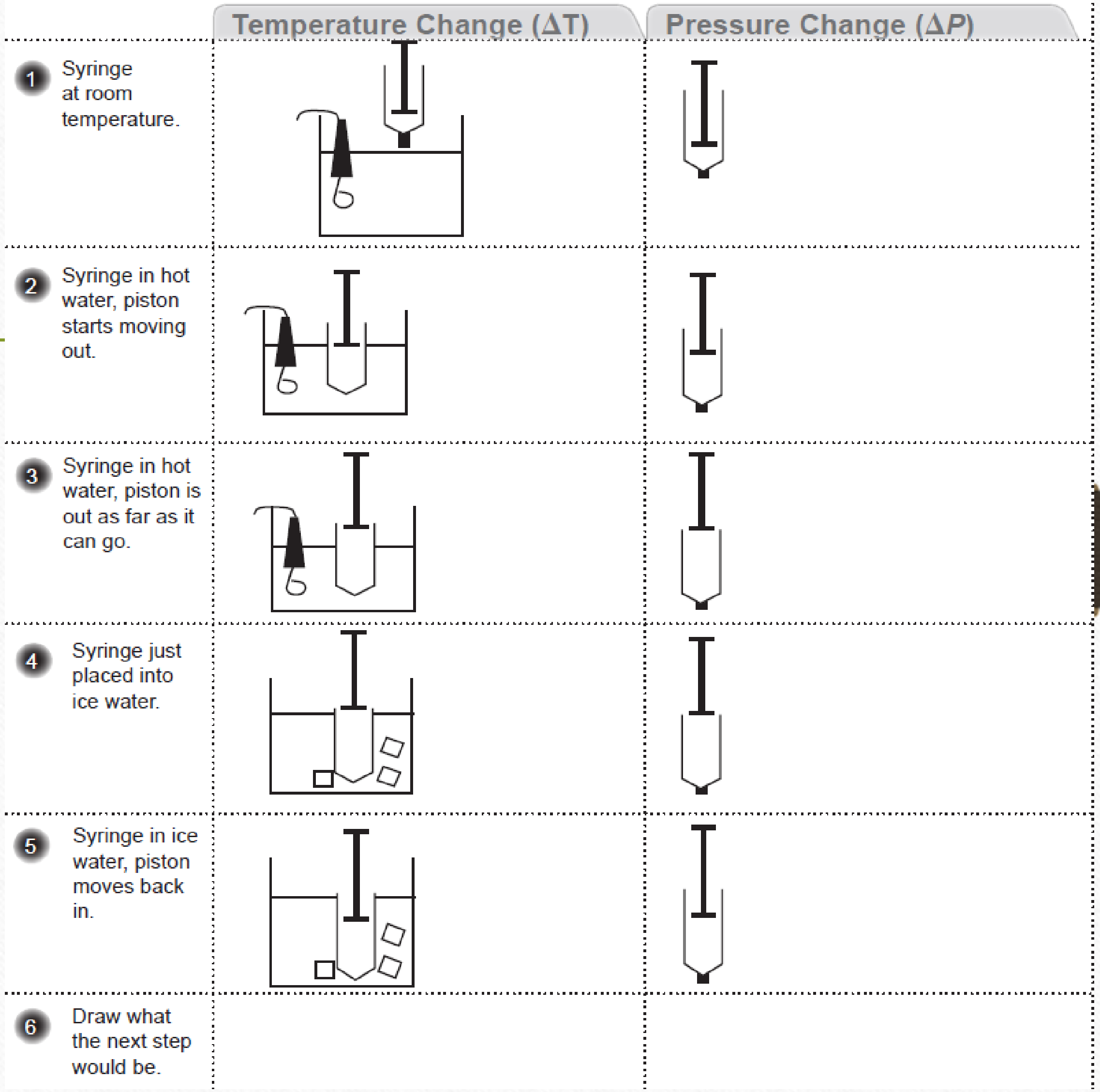
Observing an Acetone Engine

- Watch the demonstration of an acetone engine. A beaker is filled with water, and a syringe filled with acetone is submerged in water. The water is heated by a heating coil. After some time the syringe is removed from the hot water and put into ice water. (A clothes pin can be used to remove the syringe.) Watch how the piston is affected by the changes in temperature.
- What do you observe? How can you explain what happened? Write your ideas below each picture and share them with a partner. Use arrows to show the syringe movement and color-coding to help you explain.



Observing an Acetone Engine

- Color Code the Pressure and Temperature changes in the Acetone Engine.



Observing an Acetone Engine

- The acetone engine demonstrates key ideas about how heat engines work. What are your ideas about the acetone engine? Compare your ideas with another student to see if you agree.
- A **heat engine** is a device that converts thermal energy into mechanical energy. What is the mechanical energy in an acetone engine?
- “It takes a difference to make a difference”; or “difference drives change”. What that means in terms of the acetone engine.

Observing an Acetone Engine

When steam engines were starting to be used in factories, scientists and engineers wanted to better understand the relationship between temperature (T), pressure (P), and volume (V) so they could build better steam engines.

Boyle's Law

In the 1600s, Robert Boyle discovered the relationship between the volume and pressure of a gas kept at constant temperature.

$$P_1 V_1 = P_2 V_2$$

Charles' Law

In the 1700s, Jacques Alexandre César Charles discovered the relationship between the temperature and volume of a gas at constant pressure.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Guy-Lussac's Law

In the 1800s, Joseph Louis Gay-Lussac discovered the relationship between the temperature and pressure of a gas kept at constant volume.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

If you combine these relationships, you have the combined gas law for a closed system.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Observing an Acetone Engine

- Using the combined gas laws – explain what is happening in the drinking bird.

If you combine these relationships, you have the combined gas law for a closed system.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Drinking Bird Engine

Drinking Bird Engine

- The fluid inside the bird is methylene chloride. Both methylene chloride and acetone evaporate very quickly and can expand to many times their liquid volume.

- Recall the combined gas law equation for a closed fluid system on the previous page. If you take 1 to be the state when the drinking bird is upright, and 2 to be the state when the bird has tipped over to "drink," explain which terms (*P*,*V*, and *T*) have increased and which have decreased when the bird moves from state 1 to state 2.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Efficiency of a Heat Engine

- In 1824, when Nicholas Leonard Sadi Carnot was just 28 years old, he published a book about his life in which he discussed heat engines. At that time, steam engines were driving the industrial revolution. Carnot discussed the science behind these technological devices and how more of the energy that was being put into the engines could be used to do something useful besides just warming up the environment.

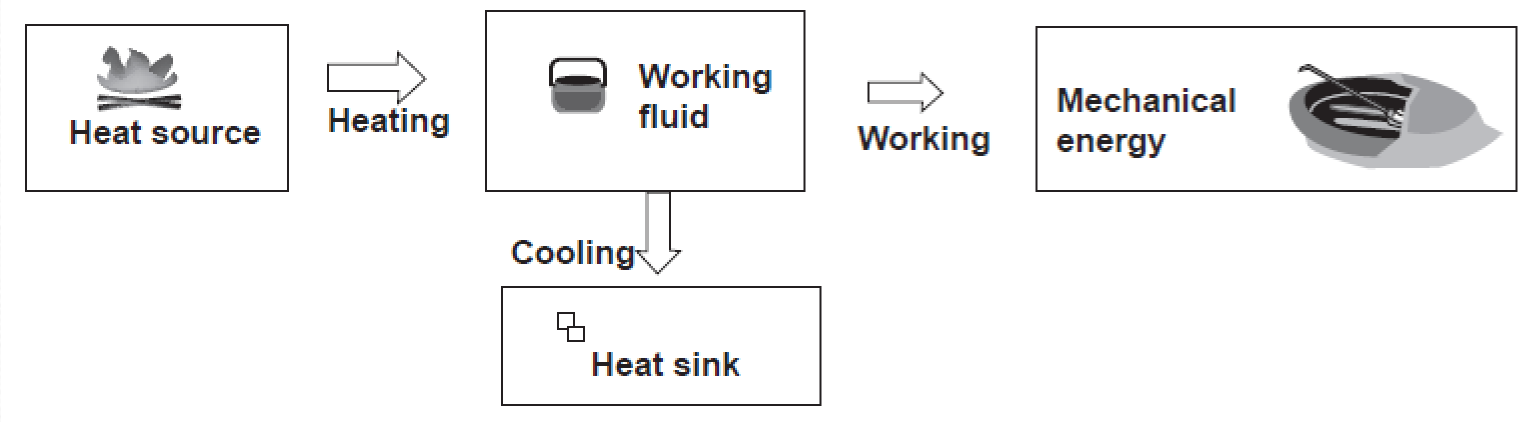
Efficiency of a Heat Engine

- Carnot realized that engines not only need a heat source (a way to get hot), but also a heat sink (a way to get cool again). It's the difference in temperature between source and sink that determines the maximum efficiency of any engine. The drinking bird engine is an excellent example because it's not how hot you make the engine that makes it work efficiently, but how cool you can make it by dunking the absorbent bill into the water, so that it can be cooled by the air. So heat alone does not drive a heat engine—it's the difference between the hot side and the cool side of the engine that matters. The efficiency of an engine is defined as the following:

$$\textit{Efficiency} = \frac{\text{Amount of energy doing what you want}}{\text{Total energy put in}} = \frac{\text{useful output}}{\text{input}}$$

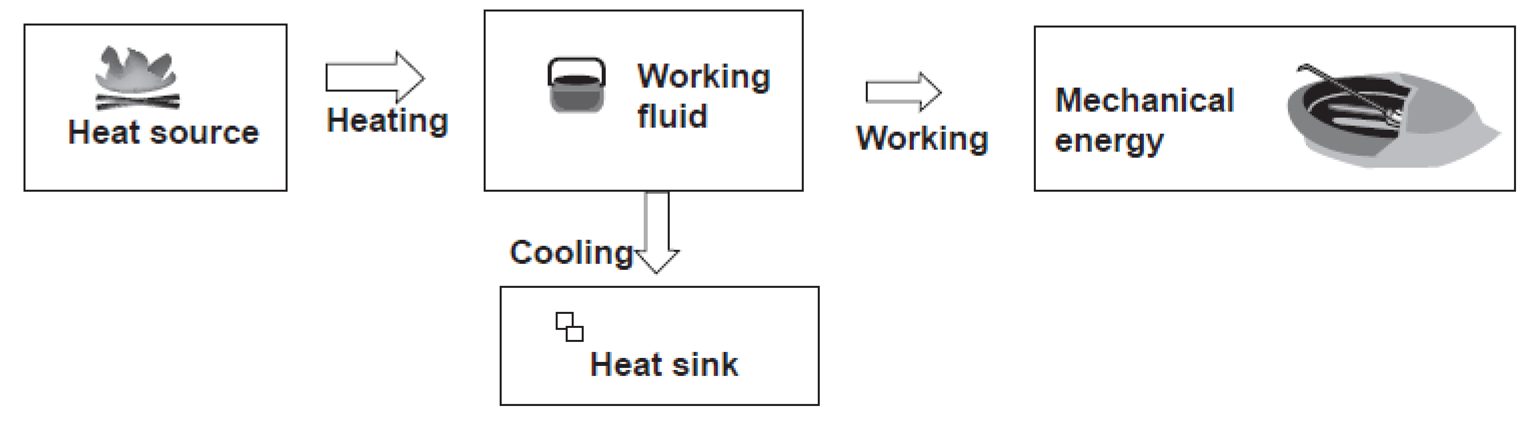
Efficiency of a Heat Engine

- It is impossible for the efficiency of an engine to be 100%, because no matter how hot you get the engine, you still need to cool it back down. This idea is illustrated by the following diagram showing what happens to the energy in a heat engine. Notice that some of the energy must be lost in cooling the working fluid so that it can be heated again, then the process starts over again.



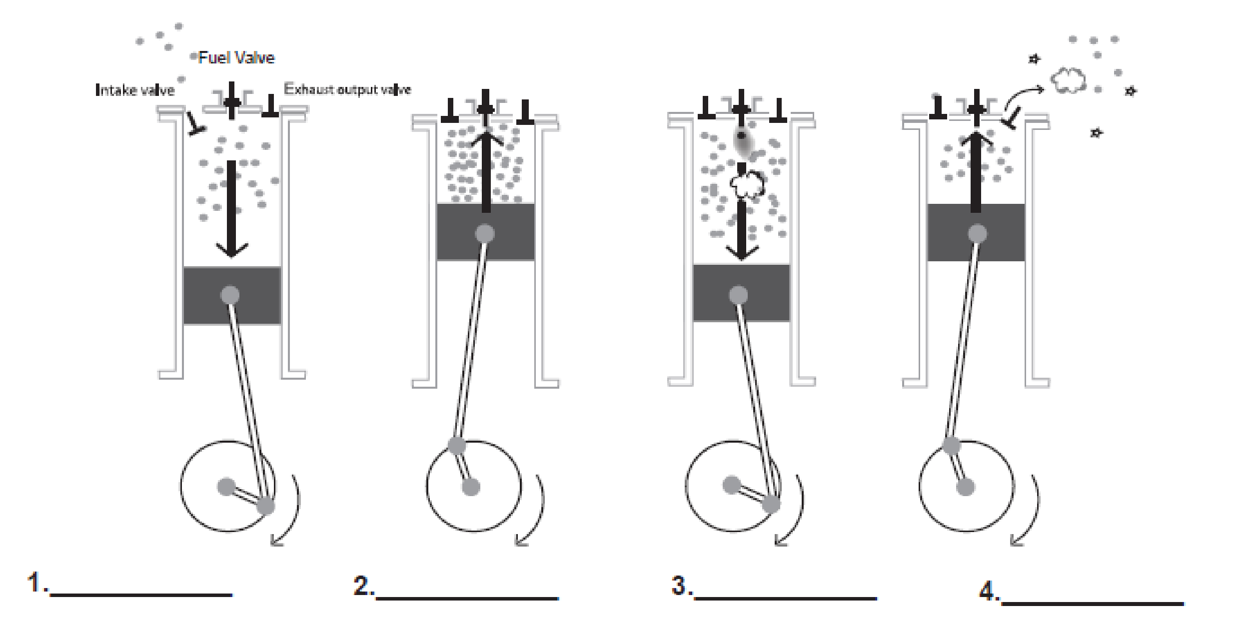
Efficiency of a Heat Engine

- What is the **heat source** for the drinking bird? For the putt-putt boat?
- What is the **heat sink** for the drinking bird? For the putt-putt boat?



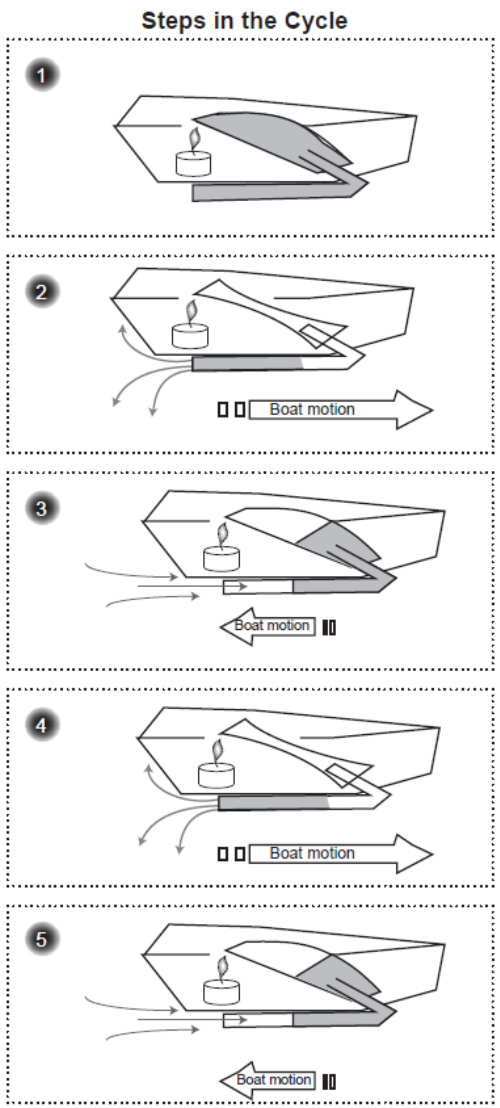
Otto Heat Engine Cycle

- Most automobile engines are based on the four-stroke Otto cycle.
- In an automobile engine, as the piston rises it increases the pressure in the cylinder, and the temperature of the gas-air mixture increases slightly. Then a spark plug sends an electrical charge into the cylinder and ignites the fuel, which violently increases the pressure and thrusts the piston downward.



Piot Engine Cycle

- Now you are ready to think about the putt-putt boat's engine cycle. It is a bit tricky because the pressure, temperature, and volume are all changing at the same time. Look at the diagrams below and write a few sentences for each set of pictures that describes how you think the putt-putt boat engine works. You may use color-coding to help you.
- Be sure to consider how differences in **pressure** and **temperature** are causing changes such as the flow of fluids and the motion of the boat.



Benchmark

Acetone Engine

1) Why is acetone, not hot water, used in the syringe?

2) If you keep the syringe in the hot water, is it possible that the piston will be pushed completely out of the syringe as the acetone continues to boil? Why or why not?

3) What if you took the piston out of the hot water but did not put it in the ice bath? Would it still cool down? What would happen to the position of the piston? Why?

Benchmark

Drinking Bird Engine

4) Explain why the liquid moves up the tube in terms of the combined gas law.

5) Where do conduction, convection, and radiation come into play in the drinking bird engine?

6) What are the main thermal transfers that are occurring in the drinking bird heat engine?

Otto Engine

7) The Otto engine is an **internal combustion engine** because fuel is burnt inside the engine. In the Stirling engine heat is provided by a source outside of the engine, so it's called an _____________________ combustion engine.

Benchmark

Piot Engine

8) At what point in the Piot engine cycle does cooling occur?

9) What would happen if the Piot engine didn't include a cooling cycle?

10) What are the sources of inefficiency for the Piot engine cycle?

All Engines

11) What do all of these engines have in common?

12) What are some ways that engine efficiency can be improved?

3.6 The Rocket Effect

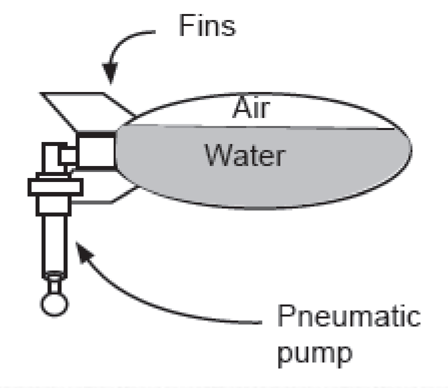
- Which travels faster, a water rocket or an air rocket? How would Newton explain this difference?
- How do rockets work in space? How does this relate to the putt-putt boat?

The Rocket Effect

- You have probably noticed bubbles escaping out of the tubes from the putt-putt boat's engines Do these bubbles push the boat forward? Or is it the water that is pushed out by the bubbles? Even more important, why does a fluid expelled from the back of the boat make it go forward at all? In this activity you'll find the answers to these questions as you investigate the propulsion system of a rocket and compare it to the putt-putt boat.

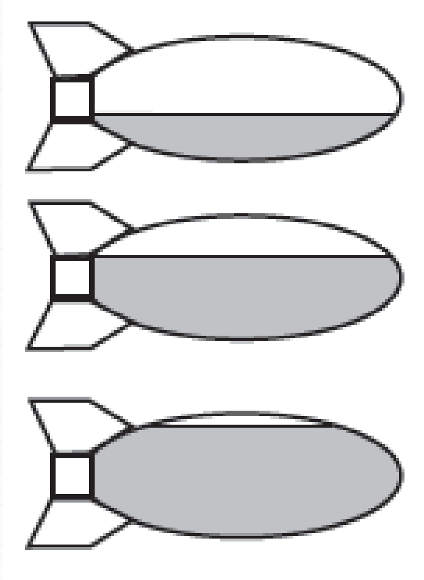
The Rocket Engine

- Just about everyone has observed the rocket effect by blowing up a balloon and then letting go. The balloon flies all over the room as the air escapes from the hole in the balloon, which pushes the balloon forward.
- As in the engines you've looked at previously, it's the difference in pressure that drives the transfer of energy. When you blow up a balloon you are storing energy in the pressurized air. When you let it go, the air flows from the region of high pressure (inside the balloon) to low pressure (outside the balloon), until the pressure is equalized.
  - How do you think a rocket engine is different from the heat engines you observed in the previous task?
  - A water rocket is like a balloon, except it has fins to keep it flying straight. It is pressurized by a pneumatic pump. When released it is propelled by escaping air (like the balloon) or water. Observe the rocket as it is propelled with air, and then with water. What does this tell you about the rocket effect?



The Rocket Engine

- What is the optimal percentage of the rocket that should be filled with water?
- Remember that because air is a gas, it is compressible, so it can store energy. However, water is a liquid, so it is not compressible. You can increase the pressure of water and use it to transfer energy, but it cannot store energy. Explain how a water rocket takes advantage of the properties of both liquids and gases.

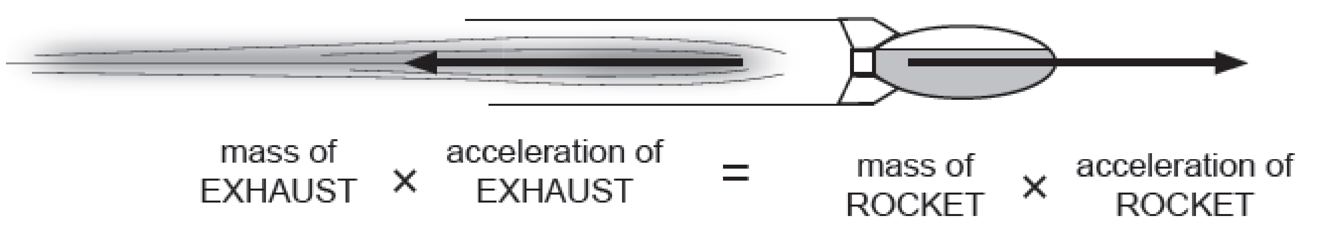


Newton's Laws of Motion

- The rocket effect is best described by Sir Isaac Newton, whose three laws of motion, which he published in 1687, have been among the most important scientific findings of all time.
- **First Law: An object in motion remains in motion unless acted on by an outside force.** This means that a rocket in space, with its engine turned off, will keep going with the same speed and direction because there is no air in space to slow it down. But if its engine is fired, it will speed up or change direction.
    - ***Acceleration*** is the scientific term for speeding up or changing direction.
- **Second Law: Force equals mass times acceleration:** $\boldsymbol{F = ma}$. This means that the force provided by the rocket exhaust equals the mass of the exhaust material (water and/or air) times its acceleration. Water has a lot more mass than air, so it gives the water rocket a much bigger push.

Newton's Laws of Motion

- **First Law: An object in motion remains in motion unless acted on by an outside force.**
- **Second Law: Force equals mass times acceleration: *F = ma.***
- **Third Law: Every action has an equal and opposite reaction.** The water and air pushed out of the back of the rocket gives the rocket a push in the opposite direction.



The Rocket Effect and the Piot Engine

1. Both the rocket engine and the Piot engine are primed with water. What happens to the water

   A. in the rocket engine? B. in the Piot engine?

2. Some people think the bubbles drive the putt-putt boat forward and others think that it's water pushed by the bubbles that drive the putt-putt boat forward. Who do you think is right, and why?
3. Is the water rocket a pneumatic system, a hydraulic system, or both? Explain your answer.
4. Is the Piot engine a pneumatic system, a hydraulic system, or both? Explain your answer.
5. Is the water rocket an open system or a closed system? Explain your answer.
6. Is the Piot engine an open system or a closed system? Explain your answer.
7. How is the Piot engine similar to a rocket engine?

Trade Off of Mass vs. Acceleration

- **Remember Newton's second law: *F = ma.*** If you can increase the mass (amount) of water that flows out of the back of the putt-putt boat, you can increase the force driving it forward. And if you can get the water to flow faster, that will increase the force on the putt-putt boat too. Unfortunately, it's not easy to do both.
- Why is there a trade off between mass and acceleration when designing an engine that uses the rocket effect?