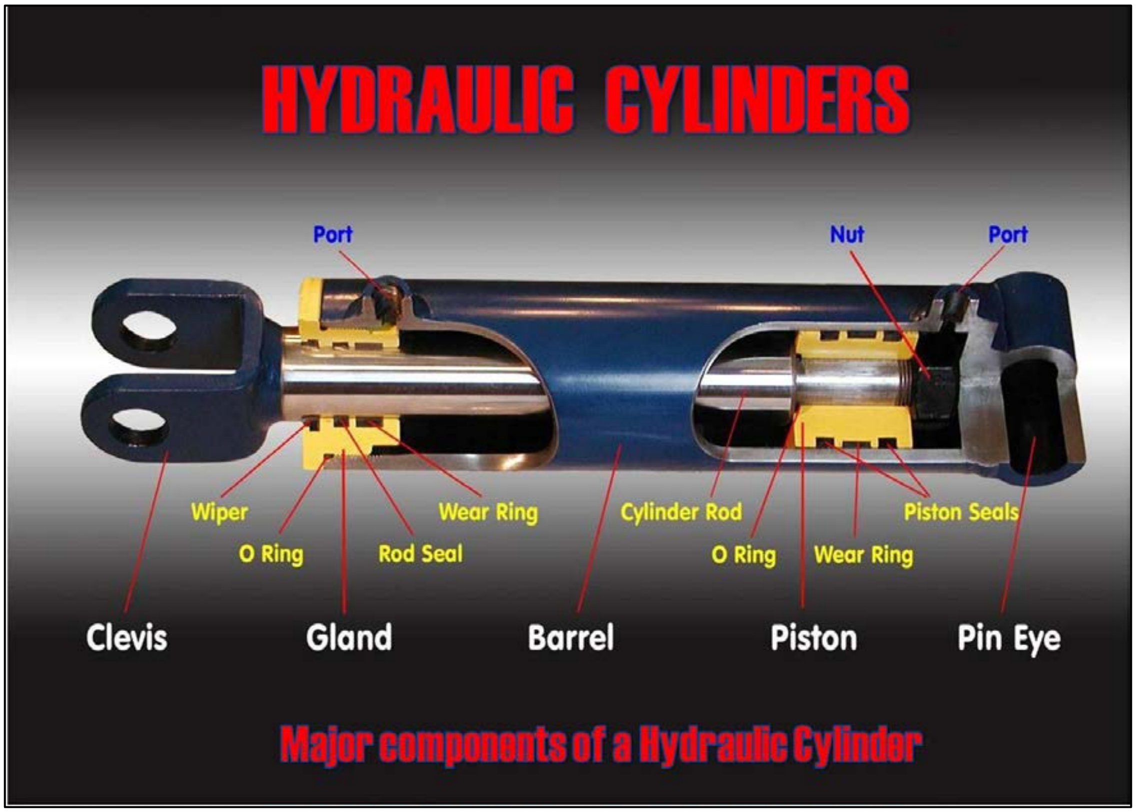
STEM REFLECTIVE GUIDE

Course Title: CADD

Unit: STEM concepts learned from designing a Hydraulic Cylinder

Activity: STEM associated with Cylinders



http://www.hycocanada.com/cylinderintro.php

The video resources for advanced hydraulic cylinders exposed you to the step by step process to model a hydraulic cylinder. A hydraulic cylinder is a very important mechanism for heavy duty machinery and industrial equipment. As you analyze cylinders that use hydraulic fluid or air you will find there are a lot of STEM concepts associated in their design and operation. In this STEM reflective guide we will address some of them.

WHAT IS A HYDRAULIC CYLINDER?

Introduction to Hydraulic Cylinder Basics

Hydraulic cylinders convert energy produced from a hydraulic pump into a linear mechanical output so they can perform useful work.

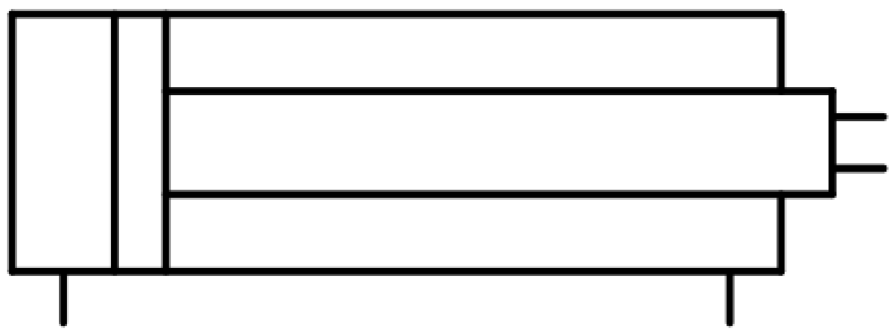
Hydraulic cylinders are also referred to as hydraulic rams, hydraulic jacks, linear hydraulic actuators, and hydraulic actuators. Although these terms are all synonymous, the terms "hydraulic ram" and "hydraulic jack" are usually applied to short stroke, single acting cylinders with large diameter piston rods. Hydraulic cylinders are the muscles of machinery.

Hydraulic cylinders are so named because they consist of a piston that moves through a smooth round cylinder or tube. This cylindrical tube must be sealed at both ends with end plates. The end plates are also called end caps or cylinder heads. The piston is firmly connected to a shaft called a piston rod that exits the cylinder through a hole in one end cap. This is called the rod end. The opposite end of the cylinder is called the cap end or the blind end (because it does not have an eye for the rod to stick out).

The cylinder end caps also contain ports where hydraulic fluid is admitted into the cylinder. The piston rod is the working end of the cylinder and is usually fastened to a load that must be moved. The opposite end of the cylinder body is called the cap end or blind end. Although it is usually attached to a surface which the actuator pushes against, a large variety of mountings are available that can be mounted at various positions over the body of the actuator.

The cylinder barrel or tube is usually made from high strength seamless steel tubing that has been honed or skive roller burnished to a fine finish on the inside diameter. This will provide a smooth surface for the hydraulic piston to slide through. The tube must be of sufficient thickness to contain the hydraulic pressure that will be used. In a welded body hydraulic cylinder, the barrel must also provide mechanical strength and rigidity to support the loads the body of the actuator will experience. This is especially true when a mid trunnion mount is attached to the center of the cylinder barrel.

Hydraulic cylinders are specified by bore size, stroke, mounting style, rod diameter, and pressure rating. Other details include seal material, temperature rating, materials of construction, and cushioning.
Hydraulic rod cylinders are often shown in machine diagrams by the following standardized ISO symbol:



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Difference between Hydraulic and Pneumatic Cylinders

It is necessary to mention at this point that hydraulic cylinders are just one type of cylinder. There are also pneumatic cylinders. Pneumatics refers to the branch of physics concerned with mechanical properties of gases. Therefore the main difference between the two types of cylinders is one is operated by hydraulic oil (petroleum based fluid) and the other is operated by air. There are also other types of functional differences between these two types of cylinders.

Hydraulic Cylinder	Pneumatic Cylinders
• Uses the oil pump to provide the fluid to the **hydraulic cylinder**.	• Uses the air compressor to provide pressurized air to the **pneumatic cylinder.**
• Has greater output power.	• Light quality, lower price, no resistance, it also can realize long-range control.
• It can move at steady or variable speeds.	• No pollution and easier handling. Used more in food processing industries.
• Action is smoother and shockproof.	• Works faster than a **hydraulic cylinder**.
• Low noise.	

Do you know any science principles that are associated with the operation of a hydraulic cylinder?

The activities in this section will enable you to reflect on science concepts important (or essential to the operation) in the operation of hydraulic cylinders

A hydraulic cylinder is a machine and like any other machine it was invented to perform work. Machines are surrounded by physical elements which hinder the performance of work. These elements include **force** which is any influence capable of producing a change in the motion of a body. There is also **friction** which is any force which can stop or retard the movement of a body. As a machine operates under the influence of an applied force it produces energy. There are different types of energy in mechanical systems: **a) kinetic energy** b**) potential energy c) thermal energy**. One important principle you learned in your science class about energy is that it changes states. So potential energy has the ability to change to kinetic energy. Kinetic energy also can change to thermal energy.

Another element is **work**. Work is the application of a force to cause movement of an object through a distance. The unit for measuring work is ft.lb. (Joule or Newton-meter). An example of doing work would be a forklift loading a truck. If the forklift exerted a force of 2000 lbs (8800Newton) over a vertical distance of 5ft. (1.524 m) to load each pallet, then 10,000 ft.lbs (13533.1 N.m or 13533.1 J) of work would be done per pallet.

Work = distance moved x force exerted

10,000 ft.lb = 5 ft x 2000 lbs

Power is the speed or rate at which work is done. Power is calculated by simply dividing the work done by the time taken to do the work. In our example of loading the truck, if the 10,000 ft.lbs were done in 5 seconds, the rate of doing work would be:

$$\frac{10{,}000 \text{ ft. lbs}}{5 \text{ seconds}} \quad \text{or} \quad \frac{13533.\,1 \text{ J}}{5 \text{ sec}}$$

or 2000 ft. lbs/s. (2706.6 J/s)

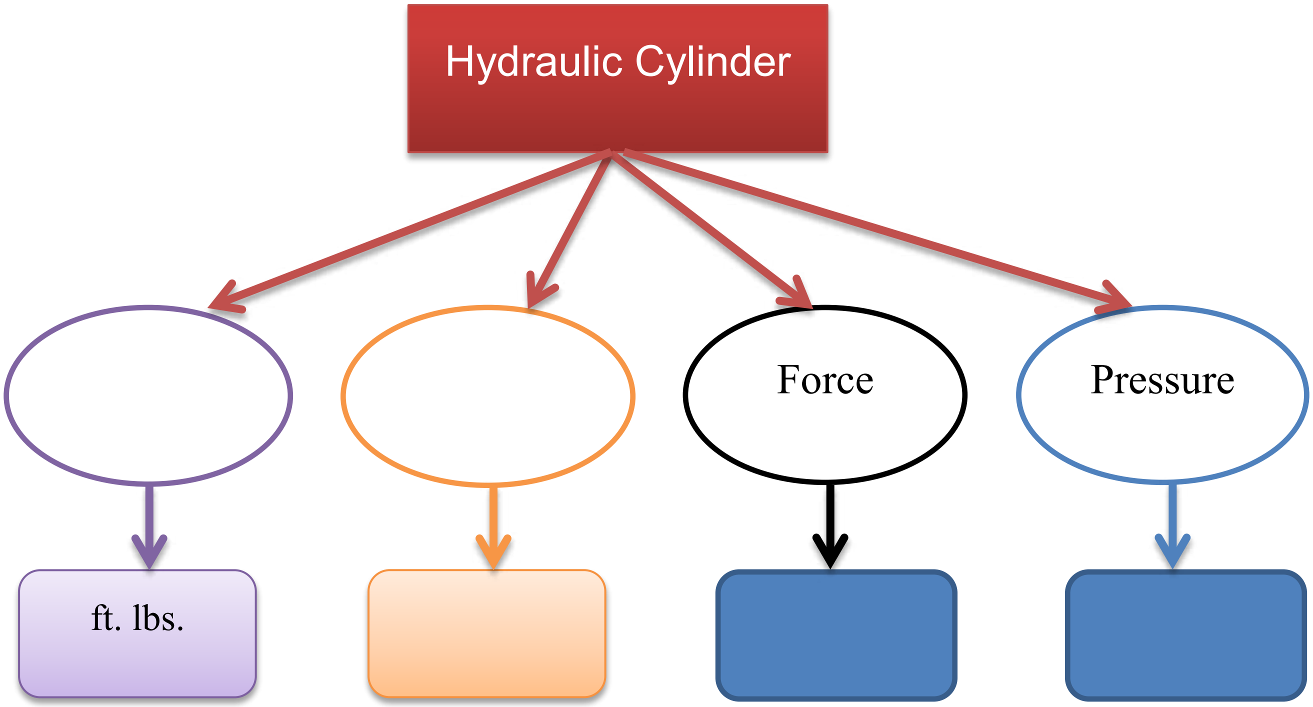
Pressure is a measure of a force's intensity. Many times the intensity of a force is of more interest and greater concern than the actual force itself. To determine the pressure, that is the intensity of a force, the total force is divided by the area (square inches or square centimeters) on which it is acting. The result is pressure, that is, the amount of force per square inch or square centimeter.

$$\text{Pressure} = \frac{\text{Total force (lbs.)}}{\text{Area on which total force acts (in}^2\text{)}}$$

To date the accepted SI (metric) unit for pressure is the bar.

1 bar = 10^5 N/m = 10^5 Pa (Parker Training, 1997)

Now you are acquainted with some of the common physical elements a machine, such as a hydraulic cylinder, faces when it is in operation, fill in the blank boxes and circles in the map below. The middle level represents a physical element and the bottom level represents the unit.



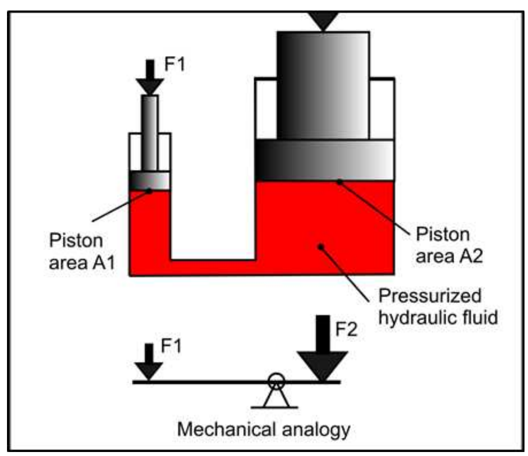
Fill in the blank boxes and circles

SCIENCE

Hydraulic Lever

Science Learning Experience # 1

There are several scientific principles associated with the function of a hydraulic or pneumatic cylinder. However, in this first activity we will focus on the hydraulic lever.

Activities	Special Instructions
The unique behavior of a fluid, including its ability to transmit an omnidirectional force, was summarized by Blaise Pascal in a theory known as Pascal's principle in 1653. Pascal's principle may generally be stated as follows: *"The pressure applied to a confined fluid is transmitted undiminished in all directions to every portion of the fluid."* This characteristic of a fluid allows it to function as a hydraulic lever. Its function therefore is similar to a mechanical lever. The brake system in a car uses a hydraulic cylinder that follows the same principle of a mechanical lever. Follow the instruction in the column to your right to understand more about the principles behind a hydraulic lever.	**Read** this webpage. It explains how a hydraulic brake system functions as a lever. **Watch** the following YouTube Video: Pascal Law and Hydraulic Brake System. Note in some places the video will pause momentarily. After a few moments it will continue.  Watch this other YouTube about Pascal's Law and Hydraulic Levers.

After you complete the activities above, let's see how well you can apply the principles you have just covered.

Consider the two-piston hydraulic system shown in the Figure below. The system consists of two pistons that are free to slide in their respective cylinders connected by a continuous path of incompressible liquid. We shall see this system is equivalent to a hydraulic lever.

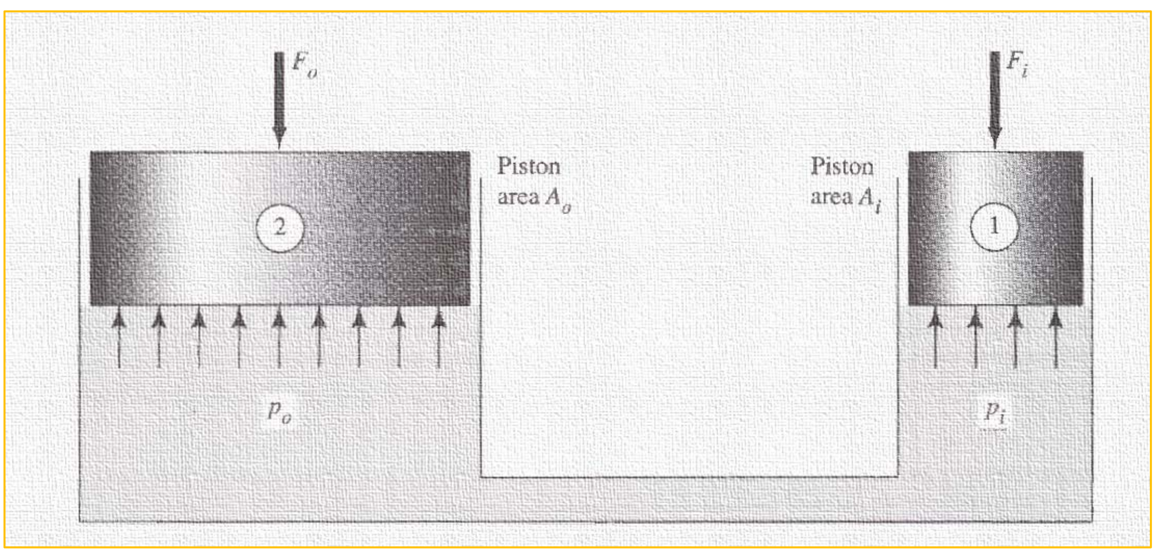
If an input force, F_i, is applied to a piston of area A_i,

a) What force (F_o) can be supported on a piston whose area is A_o?
b) What is the mechanical advantage of the system?

The condition of the equilibrium here is not one of balance torques, but of equal pressures. Input force Fi creates a pressure directly beneath piston 1. This pressure is simply:

$$p_i = \frac{F_i}{A_i}$$

But Pascal's principles states that because of the characteristics of a fluid, the pressure created by $\mathbf{F_i}$ must be transmitted undiminished throughout the system (Kokernak, 1999).



Therefore, the pressure, p_o, under piston 2 must be equal to p_i or

$$p_o = p_i$$

Then: $$\frac{F_o}{A_o} = \frac{F_i}{A_i} \qquad (1)$$

and, $$\frac{F_o}{F_i} = \frac{A_o}{A_i} \qquad (2)$$

For circular piston, $A_o = 0.7854\ D_o^{\ 2}$, $A_i = 07854\ D_i^{\ 2}$ and equation (1) becomes

$$M.A. = \frac{F_o}{F_i} = \frac{D_o^{\ 2}}{D_i^{\ 2}}$$

$$F_o = F_i \times \frac{D_o^{\ 2}}{D_i^{\ 2}}$$

Remember:

The Mechanical Advantage of a simple machine represents the factor by which an input force is magnified by the simple machine to produce some output force.

HERE IS AN IMPORTANT CONCEPT!!

There are several important differences between a mechanical and hydraulic lever. In order to obtain a magnification of force with the former, input force F_i is applied to the larger of the two moment arms. In a hydraulic lever, however, that input force is applied to the piston having the smallest cross-sectional area. Also, the M.A. for a mechanical lever is proportional to the simple ratio of lever arm lengths—doubling this ratio doubles the M.A. For circular pistons however, the M.A. of a hydraulic lever is proportional to the square of the ratio of the diameters—doubling this ratio causes a quadruple increase in M.A.

Science Challenge

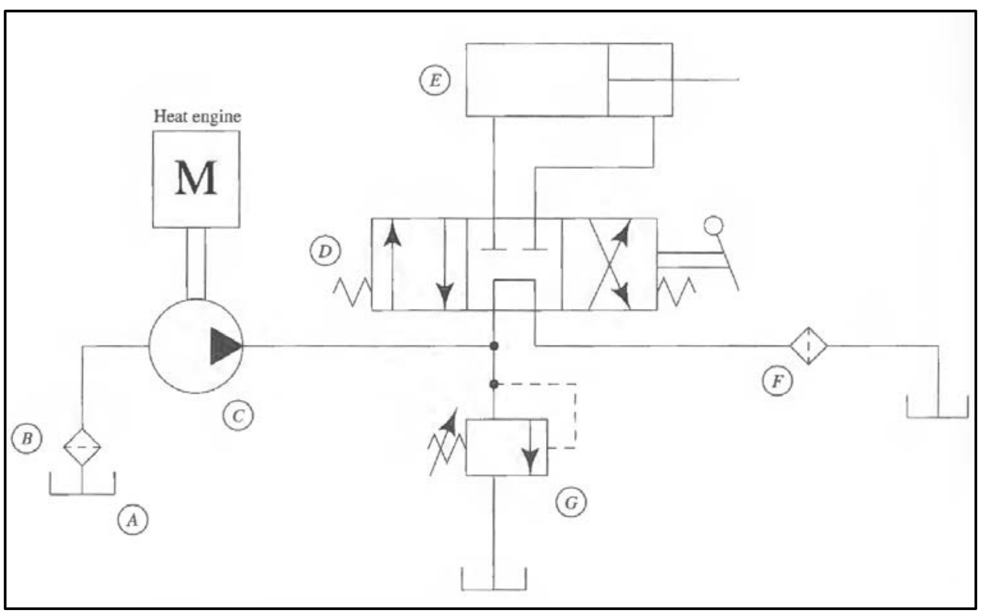
Now try this simple problem by referring to the diagram above (if you need additional assistant ask your science teacher).

Find the piston diameters required in the two-piston hydraulic system that produces an **output force of 800lb** for an **input force of 50lb** and operates at a **pressure of 600 psi**.

How far must the input travel in order to move the output force through a **distance of 2.0 in**?

Technology

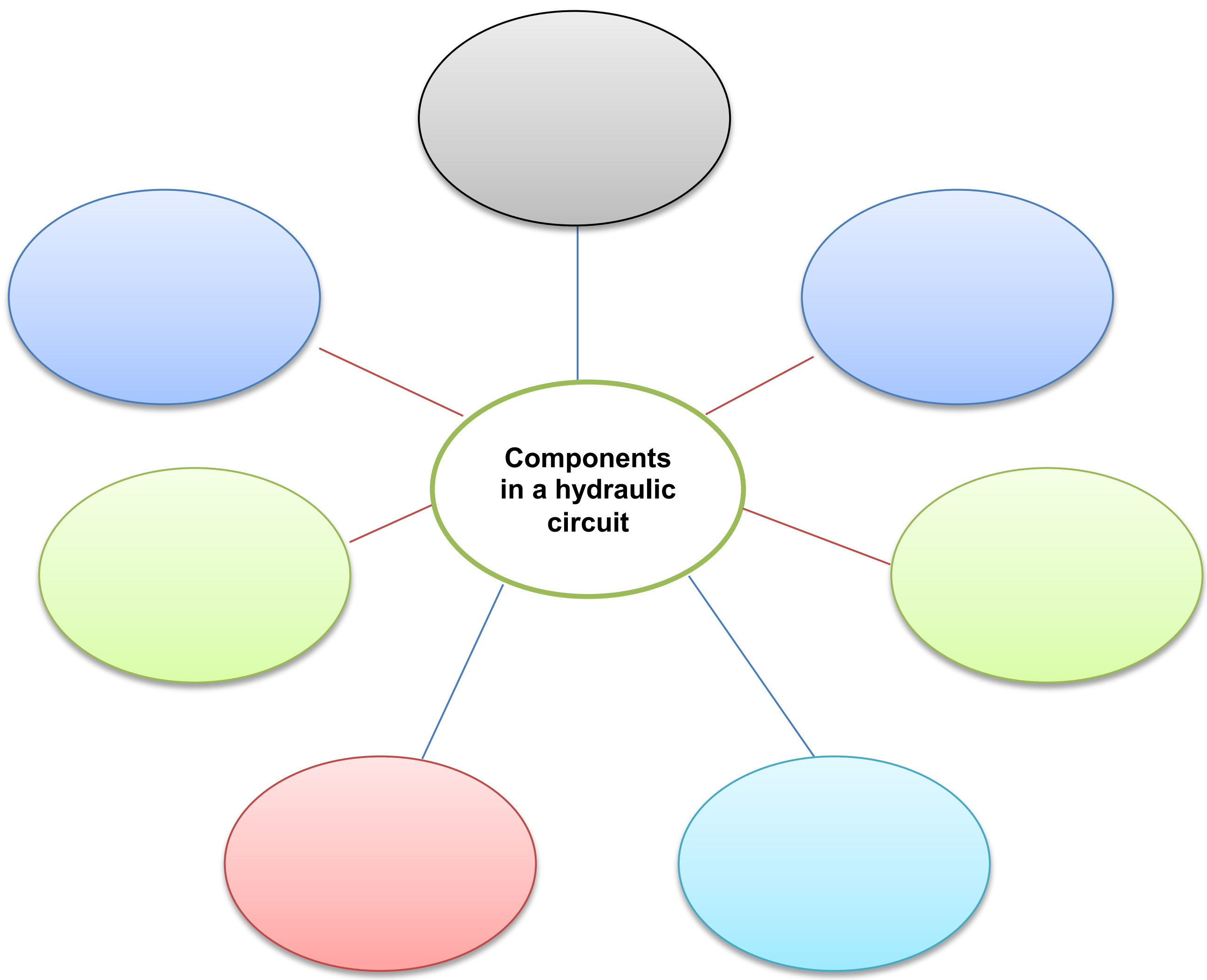
Basic Hydraulic Circuits



Adopted from Kokernak (1999)

The schematic diagram for a typical double-acting circuit is shown on the previous page. Liquid from reservoir (A) is drawn through a tank mounted strainer (B) by a fixed capacity, nonreversible pump (C). The fluid passes through a lever operated, 3 position, 4-way directional valve (D) and on to the double-acting cylinder (E). Liquid leaving the cylinders flows back through the valve, passing through filter (F) on its return to the reservoir. If the valve itself does not contain provisions for internal pressure relief, then an external pressure relief valve (G) must be included in the circuit. This valve prevents the damaging effects of excess pressure that can develop in the system if the flow path is blocked by a jammed or overloaded piston (Kokernak, 1998, p. 281).

Based on your reading about a simple hydraulic circuit, name seven components found in a simple hydraulic in the Concept map below.



Technology Learning Experience

The following activities will increase your understanding of how a hydraulic circuit works

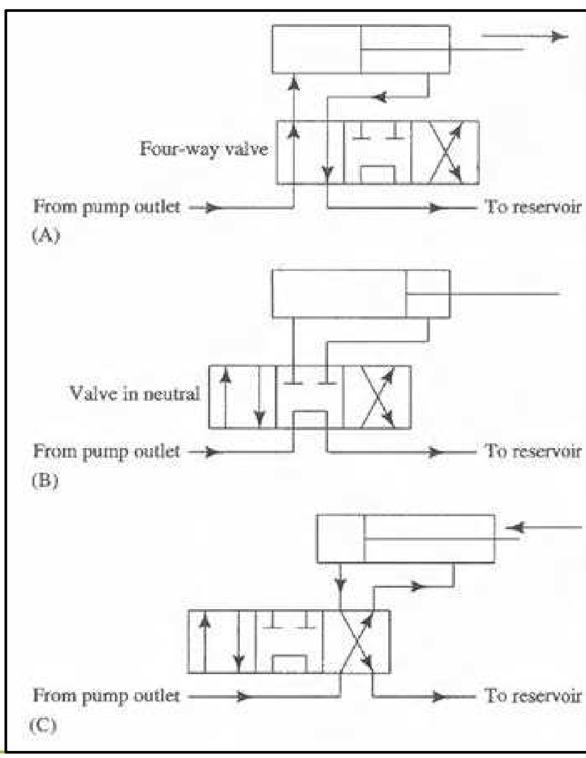
Activities	Special Instructions

Activities

Read the information below

Directional control valves are used in fluid power circuits to control the movement of fluid between components. A metal spool inside the valve is machined in a series of lands and grooves that cover various combinations of inlet and outlet ports as the spool slides within the valve body. Positioning of the spool can be accomplished by a variety of manual, electric, hydraulic/pneumatic actuators or controls.

A double acting cylinder rod motion (extension and retraction) is generally controlled by a four-way, three-position valve. This means that the valve allows the rod to assume three positions (extension, locked in position, retraction) through the flow of the hydraulic fluid in four directions (as seen by the arrows on the valve).



Special Instructions

Look at the diagram to your left. Notice in the top schematic diagram when the spool is to the left (A), hydraulic fluid is pumped into the left space of the cylinder. This causes the rod to extend to the right. Fluid in the right space of the cylinder flows back to the reservoir. When the spool is in the center position (neutral) (B), the fluid bypasses the cylinder and flows back to the reservoir. When the spool is in the right position the fluid from the pump flows to the left space of the cylinder so the rod retracts. The fluid in the left space of the cylinder flows back to the reservoir.

Watch this animation on how a valve and cylinder operates.

Let's watch how a manually operated valve is used to operate a hydraulic ram

Do you need more assistant to understand how a hydraulic ram works? Why not ask your technology education teacher.

This video gives more information about how hydraulic cylinders are used and the various types of cylinders

Now you have a basic understanding of how a hydraulic circuitry functions, let's see how well you can answer these few questions.

1. What are three types of actuators or controls used to control the movement of the spool in a directional valve?

2. Search the Internet for examples of the following:
   a) Double acting cylinder.
   b) Directional valve.
   c) Hydraulic pump.
   d) Pressure relief valve.

Now present the results of your search to your class!!!

Engineering

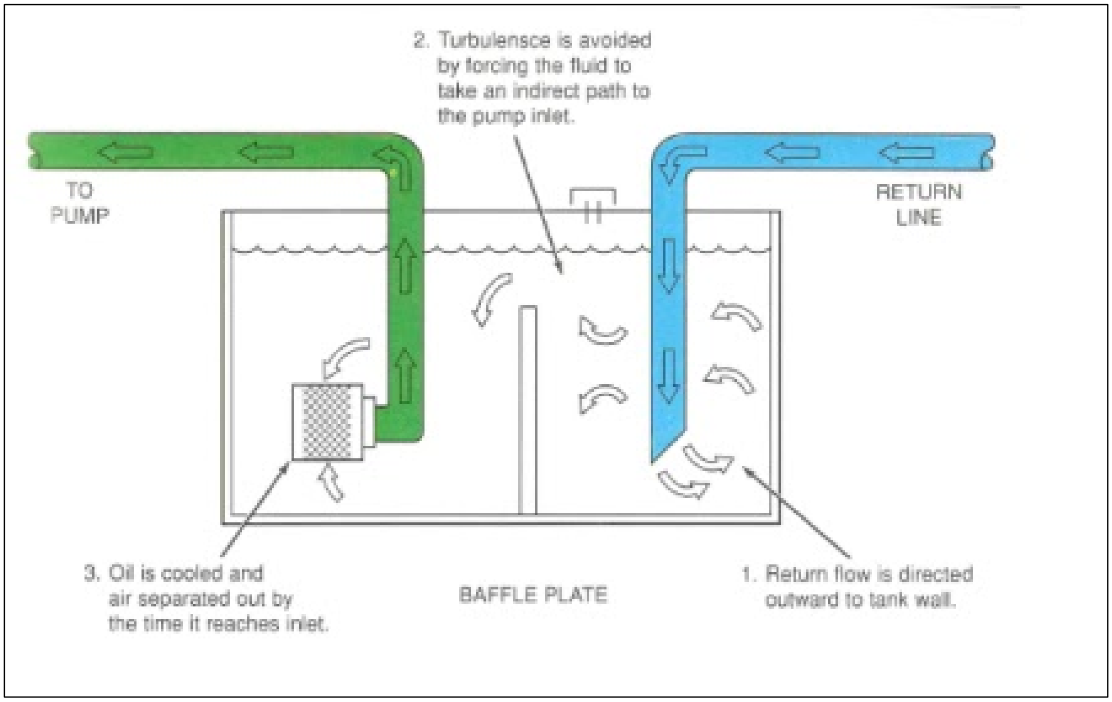
Hydraulic Reservoir and Pump

As you learned, a hydraulic cylinder uses hydraulic fluid to operate its' piston. Similarly, a pneumatic cylinder uses air to operate its' piston. Although the primary function of a reservoir is to store liquid, it has several important secondary functions that are often overlooked. These include;

- Cooling of the liquid
- Elimination of air and settling contaminants

- Access to liquid for maintenance operations

Each function should be considered in the design of a reservoir.



<table>
<tr><td colspan="2">Engineering Learning Experience

The following material will increase your awareness of design requirements that must be considered when designing a reservoir and pump.</td></tr>
<tr><th>Activities</th><th>Special Instructions</th></tr>
<tr><td>Read the information below

In general reservoir tanks should incorporate the following features:

Adequate Capacity: To maintain the desired viscosity of the liquid and reduce the sludge formation caused by oxidation, the temperature of the liquid must not become excessively high. One way to minimize the degrading effects of heat on fluid power systems is to increase the amount of liquid in the system. A rule of thumb for determining adequate reservoir size is as follows:</td><td>Let's review how the reservoir functions by watching this simulation.</td></tr>
</table>

Required volume (gallons) = 2.5 x pump flow rate in gpm + Volume (gallons) of cylinders/lines ***Provisions for Heat Dissipation***: Several measures can be taken to increase conduction of heat away from the liquid. These include locating the reservoir away from objects that can block the flow of air around the unit such as; placing the reservoirs on legs (typically pieces of channel or angle iron) to promote air flow, increasing reservoir surface area by attaching external cooling fins, and enhancing air flow by use of an auxiliary fan. For extreme cases, the reservoir can be used in conjunction with a heat exchange whose cooling is placed directly in the stored liquid. ***Vented Filler Cap***: During operation of a fluid power system, the volume of the liquid stored in the reservoir can vary with time. If the amount of gas (air) above the liquid is held constant by sealing the tank, then any changes in the liquid level may result in gas pressures that are slightly above or below atmospheric pressure. In an extreme case, if enough liquid is drawn from the tank by a pump and little or none is returned (perhaps of leaks elsewhere in the system); sufficient vacuum can develop with the tank to cause its collapse. To prevent this from happening, most reservoirs are vented or open to the atmosphere, however, this also provides a means by which airborne dirt, moisture, and other contaminants can enter the system. V**enting is therefore best achieved through a filler cap that contains an air filter.** ***Appropriate Locations of Tank Openings*****:** The reservoir outlet, which carries fluid from the tank to the pump inlet, is normally located well below liquid level to minimize the possibility that a drop in level will cause the pump to run itself dry. The outlet should also incorporate a strainer on the inside of the tank to filter out large particles that, if allowed to pass into the system could damage the pump or other major components. ***Proper Location Relative to Pump***: Most pump manufacturers specify the maximum vertical distance above the liquid surface in the reservoir at which a particular pump can be located. (Kokernak, 1997)	The suction head of the hydraulic pump is connected to the reservoir. Sometimes the pump may fail. Let us see why hydraulic pumps fail and how to prevent pump failure.

Now you have completed the activities above let’s see how well you will answer:

1. What are the primary functions of a hydraulic cylinder?

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2. How can hydraulic pump failure be prevented?

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3. Occasionally, hydraulic reservoirs are sealed rather than vented. Such units generally contain a pressurized gas above the surface of the liquid instead of air at atmospheric pressure. Are there advantages or disadvantages in using such a reservoir?

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Mathematics

Cap Area and Effective Area

When working with hydraulic (and also pneumatic) systems you will come across many equations that are used to define operation of systems. These equations will include concepts you learned about in mathematics (e.g. area and volume) and science (e.g. force and pressure).

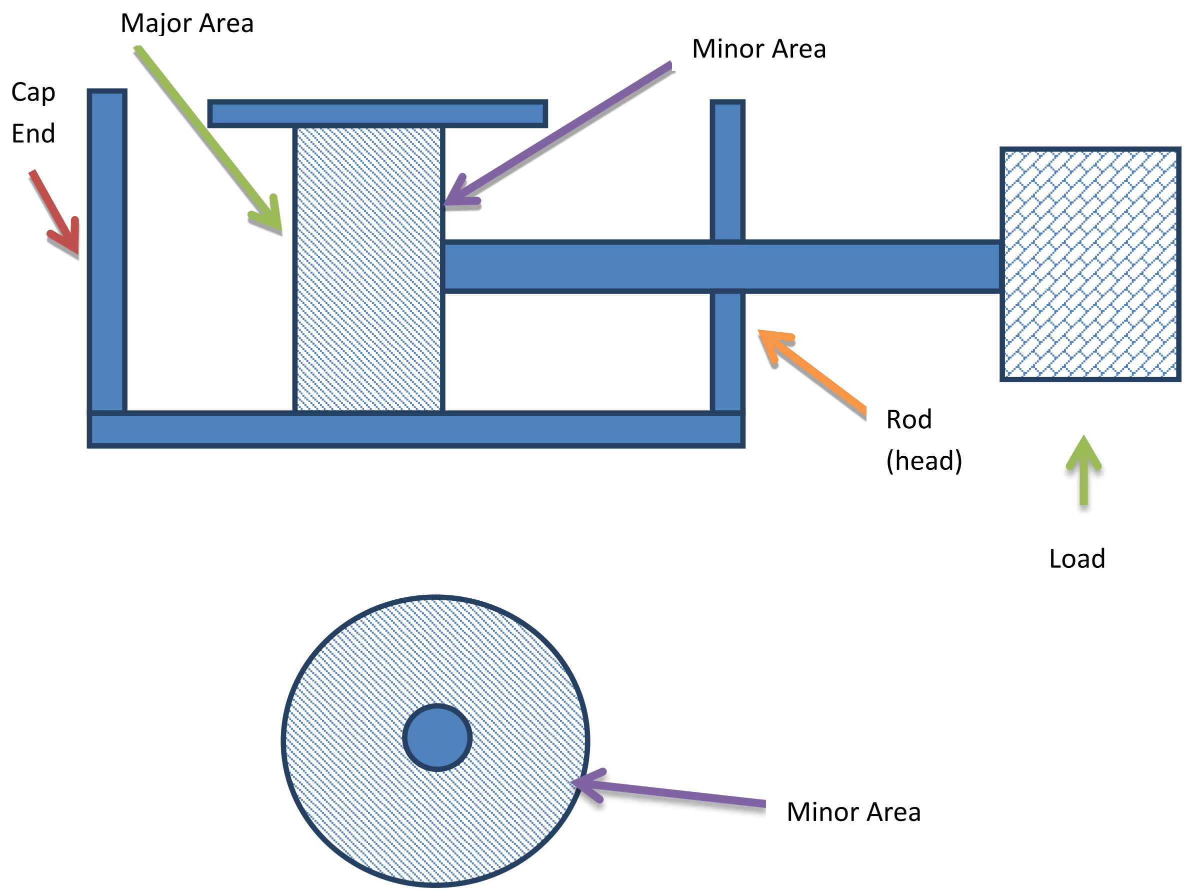
Remember, in order to perform work, the rod of a hydraulic cylinder must extend and retract. When extending, the mechanical force developed by a cylinder is the result of hydraulic pressure acting on the cap end of the cylinder. This is expressed by the formula:

Force (lbs) = pressure (psi) x Area (in^2)

(Newton's) = Pressure (bar) x Area (m^2)

Piston major area and effective piston area

Piston major areas and effective piston areas are generally used in reference to areas on a double-acting single rod cylinder. ***Piston major area*** refers to the piston area exposed to pressure at the cylinder cap side. ***Effective minor area*** (also called the annulus area) refers to the piston area exposed to pressure on the cylinder rod side. Since the rod covers a portion of the piston at this point, effective area is always less than the piston area.



Examine the diagram above. The piston is used to move a load to the right. Fluid flows into the cap end of the cylinder and a force is exerted on the major area of the piston and the rod extends. The piston retracts when fluid enters from the rod end of the cylinder. A force is exerted on the minor area of the cylinder and the rod retracts.

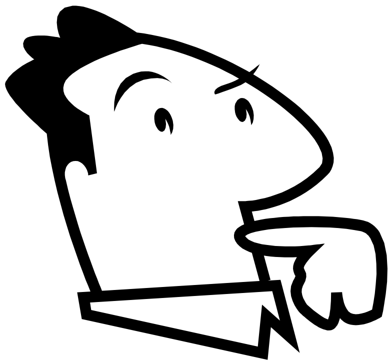
The minor area is less because you have to subtract the area of the rod from the major area to get the minor area.

Mathematics Learning Experience

The following material will reinforce your ability to calculate volume, pressure and area in hydraulic system.

Activities	Special Instructions
For example, if a load offers a resistance to move of 5000 lbs and the area of the cylinder piston is $10 in^2$, then a hydraulic pressure of 500 psi is required to equal the load. Pressure (psi) = $\frac{\text{force (lbs.)}}{\text{Area } (in^2)}$ $\frac{\text{(Newtons)}}{(cm^2)}$ = $\frac{5{,}000 \text{ lbs.}}{10 \ in^2}$ $\frac{22200 \text{ N}}{64.54 \ cm^2}$ = 500 psi (34.4 bar)	**Watch** this video to remind yourself how to calculate the area of a circle
Note: the assumption was made that pressure was zero on the other side of the piston. Even though the piston minor area is drained to the tank while extending, tank line pressure or back pressure, can be as high as 100psi (6.9 bar) in some systems. So, let's assume the back pressure is 100 psi, and the effective area is $8 \ in^2$, then on extension, the piston would face an addition resistance of: 100 psi X $8 \ in^2$ = 800 lbs (3552 N).	
So the total load would be 5000 +800 = 5800 lbs (25752 N). The total pressure to extend the cylinder would be Pressure (psi) = $\frac{\text{force (lbs.)}}{\text{Area } (in^2)}$ $\frac{\text{(Newtons)}}{(cm^2)}$ = $\frac{5{,}800 \text{ lbs.}}{10 \ in^2}$ $\frac{25752 \text{ N}}{64.54 \ cm^2}$ = 580 psi (34.4 bar) **Cylinder force while retracting** While retracting, the mechanical force developed by a cylinder is the result of hydraulic pressure acting on the effective area. The same formula as above is used. However in this instance, the effective area of the piston is used.	**Watch** this presentation from Kahn's Academy. It reinforces the importance of area in closed fluid system

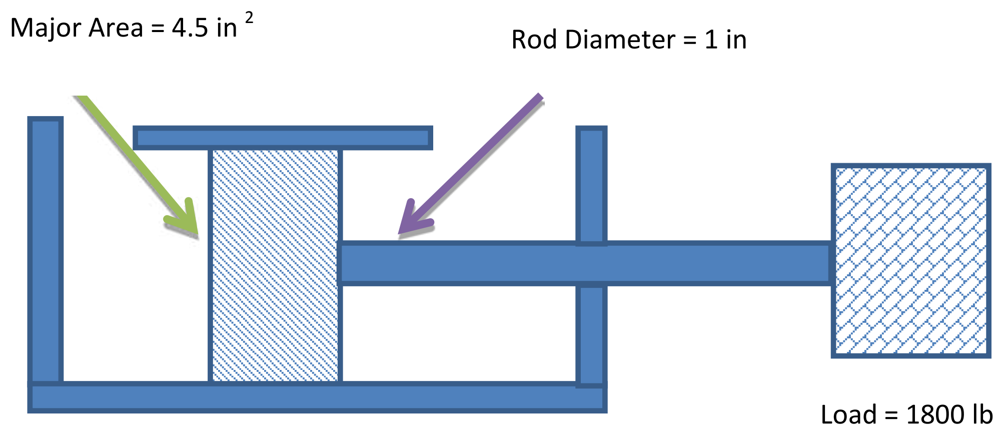
For example, if a load offers a resistance to move of 5000 lbs. (22200 N) and the effective area of the cylinder piston is 8in^2 (51.60 cm^2), then a hydraulic pressure of 625 psi (43.1 bar) is required to equal the load as calculated by the formula. Pressure (psi) = $\frac{\text{force (lbs.)}}{\text{Area (in}^2)}$ $\frac{\text{(Newtons)}}{(\text{cm}^2)}$ = $\frac{5{,}000 \text{ lbs.}}{8 \text{ in}^2}$ $\frac{22200 \text{ N}}{51.6 \text{ cm}^2}$ = 625 psi (43.1bar) Again we are assuming here, no back pressure is present at the cap end. In practice, however, back pressure is even more pronounced while retracting than extending. So let's assume that the back pressure is 125 psi (8.62 bar) Therefore, there would be an additional resistance of F= 125 psi x 10 in^2 = 1250 lbs. (5550 N). So the total load would be 5000 lb. +1250 lb. = 6250 lbs. (27750 N). Pressure (psi) = $\frac{\text{force (lbs.)}}{\text{Area (in}^2)}$ $\frac{\text{(Newtons)}}{(\text{cm}^2)}$ = $\frac{6250 \text{ lbs.}}{8 \text{ in}^2}$ $\frac{27750 \text{ N}}{51.6 \text{ cm}^2}$ = 781 psi (53.86 bar) (Parker Training, 1999)	



Reflect on the information in the activity on the previous page.

What did you noticed about the pressure when extending the piston in comparison to the pressure when retracting the piston?

How do you think this might affect the speed of the piston?



In the cylinder illustrated above, determine (assume there is no back pressure):

A. The pressure to extend the cylinder rod

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B. The pressure to retract the cylinder rod

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Want to be a little adventurous? Assume there is a back pressure of **90 psi** in the hydraulic line when the cylinder extends and **110 psi** when it retracts. How will the answers for A and B change. (Parker Training, 1999)

References:

Parker Training. (1997). *Industrial hydraulic technology*. Cleveland, Ohio: Parker Hydraulic Corporation.

Kokernak, R. P. (1999). *Fluid power technology*. Upper Saddle River, NJ: Prentice Hall, Inc.

http://auto.howstuffworks.com/auto-parts/brakes/brake-types/brake1.htm

https://www.khanacademy.org/science/physics/fluids/v/fluids--part-2

http://www.youtube.com/watch?v=aqk1Np9P2vE

http://www.youtube.com/watch?feature=fvwp&v=svdsbL4PLL4&NR=1

http://www.youtube.com/watch?NR=1&v=54Hj1mO5Lng&feature=endscreen

http://www.youtube.com/user/TutorVista