EVALUATING ACADEMIC READINESS FOR APPRENTICESHIP TRAINING

Revised for

ACCESS TO APPRENTICESHIP

SCIENCE SKILLS
FLUIDS AND PRESSURE

AN ACADEMIC SKILLS MANUAL
for
The Precision Machining And Tooling Trades

This trade group includes the following trades:
General Machinist, Tool & Die Maker,
Pattern Maker, Mould Maker, and
Machine-Tool Builder Integrator

Workplace Support Services Branch
Ontario Ministry of Training, Colleges and Universities

Revised 2011

In preparing these Academic Skills Manuals we have used passages, diagrams and questions similar to those an apprentice might find in a text, guide or trade manual.

This trade related material is not intended to instruct you in your trade. It is used only to demonstrate how understanding an academic skill will help you find and use the information you need.

SCIENCE SKILLS
FLUIDS AND PRESSURE

An academic skill required for the study of the Precision Machining and Tooling Trades

INTRODUCTION

Liquids and gases have many properties in common. The term ***fluid*** includes both liquids and gases because of these common properties. The most notable difference between liquids and gases is that gases can be ***compressed*** under pressure into a smaller volume, while liquids basically keep the same volume, even under pressure. Except for the property of compression, the principles that explain fluid power systems apply to both liquids and gases.

Fluids can transfer force from one area to another. The pressure exerted by water can be used to force a solution through a hose where it is to be applied. Gasoline from the gas tank can be moved by pressure into the cylinder where it is ignited. The combustion of the gas produces pressure on the piston. The up and down motion of the piston is converted into the rotating motion of the mower. This transfer of force takes place because the heat energy contained in the gasoline can be transferred to the cylinder where it is used to produce motion.

When gases and liquids are used to transfer force, they are usually confined in an enclosed container such as a tank or a hose. The flow rate of a fluid in a hose is closely related to the diameter of the hose. Changes in pressure can be created by changing the diameter of the hose.

In this skill manual, we will look at how fluids transmit energy and the motion of fluids in confined areas. The following concepts are covered:

- Definitions of energy, force and pressure
- Pressure exerted by a fluid
- Pascal's Principle
- Flow rate
- Bernoulli's Principle

DEFINITIONS OF ENERGY, FORCE AND PRESSURE

Energy, Work and Power

Whenever a force moves an object, work is done. Work and energy are closely related concepts. ***Energy*** *is the ability to do work. W**ork** is the result of a force applied over a distance*. The amount of work done is calculated as force multiplied by distance. The formula for work is:

Work = Force x distance

Or

W = F x s.

Note: *The variable (letter) "**s**" is used to represent the distance an object is moved in this formula.*

The unit for work is the ***joule (J)*** which is equal to a force of 1 newton acting over a distance of 1 meter. The joule is also the unit for potential and kinetic energy because whenever work is done, energy is used.

Imagine you moved a load weighing 100 kilograms a distance of 2 meters in 30 seconds. Your friend moved the same load the same distance but he needed 60 seconds to do it. You each did the same amount of work, but you had more power because you did it faster.

Powe*r is the rate at which work is done.* It is calculated by dividing the work done by the time. The formula for power is:

Power = work ÷ time

or,

P = W/t

The unit of power is the ***watt (w)*** in the metric system and the ***horsepower (hp)*** in the imperial system.

Force

All objects have mass, and because of their mass, they have a property called inertia. ***Inertia** is the tendency to resist a change in motion.* A moving object tends to keep moving. An object at rest resists being moved.

- The inertia of the spinning flywheel on a crankshaft moves the piston back up in the cylinder. Once the flywheel is in motion, it tends to stay in motion.

Because of inertia, a force must be applied to an object:

- to move it if it is at rest,
- to change its velocity if it is moving, or
- to stop its motion if it is moving.

*A **force** is defined as an external agent that moves an object or that has a tendency to do so.* An applied force is felt as a push or pull by an object. Usually a force causes an object to move. When the object does not move because it is held in place, the force is felt as a ***stress*** or as ***pressure***.

The units of force are ***newtons (n***) in the metric system and ***pounds (lb)*** or pounds-force in the imperial system.

Pressure

Force is usually exerted over a certain area. When you step on the floor, the force of your weight is exerted over the area of your feet. If you know your weight (the amount of force) and the area of your feet, you can then find the pressure. ***Pressure** is the force per unit area*. It is calculated by dividing the force by the area.

The formula is:

Pressure = Force ÷ Area

or

P = F/A

Pressure is expressed in ***pounds per square inch (psi)*** and in ***newtons per square meter*** ***(n/m***^{2}***)***, which is also called a pascal (Pa).

If you weigh 145 pounds and your feet cover an area of 60 square inches, what is the pressure you exert on the floor?

P = F/A
= 145 lb ÷ 60 sq in
= 2.42 psi (pounds per square inch)

The pressure exerted by a gas such as air can be measured by the height that its pressure causes mercury to rise in a barometer. The air at sea level exerts 760 mm or 29.9 inches of pressure on a column of mercury. The pressure from the weight of the air is called ***atmospheric pressure***.

How fluids move:

- Fluids move from an area of higher pressure to an area of lower pressure. They will even out any pressure differences if they are free to move.
- When air molecules are removed from a space, the pressure becomes less than atmospheric pressure. A partial vacuum is created.
- If there are any openings, a fluid such as air from outside will rush in to the lower pressure area in an attempt to even up the pressure.

PRESSURE EXERTED BY A FLUID

Solids have a definite, self-supporting shape. For this reason, they exert pressure only in a downward direction.

Fluids do not have a definite shape but take the shape of the container they are in. For this reason, they exert pressure not just on the bottom of their container but also on the sides. Pressure in a liquid is still defined as force exerted divided by area (P =F/A), but the area of the sides of the container must be included in the calculations.

*Liquids and gases that fill a **completely enclosed** container exert pressure equally in all directions, including the top wall of the container.*

- If you put a stopper in one end of a pipe, fill it with water, and then push another stopper into the open end, the original stopper will pop out. This occurs because the pressure you exert with the second stopper is transmitted to the other end.

*Fluids **at rest** transmit pressure equally in all directions.*

- The pressure exerted by a fluid at rest depends on the weight of the fluid and the area of the walls of the container.
- If an outside force is exerted anywhere on the fluid, this force increases the pressure the fluid now exerts back on the walls.
- The fluid transmits this increased pressure evenly everywhere on the container.

The formula for finding the pressure in pounds per square inch (psi) exerted by water at the bottom of a container is:

$$\text{Pressure} = \frac{62.4}{144} \times \text{depth of water in feet}$$

Example: A full water tank is 40 feet high. What is the pressure in psi at the bottom?

$$P = \frac{62.4}{144} \times \text{depth}$$ use P for pressure

$$P = \frac{62.4}{144} \times 40 \text{ ft}$$

$$P = 17.3 \text{ psi}$$

PASCAL'S PRINCIPLE

Pascal studied the transmission of pressure by fluids. He found that the force exerted by one man pushing against a small piston (1 square foot in area) inserted into a cylinder of water could hold back the force exerted by one hundred men pushing against a piston that was 100 square feet. See Figure 1.

One man pushing against a small piston can hold back the force of 100 men pushing against a piston that is 100 times larger. This is how a hydraulic press multiplies force.

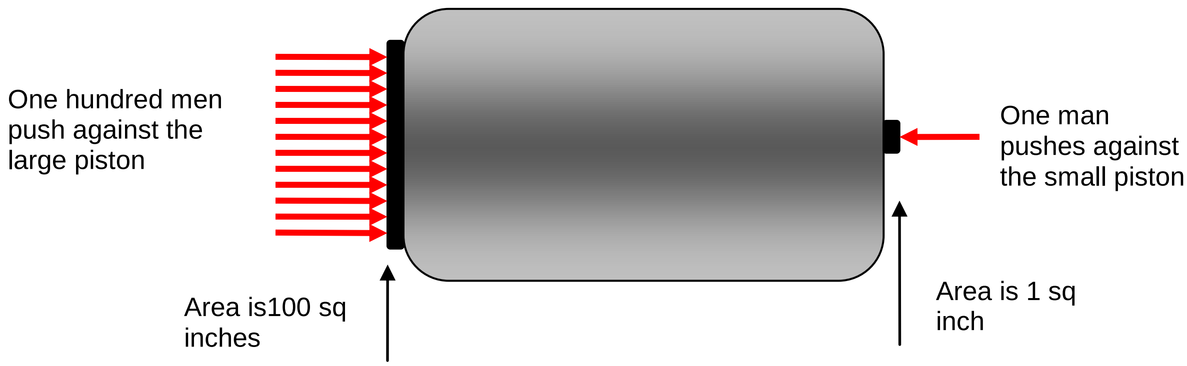


FIGURE 1: Principle Of A Hydraulic Press

How does this happen? A force is exerted on the enclosed water. The water exerts a force back on all surfaces, including the pistons, ***equally on equal areas***. Say the water is exerting a force of 1 pound on every square foot area or 1 lb/sq ft. The small piston has an area of one square foot. It receives a force of 1 pound.

$$\text{Force} = 1\ \cancel{\text{sq ft}} \times \frac{1\ \text{lb}}{\cancel{\text{sq ft}}}$$
$$= 1\ \text{lb}$$

The large piston has an area of one hundred square feet. It receives a force of 100 pounds over its total area.

$$\text{Force} = 100\ \cancel{\text{sq ft}} \times \frac{1\ \text{lb}}{\cancel{\text{sq ft}}}$$
$$= 100\ \text{lb}$$

- The force exerted on the 1 square foot area is one hundred times smaller than the force exerted on the 100 sq. ft. area.
- The man pushing on 1 square foot only has to hold back 1/100 of the force.
- The force exerted by one man on 1 square foot is exactly balanced by the force exerted by 100 men on an area 100 times as large.

Pascal used the information from his experiments to develop one of the basic principles concerning the pressure exerted by fluids. ***Pascal's Principle states*****:** *Pressure applied to a fluid at rest is transmitted equally in every direction at right angles to the walls of the container.*

Using Liquids to Multiply Force
Pascal realized that his principle of mechanics could be used to create a machine that would greatly magnify the original applied force. This led to the development of the hydraulic press, a machine that multiplies force.

In a hydraulic press, a downward force of 1 newton applied to a small piston of .1 metre^2 will balance a piston supporting a weight of 100 newtons with a surface area of 10 metres^2. If the downward force on the small piston is increased slightly, it can actually lift the 100n weight on the large piston.

This follows the same principle as the previous example. See Figure 2.

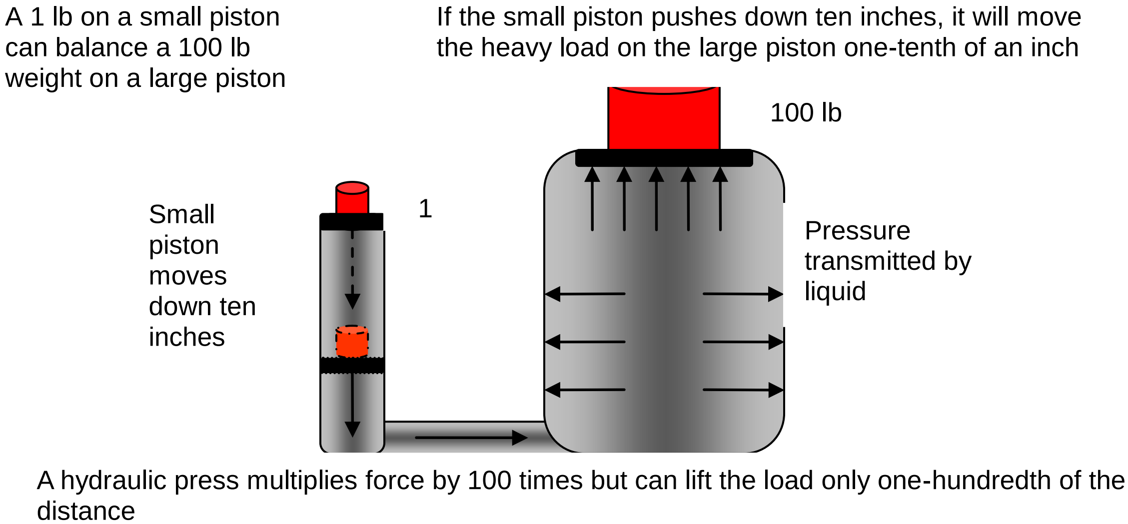


FIGURE 2: A Hydraulic Press

- Even though the force from the small piston is able to lift the larger (100 lb) load, it will not be able to lift it very high.
- The load is only lifted one-hundredth of the distance the smaller piston moves.
- If the weight of the load is increased, the height that the load is lifted becomes smaller.

The hydraulic lift is a useful machine for lifting large weights, such as a tree pruner plus equipment, up to where branches need pruning or cutting. Complex hydraulic systems use more than one cylinder and have valves to direct the pistons. Examples are hydraulic power brakes and power steering.

Pascal's principle resulted in the development of hydraulic systems. Once engineers understood the principles governing the action of pressure in a ***fluid at rest***, they used that knowledge to develop machines that used ***moving fluids*** to transfer force. But, before they could do that, they needed to understand how the velocity of a moving fluid is related to the pressure of a fluid.

FLOW RATE

Have you ever noticed how a quiet stream will suddenly became fast and turbulent when it enters a narrow area between some rocks? The same volume of water that moved through the wider area now has to pass through the narrower area of the stream. The pressure of the water flowing behind it forces the water through the narrow section *in the same amount of time* as it would take to go through the same distance in a wider section of the stream.

The water flowing in the narrow area has to move faster to get through the smaller space in the same time as the water flowing in the wider area.

Water in a tube or pipe flows in the same way as water in a stream.

- The same volume of water must be flowing everywhere in the pipe at the same time (as long as there are no side openings in the pipe).
- If the pipe narrows, the water will have to move through the narrow section more quickly.
- If the pipe widens, the water moves through that section more slowly.
- This results in a constant flow rate.

Flow rate *is the volume of fluid passing a given point in a unit of time.* The units used to express the flow rate are liters per minute (L/min) or US gallons per minute (gpm). Smaller flow rates are expressed as cubic centimeters per second (cm^3/sec) or cubic inches per minute (cu in/min).

If the flow rate is constant, the same volume of water passes any given point in the same amount of time. If a pump is delivering water at a rate of 100 liters per minute, at any point in the tube, 100 L flow by in one minute. When the tube in which water is flowing constricts (gets narrower), the same volume of water must flow more rapidly through the narrow portion to get through in the same amount of time that it flows through the wider space; the only way it can do this is by moving faster. Look at Figure 3.

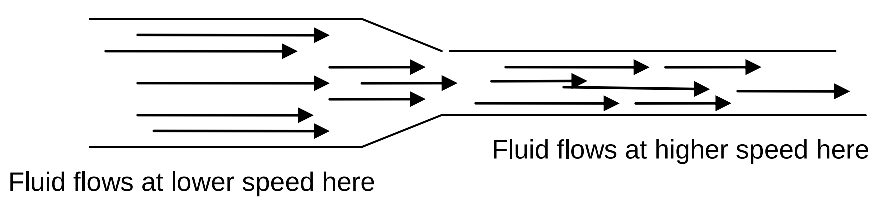


FIGURE 3: Water Flows Faster Through A Narrow Area

If gasoline is flowing through a 2 inch hose that narrows to 1 inch at the outlet, the fuel will flow out faster than if the outlet remained at 2 inches.

Velocity and Pressure

The rate at which the water is moving is called its velocity. ***Velocity** is the distance traveled divided by time,* with the direction of motion indicated. As the tube gets narrower, the velocity of the water increases.

According to Pascal's Principle, fluid at rest in an enclosed container exerts pressure equally in all directions at right angles to the surface. Any fluid has mass. The force of the earth's gravity pulls on this mass. The measure of this force is called weight. If the fluid were free to move, it would all flow down to sea level. If it is enclosed, the weight of the fluid creates ***potential energy*** that is stored as pressure (or force).

When some force like gravity or a pump acts on the fluid that is free to move, it will flow. Water flowing from a pump has both potential energy or pressure from its weight and ***kinetic energy*** from its motion. The fluid obtains its kinetic energy from the force exerted on it by the pump.

***Kinetic energy** is defined as the energy due to the motion of a mass*. The amount of kinetic energy is related to the velocity of the fluid. *The faster the velocity, the more kinetic energy*.

Fluid being pumped into a tube with a uniform diameter flows with a certain amount of energy at a constant velocity. Some of that energy is the kinetic energy from the motion of the fluid. Some of that energy is the potential energy that is expressed as the pressure of the flowing water.

The amount of energy the fluid has remains ***constant*** (unless a new force acts on it). So if the amount of ***kinetic energy increases***, the ***amount of potential energy***, and thus ***the pressure, decreases.***

Here's how this works.

- If the tube that the fluid is moving through narrows, then the fluid has to flow through the smaller space at a faster speed.
- The kinetic energy increases.
- When the kinetic energy increases, the potential energy, and the pressure, decreases.
- So, *whenever the velocity of the fluid increases, the pressure decreases*.

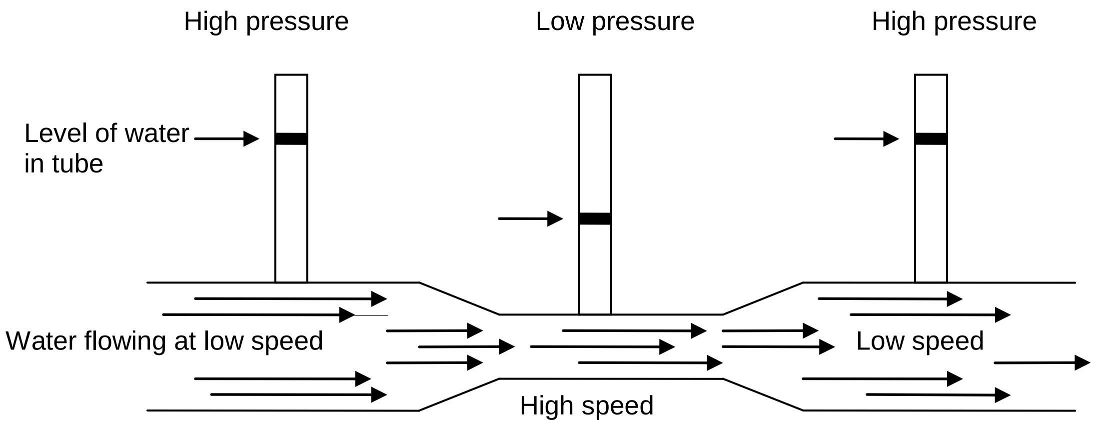


FIGURE 4: Pressure Varies Inversely With Speed Of Water

Water moving through a tube that constricts and then widens again is shown in Figure 4. Because the tube is narrower at the centre, the water flows faster there. The vertical tubes act as pressure gauges, indicating the amount of pressure (potential energy) exerted by the moving liquid. The pressure tubes indicate that the ***pressure*** *is* ***greater*** *where the water is moving* ***slowly****,* and that *the* ***pressur****e is* ***less*** *where the water is moving* ***faster.***

BERNOULLI'S PRINCIPLE

Bernoulli was a scientist who carried out further experiments with flowing water. He found that the *sum of the pressure (potential energy) plus the velocity (kinetic energy) divided by a known volume of fluid in a tube is always the same for that volume.*

$$\frac{\text{Pressure} + \text{Velocity}}{\text{Volume}} = \text{a constant}$$

This relationship is called ***Bernoulli's Principle.*** From the formula, you can see that if *the velocity of the fluid increases, the pressure it exerts decreases and if the pressure becomes greater, the velocity will decrease*.

Look at the how the formula shows this. Say the volume of the fluid and the constant do not change. When the velocity of a fluid increases, the pressure has to decrease. When the velocity of a fluid decreases, the pressure will increase.

We say that ***velocity and pressure vary inversely to one another***. As one changes, the other changes in the opposite way. Let's review these relationships concerning water moving through a tube:

- *the* ***wider*** *the tube,*
- *the* ***slower*** *its velocity*
- *and the* ***greater*** *the pressure it exerts.*

On the other hand:

- *the **narrower** the tube,*
- *the **faster** the fluid moves*
- *and the **smaller** the pressure it exerts.*

Friction

We did not consider the effect of friction on flow rate in the preceding explanation.

- Friction can cause a loss of pressure and turbulence in the flow.
- Friction in water pipes comes from water rubbing against the walls of the pipes.
- The smaller the diameter of pipe and the greater the pressure of water flowing through, the greater the effect of friction.
- Different types of pipe material cause different amounts of friction. For example, galvanized pipe causes a greater pressure loss than copper pipe.

Bernoulli's Principle Used in a Venturi

Water moving in a pipe was used to illustrate Bernoulli's Principle. Air moving in a tube shows the same behaviour.

- Air moves at a constant rate through a tube if there is no change in pressure.
- If a part of a tube is made narrower, the air moving through the constriction will flow more quickly.
- There is also a decrease in pressure in the narrow part of the tube.

This principle is used in designing a venturi. *A **venturi** is a restriction in a tube which causes passing air to move through faster, which in turn causes a reduction in the pressure.* The pressure of the outside air is greater than in the constriction. If there is an opening from outside into the venturi, this pressure difference causes air from outside to rush in.

When talking about pressure differences in an engine, any pressure that is less than normal or atmospheric pressure is referred to as vacuum pressure. Remember that air at higher pressure will move to an area with lower pressure.

Older gas engines rely on pressure differences to deliver the air-fuel mixture from the carburetor to the cylinder. As the force of the fuel explosion in the cylinder drives down the piston, a partial vacuum is created. As the intake valve opens, the air-fuel mixture from the carburetor rushes in to even up the pressure and is available for ignition in the next combustion cycle in the cylinder.

Understanding the principles of pressure differences also helps explain why the correct sizing of pipes is important.

- A too-narrow air vent and a too-narrow drain pipe can cause a buildup of pressure in the pipes, resulting in water being forced out the water traps.
- When water drains through a narrow pipe, the drain pipe completely fills with draining water. This creates a partial vacuum behind the water.
- Air from outside rushes in through the narrow vent.

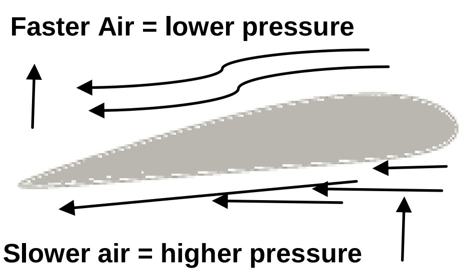
- The moving water causes pressure to build in the air already in the pipe because there is nowhere for this air to move to escape the water pressure. (In a wider pipe, less outside air rushes in and there is room for air already in the pipe to move out of the way of the draining water.)
- Trapped air traveling in front of the water can force water out of the drain traps. It can also slow down the rate of flow through the drain pipe.

Objects Moving in a Fluid
Bernoulli's principle explains some other interesting phenomena. Air is a fluid, and fluids exert pressure in all directions equally. The pressure of a fluid varies, depending on how fast the fluid is moving. ***So, a fluid, like air, exerts different amounts of pressure on top of and underneath an object moving through it.***

A baseball pitcher can throw a curve ball because of these pressure changes. A spinning baseball which is turning counterclockwise drags the air with it. The dragged air at the top of the ball moves with the normal air current, causing the air to move faster at the top.

Because the air at the ***top*** of the ball *moves faster, the pressure is reduced at the top of the ball.* The air ***below*** the ball is moving against the normal flow of air. This causes it to move more slowly. When air moves *more slowly, the pressure is increased.* This increased pressure underneath the ball pushes it onto an upward ***curved*** path.

The wing of an airplane works on the same principle. See Figure 5.



For an airplane to fly there must be greater/stronger/higher air pressure under a wing and smaller/weaker/lower air pressure on top.

Bernoulli's Principle, states that pressure decreases when air moves faster. Air moves faster over the top of a wing, which results in an area of lower pressure. Meanwhile, the bottom of the wing experiences higher pressure.

Figure 5: Bernoulli's Principle Explains Airplane Flight

Air foils on trucks are designed to lift air up and over the truck in the same way, resulting in less wind resistance. The truck can travel more efficiently, which reduces fuel costs.

CONCLUSION

Moving fluids are used to transfer energy in many systems involved in mechanical technology. This is possible because of the way fluids respond to pressure changes.

Energy in liquid fuel is transferred into vapour pressure that drives the piston in the engine. The way fluids respond to pressure is used to direct them to where they are needed. The fuel is moved from the gas tank in liquid form to the cylinder, where pressure differences cause it to vapourize.

The gas in welding cylinders is held under great pressure. This pressure must be released in a controlled way to supply the right amount of gas to the flame.

Hydraulic lifts take advantage of the way fluids transmit pressure to lift large weights. This same transmission of pressure is used to provide the power in hydraulic brake systems and power steering.

These systems take advantage of the principles discovered by Pascal and Bernoulli. Pascal's principle explains the way fluids at rest exert pressure. Bernoulli's principle explains the way fluids that are moving affect pressure. The relationship between fluids and pressure plays an important part in modern technological development.

Fill in the blank spaces with the correct answers. Answers are on the last page.

1. The term fluid includes both ______________ and _______________ .

2. Fluids can be used to transmit _________________ .

3. Pressure is the ______________ per unit area.

4. The formula for pressure is written as: _______________ .

5. A force of 150 pounds exerted over 30 square inches is equal to ___________ psi.

6. Solid objects exert ______________ only in a downward direction.

7. Enclosed liquids and gases exert pressure equally in all ____________________ at right angles to the surface.

8. Pascal's Principle applies to fluids at _______________ . Moving fluids do not transmit pressure equally.

9. In a hydraulic press, a weight of 1n applied to a piston with an area of .1m^2 will balance a load of 100n supported on a piston with an area of 10m^2. To lift the 100n load, the weight on the smaller piston is made slightly ________________ .

10. Each time the force is multiplied in a hydraulic press by increasing the area of the supporting piston, the amount the small piston can lift is increased, but the distance lifted becomes ______________ .

11. If the flow rate is constant, the _____________ volume of water flows through a narrow area as flows through a wider area.

12. When water is moving more slowly in a tube, the pressure exerted is _______________ .

13. Bernoulli's Principle states that the sum of the pressure and the velocity divided by a known volume is always a constant. This means that if either the pressure or the velocity gets larger, the other gets ______________ .

14. The air moving through the venturi in a carburetor moves faster and so has _____________ pressure than the gasoline in the fuel tank below it. This cause the gasoline to be drawn up to that area to mix with the air.

Answer page

1. liquids, gases
2. energy (or force or power or pressure)
3. force
4. P = F/A or pressure equals force divided by area
5. 5 psi
6. pressure
7. directions
8. rest
9. larger
10. smaller, or less
11. same
12. greater
13. smaller
14. lower, or less