Hydraulic Pressure

Unit: Fluids & Pressure

MA Curriculum Frameworks (2016): HS-PS2-10(MA), HS-PS2-1

AP® Physics 2 Learning Objectives: 3.4.C.1, 3.4.C.2

Mastery Objective(s): (Students will be able to…)

- Calculate the force applied by a piston given the force on another piston and areas of both in a hydraulic system.

Success Criteria:

- Pressures are calculated correctly and have correct units.

Language Objectives:

- Understand and correctly use the term "hydraulic pressure."
- Accurately describe and apply the concepts described in this section using appropriate academic language.
- Set up and solve word problems relating to hydraulic pressure.

Tier 2 Vocabulary: fluid, pressure

Labs, Activities & Demonstrations:

- Syringe (squirter)
- Hovercraft

Notes:

Pascal's Principle, which was discovered by the French mathematician Blaise Pascal, states that any pressure applied to a fluid is transmitted uniformly throughout the fluid.

Because $P = \frac{F}{A}$, if the pressure is the same everywhere in the fluid, then $\frac{F}{A}$ must be the same everywhere in the fluid.

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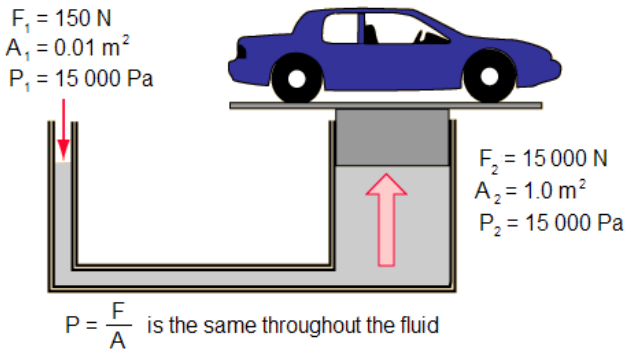
If you have two pistons whose cylinders are connected, the pressure is the same throughout the fluid, which means the force on each piston is proportional to its own area. Thus:

$$P_1 = P_2 \quad \text{which means} \quad \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

This principle is called "hydraulics." If you have a lift that has two pistons, one that is 100 times larger than the other, the larger one can supply 100 times as much force.



This seems like we're getting something for nothing—we're lifting a car by applying only 150 N of force (approximately 35 lbs.). However, conservation of energy tells us that the work done by F_1 must equal the work done by F_2, which means F_1 must act over a considerably larger distance than F_2. In order to lift the car on the right 10 cm (about 4 in.), you would have to press the plunger on the left 10 m.

You could also figure this out by realizing that the volume of fluid transferred on both sides must be the same and multiplying the area by the distance.

This is how hydraulic brakes work in cars. When you step on the brake pedal, the hydraulic pressure is transmitted to the master cylinder and then to the slave cylinders. The master cylinder is much smaller in diameter than the slave cylinders, which means the force applied to the brake pads is considerably greater than the force from your foot.

Sample Problem

Q: In a hydraulic system, a force of 25 N will be applied to a piston with an area of 0.50 m^2. If the force needs to lift a weight of 500. N, what must be the area of the piston supporting the 500. N weight?

A: $\frac{F_1}{A_1} = \frac{F_2}{A_2}$ $\quad \frac{25}{0.50} = \frac{500}{A_2}$

$$25\,A_2 = (500)(0.50)$$
$$25\,A_2 = 250$$
$$A_2 = 10\,\text{m}^2$$

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Homework Problems

1. **(M)** A student who weighs 700. N stands on a hydraulic lift. The lift has a lever, which you push down in order to lift the student. The cross-sectional area of the piston pressing on the fluid under the student is 1 m^2, and the cross-sectional area of the piston pressing on the fluid under the lever is 0.1 m^2. How much force is needed to lift the student?

   Answer: 70 N

2. **(M)** A hovercraft is made from a circle of plywood and a wet/dry vacuum cleaner. The vacuum cleaner motor blows air with a force of 10 N through a hose that has a radius of 1.5 cm (0.015 m). The base of the hovercraft has a radius of 0.6 m. How much weight (in newtons) can the hovercraft lift?

   Answer: 16 000 N (which is approximately 3 600 lbs.)

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