**Pascal's Principle**

After you study each sample problem and solution, work out the practice problems on a separate sheet of paper. Write your answers in the spaces provided.

**Problem**

A dentist's chair makes use of Pascal's principle to move patients up and down. Together, the chair and a patient exert a downward force of 2269 N. The chair is attached to a large piston with an area of 1221 cm$^2$. To move the chair, a pump applies force to a small piston with an area of 88.12 cm$^2$. What force must be exerted on the small piston to lift the chair?

**Solution**

Step 1: List the given and unknown values.

Given: 

- $F_2 = 2269$ N
- $A_1 = 88.12$ cm$^2$
- $A_2 = 1221$ cm$^2$

Unknown: 

- $F_1$

Step 2: Write the equations for Pascal's principle and pressure, force, and area.

\[ p_1 = p_2 \]

\[ \text{pressure} = \frac{\text{force}}{\text{area}} \]

Step 3: Substitute force and area into the first equation, and rearrange for the desired value.

\[ \frac{F_1}{A_1} = \frac{F_2}{A_2} \]

\[ F_1 = \frac{(F_2)(A_1)}{A_2} \]

Step 4: Insert the known values into the equation, and solve.

\[ F_1 = \frac{(2269 \text{ N})(88.12 \text{ cm}^2)}{1221 \text{ cm}^2} \]

\[ F_1 = 163.8 \text{ N} \]
Math Skills continued

Practice

1. A hydraulic lift office chair has its seat attached to a piston with an area of 11.2 cm$^2$. The chair is raised by exerting force on another piston, with an area of 4.12 cm$^2$. If a person sitting on the chair exerts a downward force of 219 N, what force needs to be exerted on the small piston to lift the seat?

2. In changing a tire, a hydraulic jack lifts 7468 N on its large piston, which has an area of 28.27 cm$^2$. How much force must be exerted on the small piston if it has an area of 1.325 cm$^2$?

3. An engine shop uses a lift to raise a 1784 N engine. The lift has a large piston with an area of 76.32 cm$^2$. To raise the lift, force is exerted on a small piston with an area of 12.56 cm$^2$. What force must be exerted to raise the lift?

Problem

An engineering student wants to build her own hydraulic pump to lift a 1815 N crate. The pump will have two pistons connected via a fluid chamber. The student calculates that she will be able to exert 442 N of force on the small piston, which will have an area of 50.2 cm$^2$. What area must the large piston be to exert the desired force?

Solution

Step 1: List the given and unknown values.

<table>
<thead>
<tr>
<th>Given</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_1$</td>
<td>442 N</td>
</tr>
<tr>
<td>$A_1$</td>
<td>50.2 cm$^2$</td>
</tr>
<tr>
<td>$F_2$</td>
<td>1815 N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_2$</td>
</tr>
</tbody>
</table>

Step 2: Write the equations for Pascal’s principle and pressure, force, and area.

$p_1 = p_2$

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

Step 3: Substitute force and area into the first equation, and rearrange for the desired value.

$p_1 = p_2$

$F_1 = F_2$

$A_1 = A_2$

$A_2 = \frac{F_2(A_1)}{F_1}$
Math Skills continued

Step 4: Insert the known values into the equation, and solve.

\[ A_2 = \frac{(1815 \text{ N})(50.2 \text{ cm}^2)}{442 \text{ N}} \]

\[ A_2 = 206 \text{ cm}^2 \]

Practice

4. In a newly designed car with a hydraulic braking system, a force of 85 N is applied to one of the master cylinders, which has an area of 8.1 cm². The master cylinder is connected to one brake piston, which exerts a force of 296 N. What is the area of the brake piston?

5. A mechanic uses a hydraulic car jack to lift the front end of a car to change the oil. The jack she uses exerts 8915 N of force from the larger piston. To pump the jack, she exerts 444 N of force on the small piston, which has an area of 3.14 cm². What is the area of the large piston?

6. A student in the lunchroom blows into his straw with a force of 0.26 N. The column of air pushing the liquid in the glass has an area of 0.21 cm². If the liquid in the glass pushes upward with a force of 79 N, what is the area of the liquid at the surface of the glass?

Problem

The motor on a construction grade hydraulic shovel exerts \(3.11 \times 10^7\) Pa of pressure on a fluid tank. The fluid tank is connected to a piston that has an area of 153 cm². How much force does the piston exert?

Solution

Step 1: List the given and unknown values.

Given: \(p_1 = 3.11 \times 10^7\) Pa

\(A_2 = 153 \text{ cm}^2\)

Unknown: \(F_2\)

Step 2: Write the equations for Pascal's principle and pressure, force, and area.

\[ p_1 = p_2 \]

\[ \text{pressure} = \frac{\text{force}}{\text{area}} \]
Step 3: Substitute force and area into the first equation, and rearrange for the desired value.

\[ P_1 = \frac{p_2}{F_2} \]
\[ p_1 = \frac{F_2}{A_2} \]
\[ F_2 = (p_1)(A_2) \]

Step 4: Insert the known values into the equation, and solve.

\[ F_2 = (3.11 \times 10^7 \text{ Pa})(153 \text{ cm}^2) \]
\[ F_2 = \left(\frac{3.11 \times 10^7 \text{ N}}{\text{m}^2}\right)(1.53 \times 10^{-2} \text{ m}^2) \]
\[ F_2 = 4.76 \times 10^5 \text{ N} \]

Practice

7. A small crane has a motor that exerts $2.41 \times 10^7 \text{ Pa}$ of pressure on a fluid chamber. The chamber is connected by a fluid line to a piston on the crane arm. If the piston has an area of 168 cm², how much force does the piston exert?

8. A bicycle pump uses Pascal's law to operate. The air in the hose acts as a fluid and transfers force and pressure from the piston to the tire. If a pump has a piston with an area of 7.1 cm², how much force must be exerted on it to create a pressure of $8.2 \times 10^5 \text{ Pa}$?

9. A small, backyard log splitter has an engine that applies $1.723 \times 10^7 \text{ Pa}$ of pressure to a fluid tank. The tank is connected to piston with an area of 81.07 cm². How much force can the piston exert?

Mixed Practice

10. A force of 38.7 N is applied to the master cylinder of a hydraulic brake system. The cylinder has an area of 7.61 cm². The force from the master cylinder is transferred, by brake fluid, to two brake cylinders that have a total area of 49.1 cm². How much total force is exerted by the brake cylinders?

11. A factory lift is used to raise a load of 2225 N on a piston that has an area of 706.8 cm². How much pressure does the lift's engine need to exert on the hydraulic fluid to lift the required load?