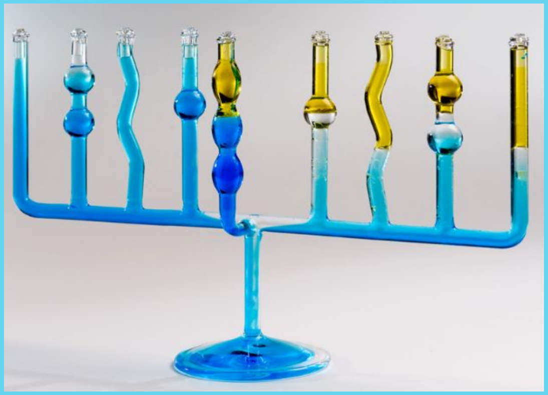
Hydrostatic Pressure

Communicating Vessels

Pascal's Principle

Hydraulic Press



LEARNING OBJECTIVES:

1. Describe hydrostatic pressure and recall, rearrange and use the equation

$p = \rho g h$;

2. Compare the effects of applying a force to a compressible fluid and an incompressible fluid;

3. Describe Pascal's law and apply it to connecting vessels and hydraulic presses.

DENSITY

The mass density of a substance is the mass of a substance divided by its volume:

$$\rho = \frac{m}{V}$$

SI Unit of Density: g/cm^3 or kg/m^3

Table 11.1 Mass Densities[a] of Common Substances

Substance	Mass Density ρ (kg/m^3)
Solids	
Aluminum	2700
Brass	8470
Concrete	2200
Copper	8890
Diamond	3520
Gold	19 300
Ice	917
Iron (steel)	7860
Lead	11 300
Quartz	2660
Silver	10 500
Wood (yellow pine)	550
Liquids	
Blood (whole, 37 °C)	1060
Ethyl alcohol	806
Mercury	13 600
Oil (hydraulic)	800
Water (4 °C)	1.000×10^3
Gases	
Air	1.29
Carbon dioxide	1.98
Helium	0.179
Hydrogen	0.0899
Nitrogen	1.25
Oxygen	1.43

[a] Unless otherwise noted, densities are given at 0 °C and 1 atm pressure.

Example - Blood as a Fraction of Body Weight

The body of a man whose weight is 690 N contains about 5.2x10^{-3} m^3 of blood.

(a) Find the blood's weight and (b) express it as a percentage of the body weight.

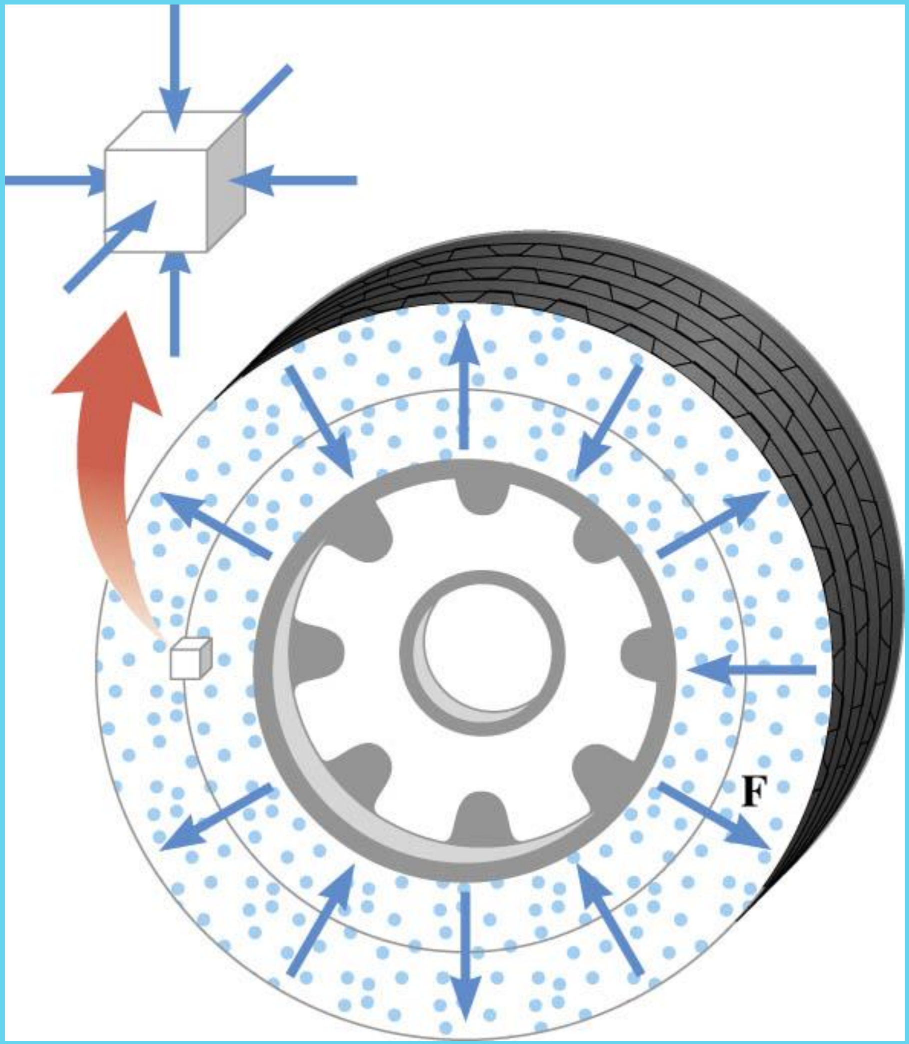
$$m = V\rho = \left(5.2\times10^{-3}\,\mathrm{m}^3\right)\left(1060\,\mathrm{kg/m}^3\right) = 5.5\,\mathrm{kg}$$

(a)

$$W = mg = (5.5\ \mathrm{kg})(9.80\ \mathrm{m/s^2}) = 54\ \mathrm{N}$$

(b)

$$\text{Percentage} = \frac{54\ \mathrm{N}}{690\ \mathrm{N}} \times 100\% = 7.8\%$$



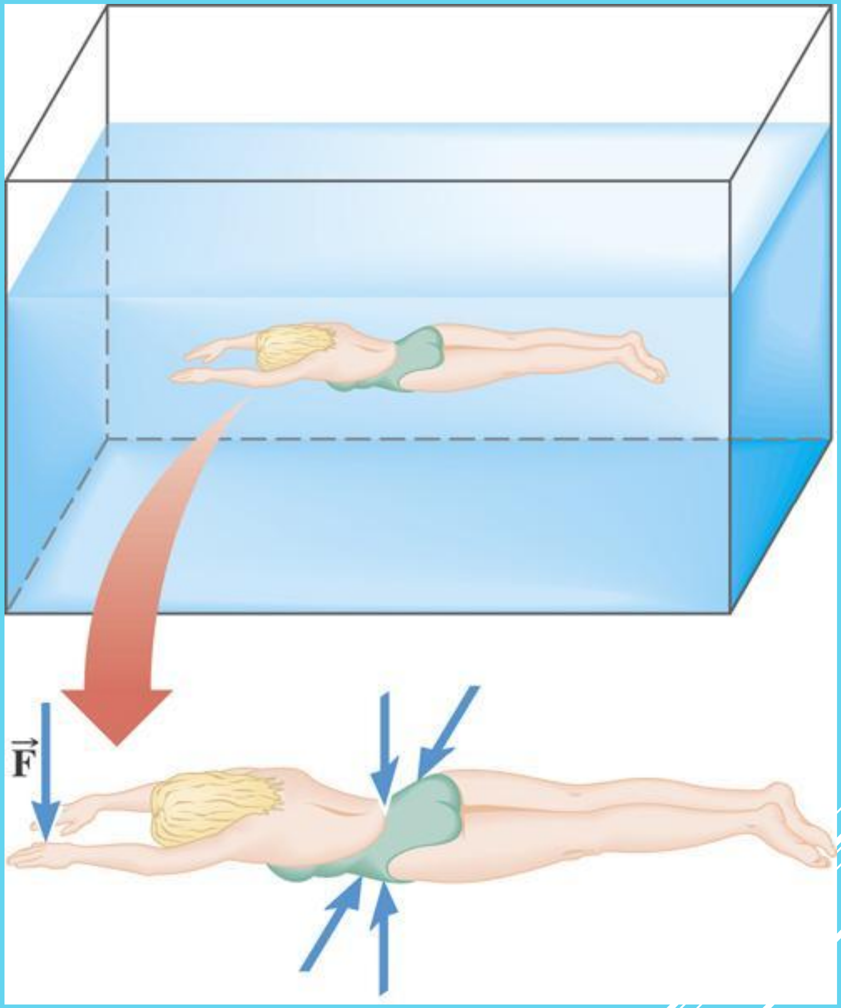
$$P = \frac{F}{A}$$

SI Unit of Pressure:

$1\ N/m^2 = 1\ Pa$

Pascal

Example: The Force on a Swimmer



Suppose the pressure acting on the back of a swimmer's hand is 1.2×10^5 Pa. The surface area of the back of the hand is $8.4 \times 10^{-3} m^2$.

(a) Determine the magnitude of the force that acts on it.

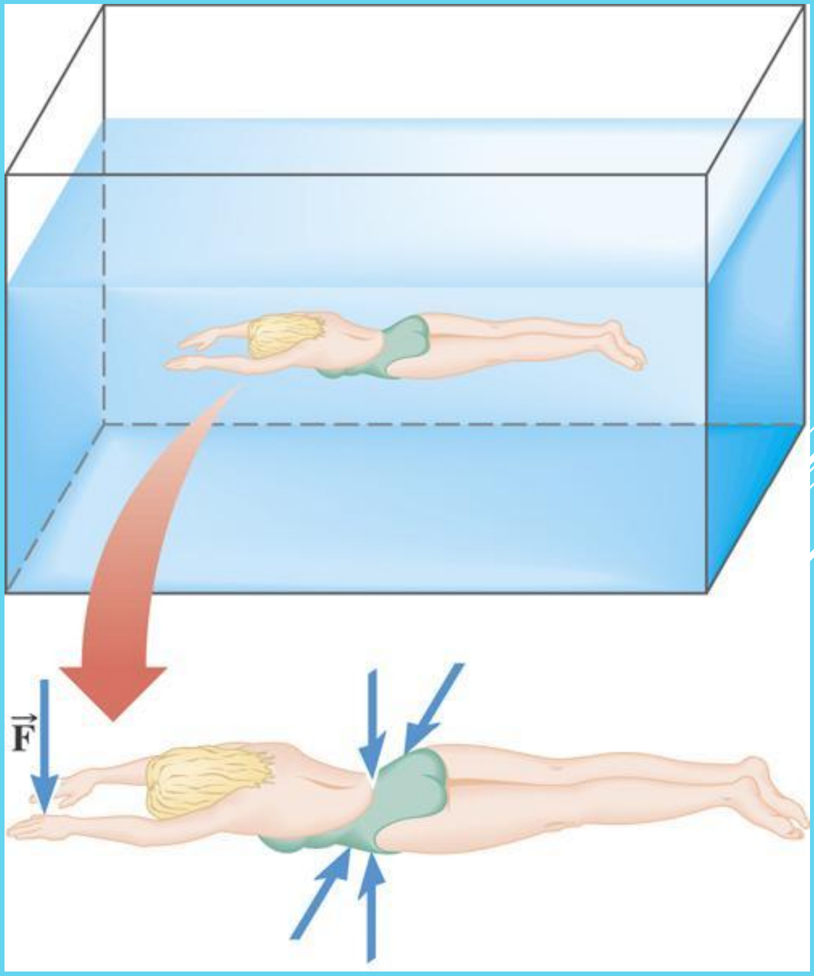
(b) Discuss the direction of the force.

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

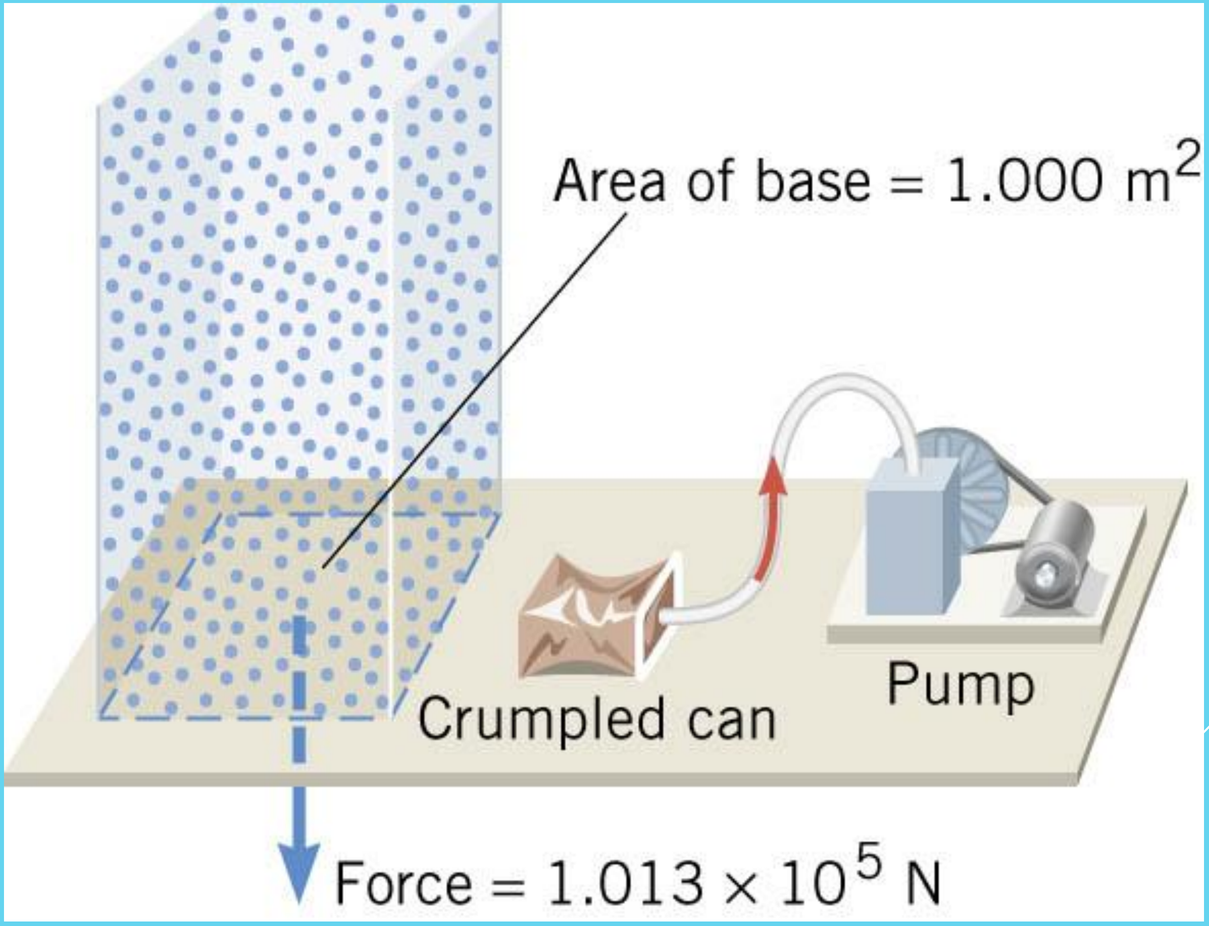
$$F = PA = \left(1.2\times10^{5}\ \mathrm{N/m^{2}}\right)\left(8.4\times10^{-3}\,\mathrm{m^{2}}\right)$$

$$= 1.0\times10^{3}\ \mathrm{N}$$

Since the water pushes perpendicularly against the back of the hand, the force is directed downward in the drawing.



Atmospheric Pressure at Sea Level:
1.013×10^5 Pa = 1 atmosphere



Why do tetra packs crush or squeeze itself when you sip too much air inside?

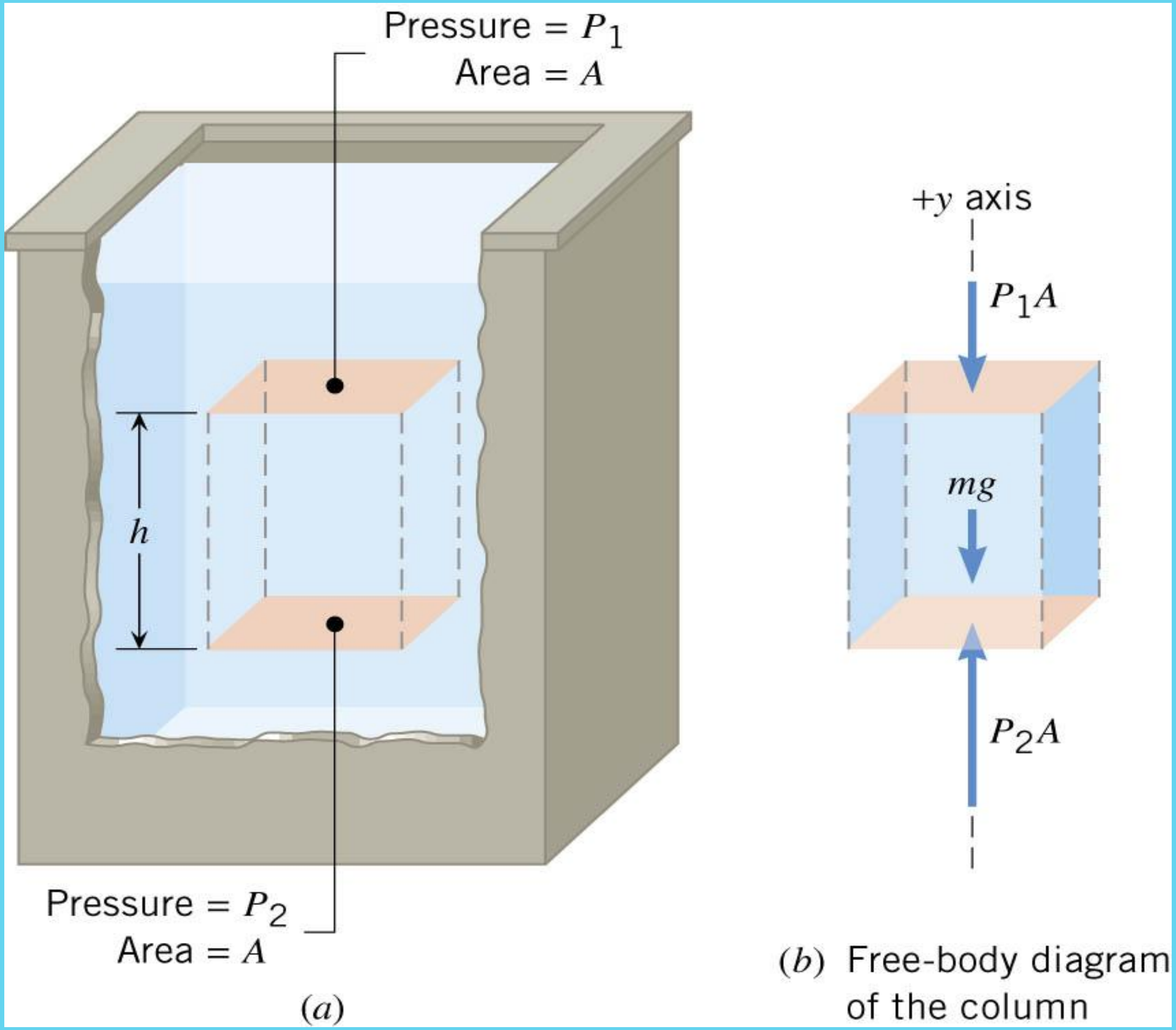
Hydrostatic Pressure

PRESSURE AND DEPTH IN A STATIC FLUID

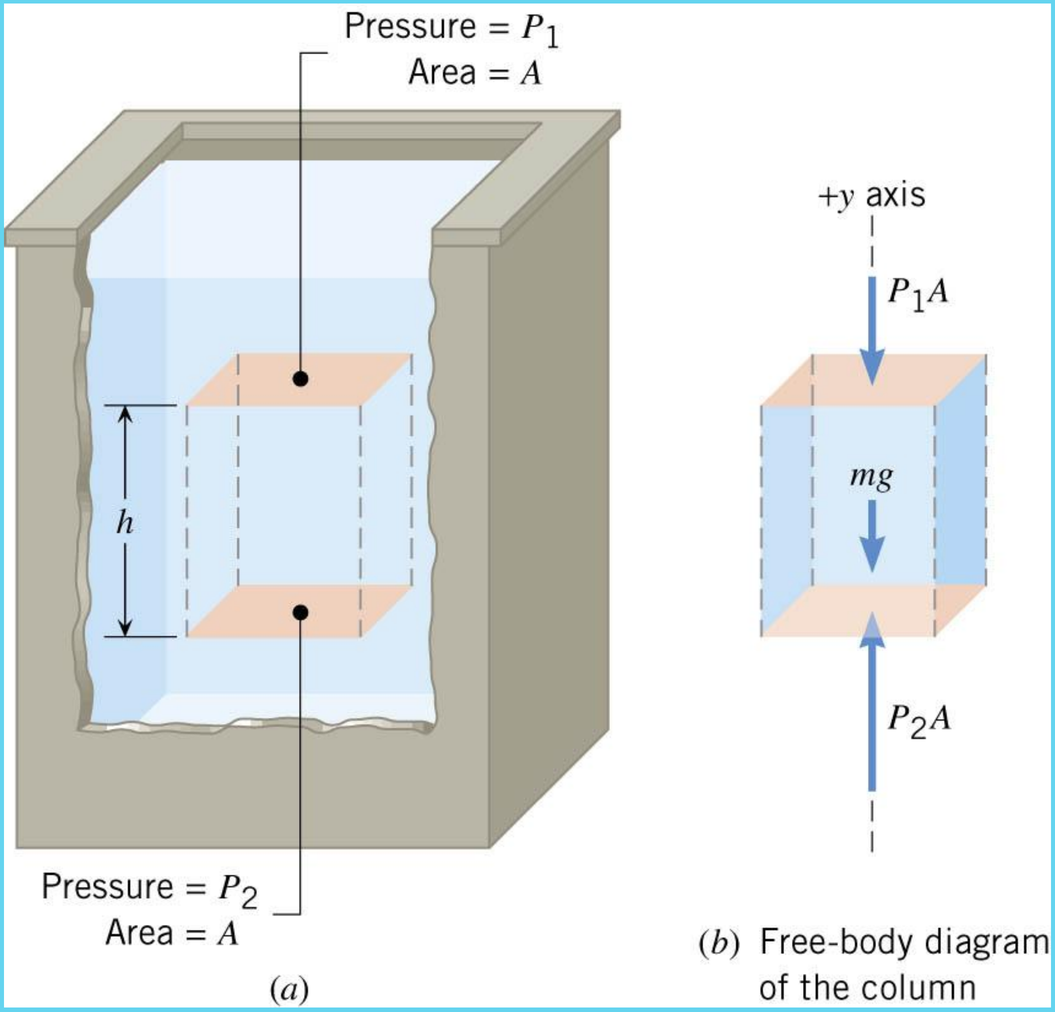
$$\sum F_y = P_2 A - P_1 A - mg = 0$$

$$P_2 A = P_1 A + mg$$

$$m = V\rho$$



Hydrostatic Pressure



$$V = Ah$$

$$P_2 A = P_1 A + \rho V g$$

$$P_2 A = P_1 A + \rho A h g$$

$$P_2 = P_1 + \rho h g$$

Hydrostatic Pressure

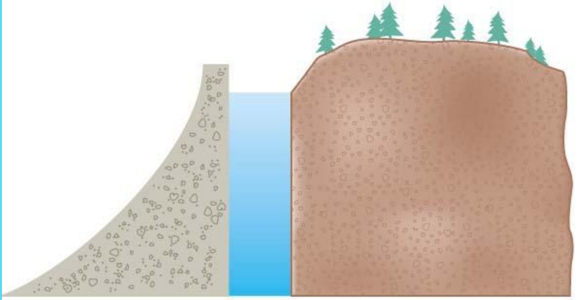
Conceptual Example - The Hoover Dam

Lake Mead is the largest wholly artificial reservoir in the United States. The water in the reservoir backs up behind the dam for a considerable distance (120 miles).

Suppose that all the water in Lake Mead were removed except a relatively narrow vertical column.

Would the Hoover Same still be needed to contain the water, or could a much less massive structure do the job?

(*a*)



(*b*)

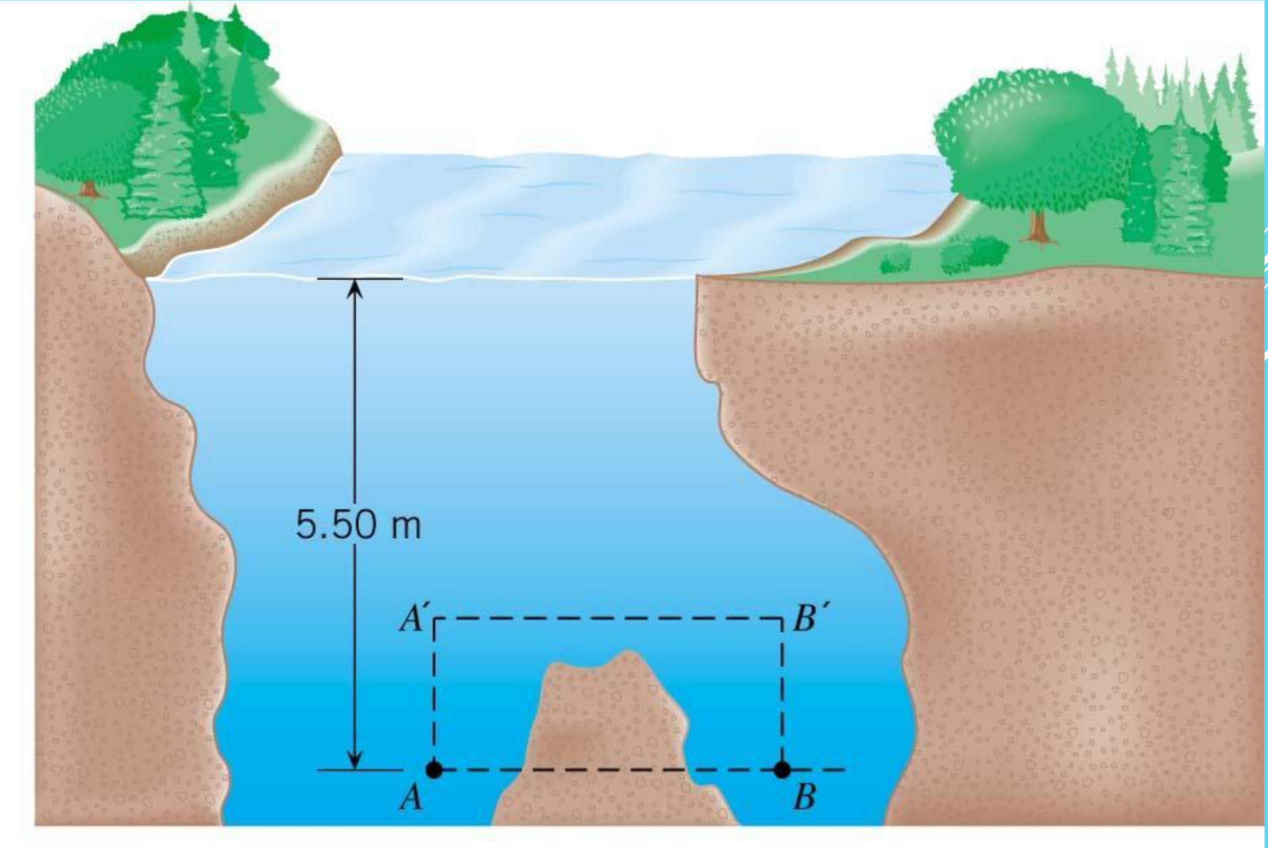
Answer:

The force exerted on a given section of the dam depends only on how far that section is located vertically below the surface. As we go deeper, the water pressure and force becomes greater. The force that water applies on the dam does not depend on the amount of water backed up behind the dam. Thus, an EQUALLY MASSIVE HOOVER DAM WOULD STILL BE NEEDED.

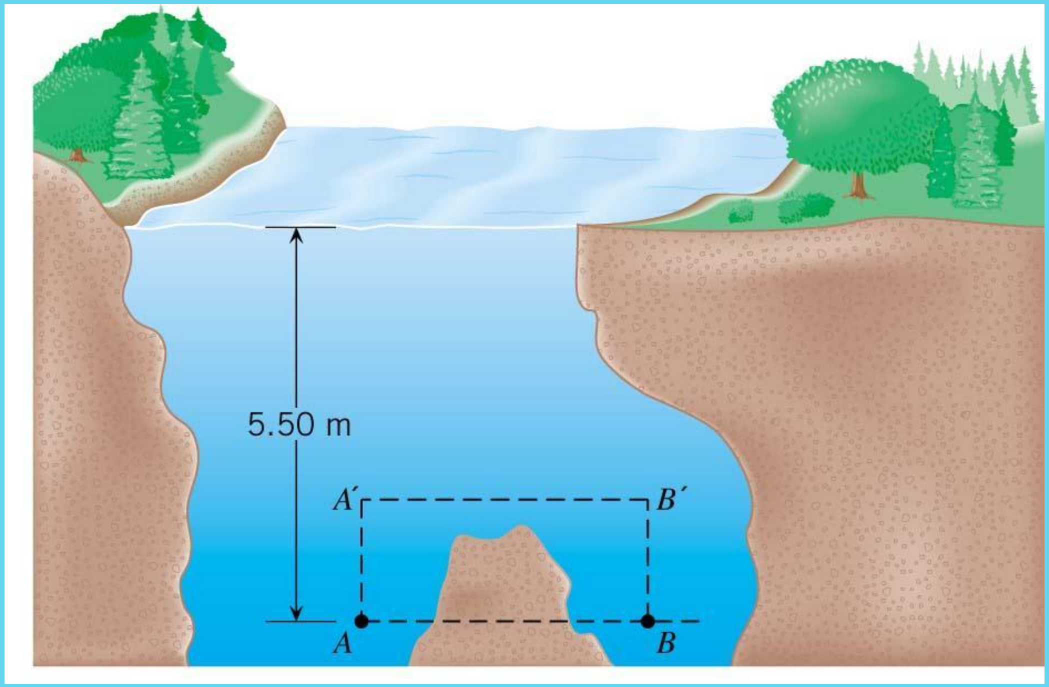
Hydrostatic Pressure

Example - The Swimming Hole

Points A and B are located a distance of 5.50 m beneath the surface of the water. Find the pressure at each of these two locations.



Hydrostatic Pressure



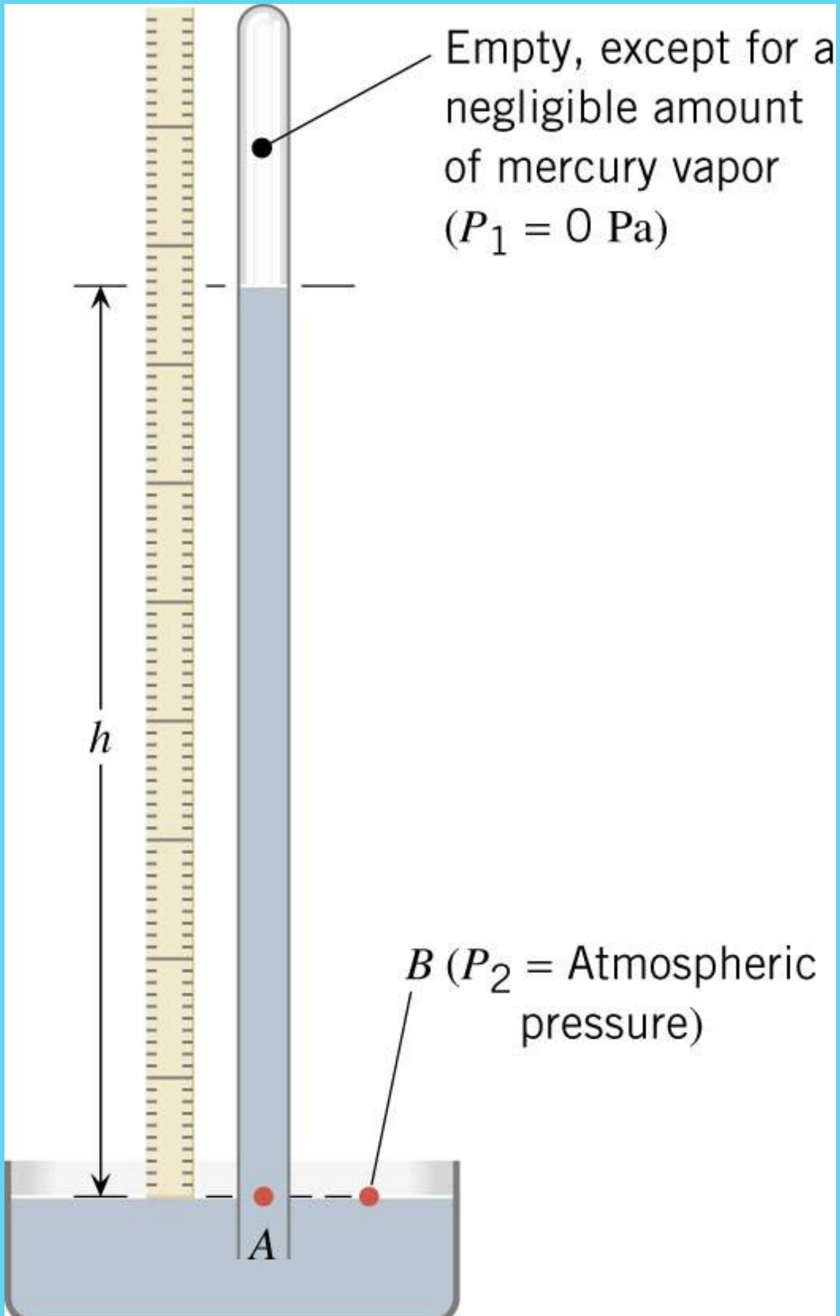
$$P_2 = P_1 + \rho g h$$

$$P_2 = \underbrace{\left(1.01\times10^5\ \text{Pa}\right)}_{\text{atmospheric pressure}} + \left(1.00\times10^3\ \text{kg/m}^3\right)\left(9.80\ \text{m/s}^2\right)\left(5.50\ \text{m}\right)$$

$$= 1.55\times10^5\ \text{Pa}$$

Pressure Gauges

PRESSURE GAUGES



$$P_2 = P_1 + \rho gh$$

$$P_{atm} = \rho gh$$

$$h = \frac{P_{atm}}{\rho g} = \frac{(1.01\times10^5 \text{ Pa})}{(13.6\times10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)}$$

$$= 0.760 \text{ m} = 760 \text{ mm}$$

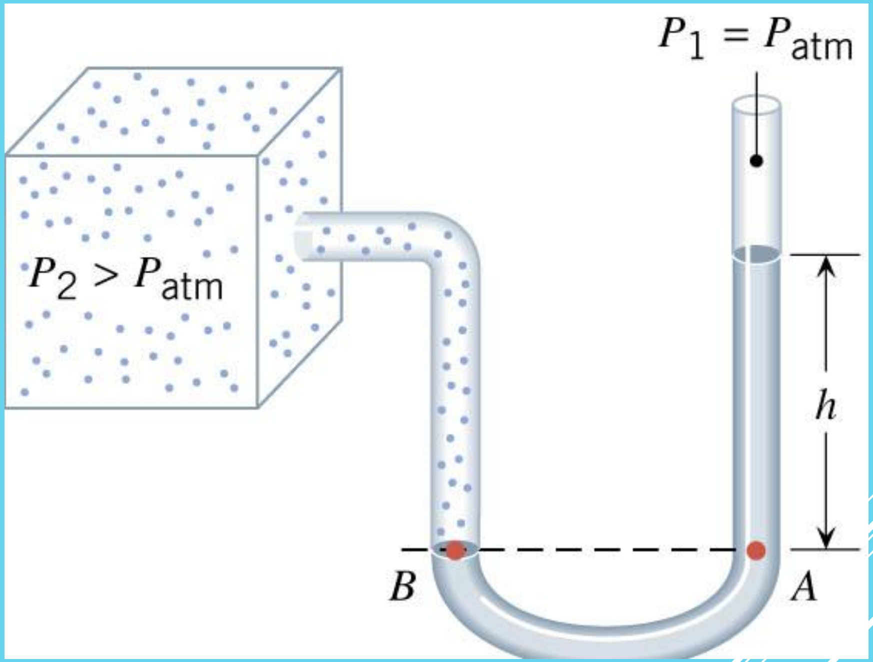
$$P_2 = P_B = P_A$$

$$P_A = P_1 + \rho g h$$

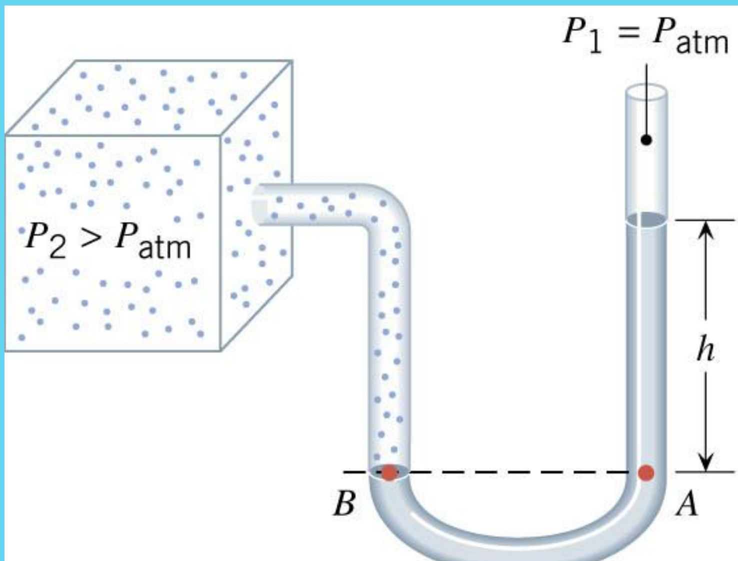
absolute pressure

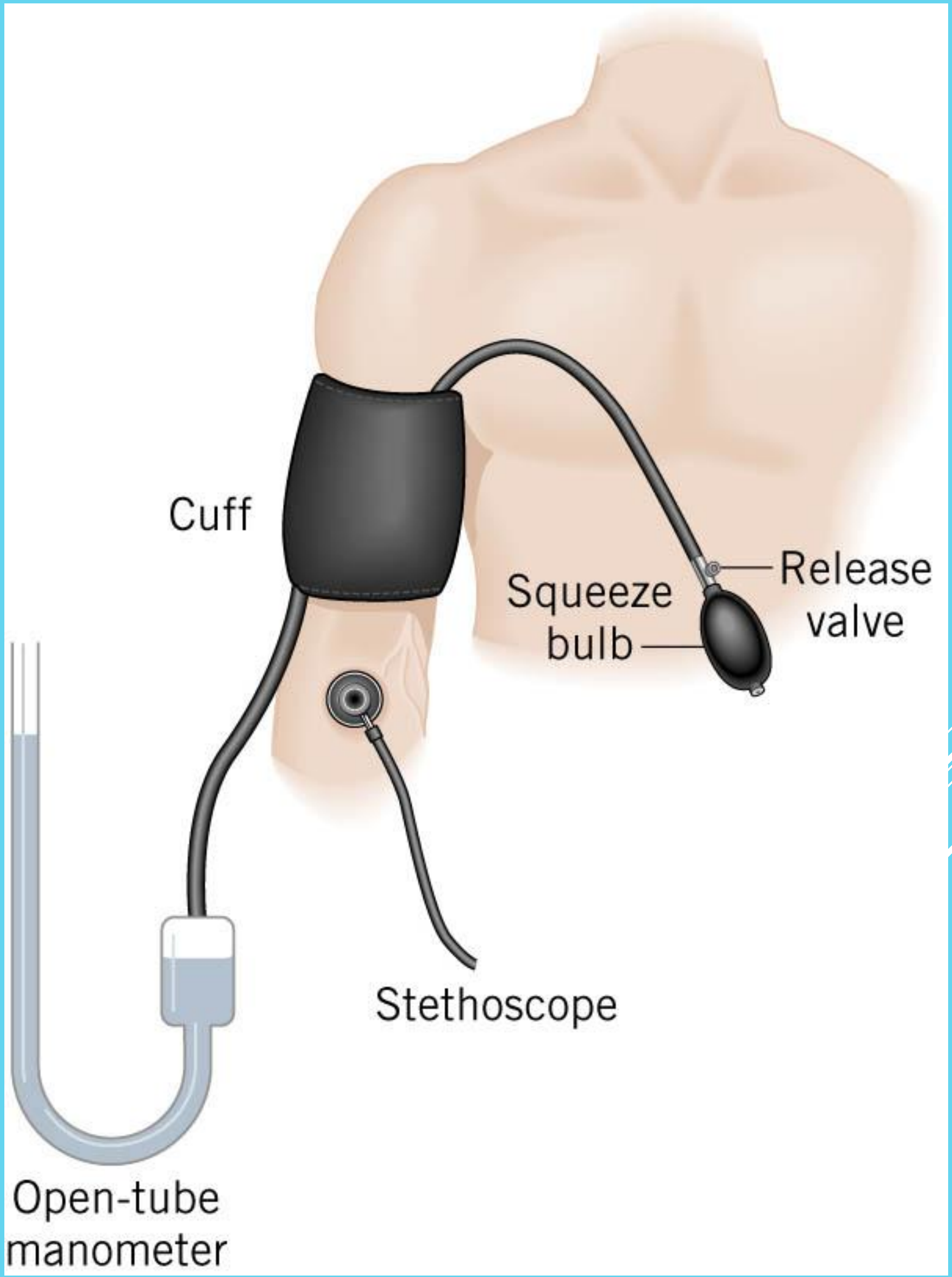
$$P_2 - P_{atm} = \rho g h$$

gauge pressure



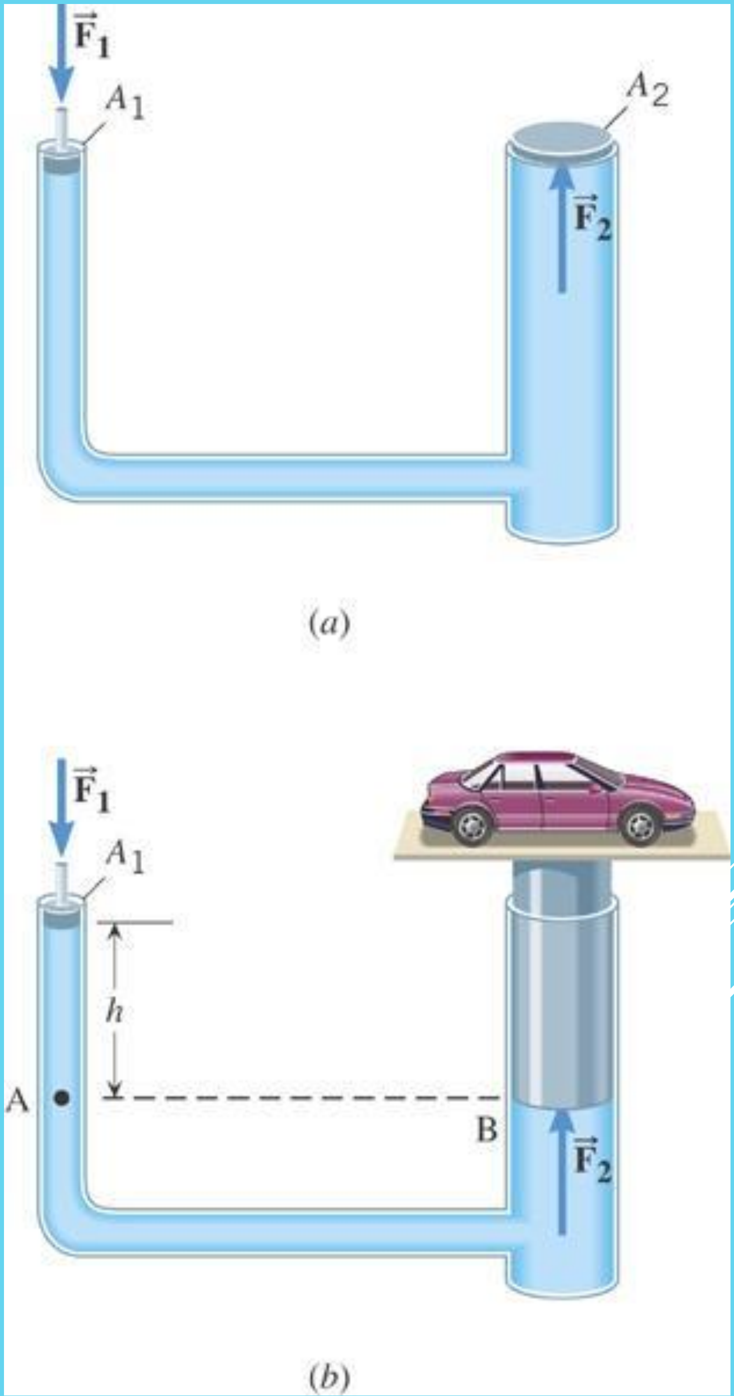
PRESSURE GAUGES



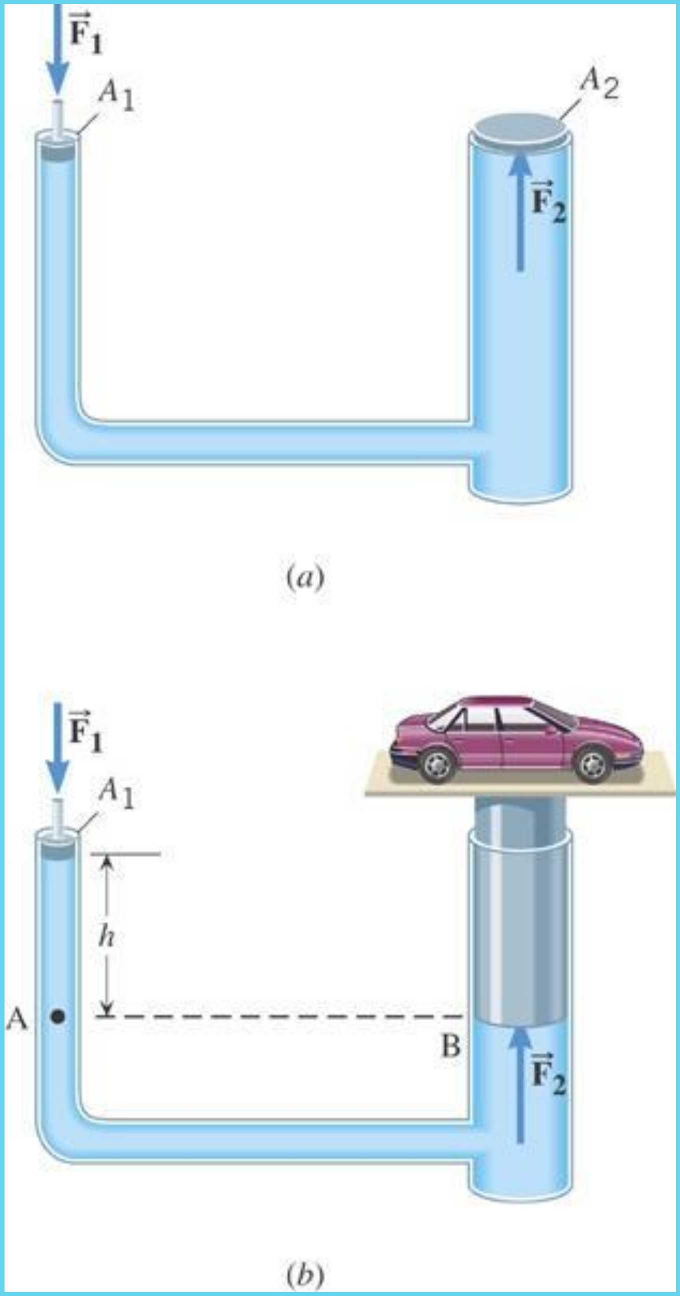


PASCAL'S PRINCIPLE

Any change in the pressure applied to a completely enclosed fluid is transmitted undiminished to all parts of the fluid and enclosing walls.



PASCAL'S PRINCIPLE



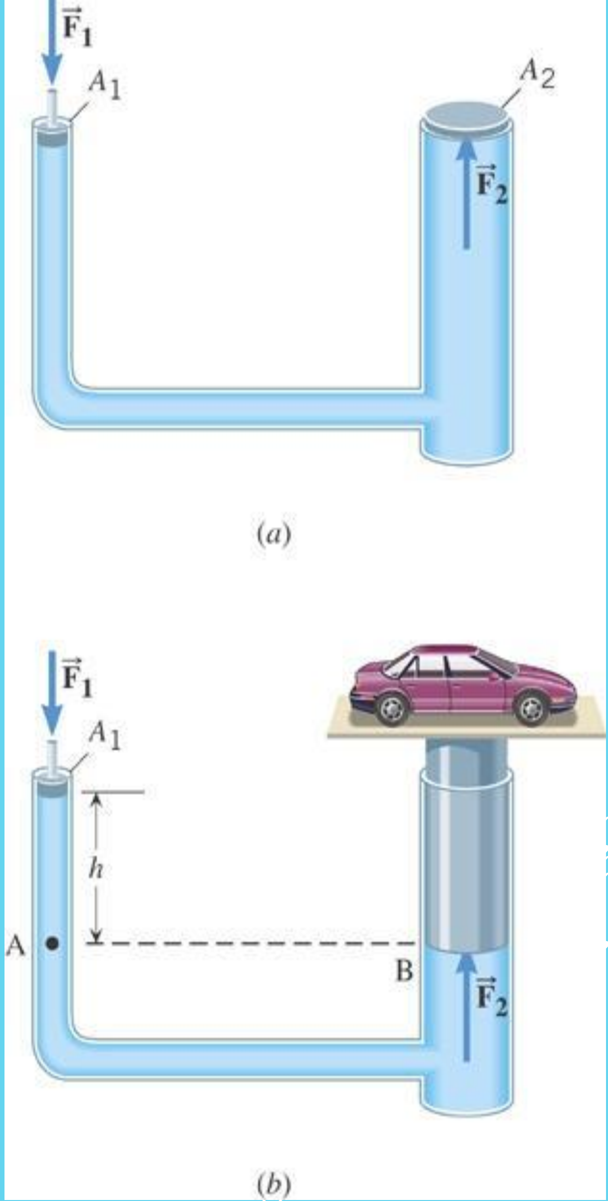
$$P_2 = P_1 + \rho g (0\,\mathrm{m})$$

$$\frac{F_2}{A_2} = \frac{F_1}{A_1}$$

$$F_2 = F_1 \left(\frac{A_2}{A_1} \right)$$

PASCAL'S PRINCIPLE

Example - A Car Lift

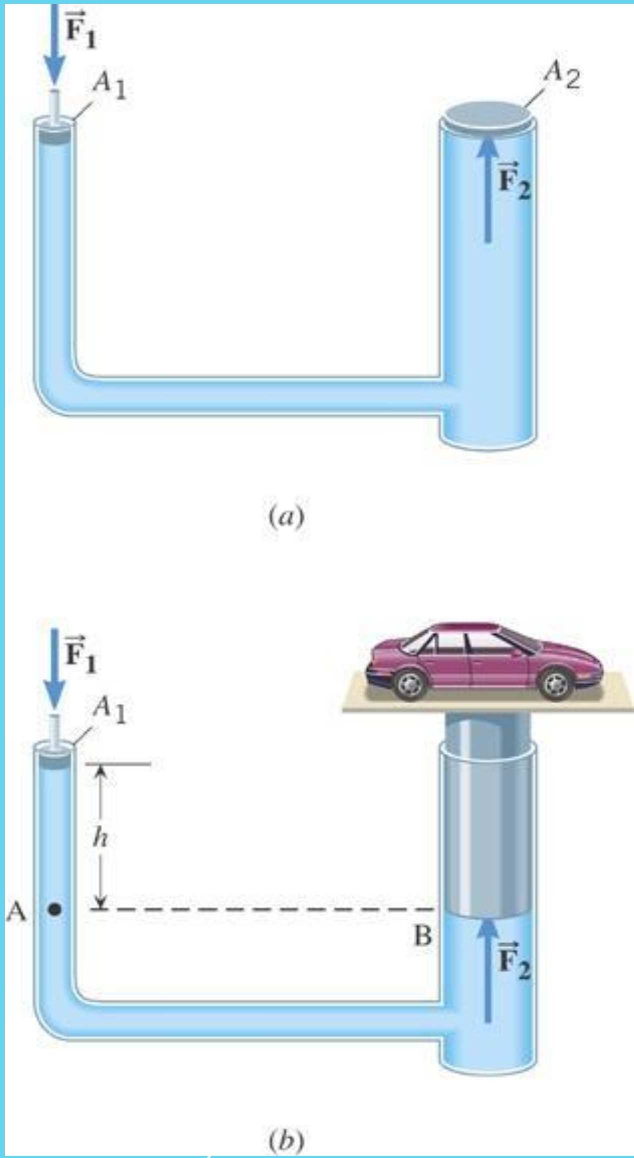


The input piston has a radius of 0.0120 m and the output plunger has a radius of 0.150 m. The combined weight of the car and the plunger is 20,500 N. Suppose that the input piston has a negligible weight and the bottom surfaces of the piston and plunger are at the same level. What is the required input force?

PASCAL'S PRINCIPLE

$$F_2 = F_1\left(\frac{A_2}{A_1}\right)$$

$$F_2 = (20500\ \text{N})\frac{\pi(0.0120\ \text{m})^2}{\pi(0.150\ \text{m})^2} = 131\ \text{N}$$



Communicating Vessel

set of containers containing a homogeneous fluid: when the liquid settles, it balances out to the same level in all of the containers regardless of the shape and volume of the containers. If additional liquid is added to one vessel, the liquid will again find a new equal level in all the connected vessels. This occurs because gravity and pressure are constant in each vessel (hydrostatic pressure).

Communicating Vessel

Containing homogeneous fluid: when the liquid settles, it balances out to the same level in all of the containers

regardless of the

the containers.

d pressure are