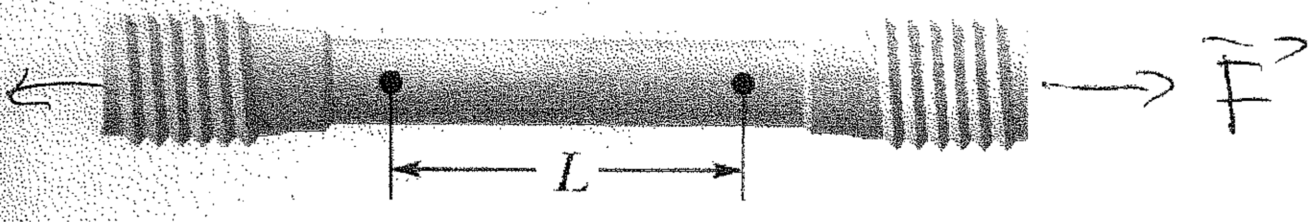
Lecture 33

(Ch10:3)



Stress → $\frac{\text{Force}}{\text{Area}}$ → $[N/m^2]$

Strain → $\frac{\Delta L}{L}$ $\frac{\cancel{[m]}}{\cancel{[m]}}$

$E\ [N/m^2]$

$$\frac{F}{A} = E\,\frac{\Delta L}{L}$$, E – Young's modulus

for tension and compression | $E = 200\times10^9\ N/m^2$ for steel; $= 13\times10^9\ N/m^2$ for wood

$$\frac{F}{A} = G\,\frac{\Delta x}{L}$$, G – shear modulus

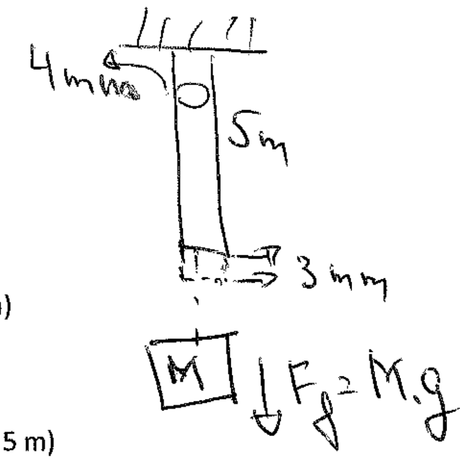
for shearing

$$\frac{F}{A} = P = -B\,\frac{\Delta V}{V}$$, B – bulk modulus

for hydraulic stress

$B = 2.2\times10^9\ N/m^2$ for H_2O

A steel rod, 5 m long, has a diameter of 4 mm. The wire stretches 3 mm when it bears a load. Young's modulus for steel is 2.0×10^{11} N/m^2. What is the mass of the load ?



$$F/A = Y.\Delta L/L$$

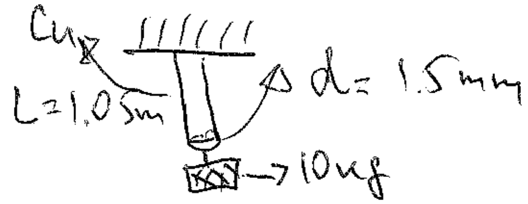
$$(M.g)/(\pi d^2/4) = (2.0 \times 10^{11}\ \text{N/m}^2) \times (3 \times 10^{-3}\ \text{m})/(5\ \text{m})$$

$$(M \times 9.82\ \text{m/s}^2)/[3.14 \times (4 \times 10^{-3}\ \text{m})^2/4] = (2.0 \times 10^{11}\ \text{N/m}^2) \times (3 \times 10^{-3}\ \text{m})/(5\ \text{m})$$

$$M = [3.14 \times (4 \times 10^{-3}\ \text{m})^2/4] \times (2.0 \times 10^{11}\ \text{N/m}^2)(3 \times 10^{-3}\ \text{m})/(9.82\ \text{m/s}^2 \times 5\ \text{m})$$

$$M = 153\ \text{kg}$$

$Y_{Cu} = 11 \times 10^{10}\ \frac{N}{m^2}$



$\Delta L = ?$

32. ORGANIZE AND PLAN The force causing the stretch is the gravitational force on the 10.0-kg mass. The stretch can be calculated from Equation 10.1 if we know the Young's modulus of copper. We can find the Young's modulus in Table 10.2.

Known: $L = 1.05$ m; $d = 1.50$ mm; $m = 10.0$ kg; $Y = 11 \times 10^{10}$ N/m^2.

SOLVE Calculate the stretch from Equation 10.1:

$$\frac{F}{A} = Y\frac{\Delta L}{L}$$

$$\Delta L = \frac{F}{AY}L = \frac{mg}{\frac{\pi}{4}d^2Y}L = \frac{(10.0\text{ kg})(9.80\text{ m/s}^2)}{\frac{\pi}{4}(1.50\text{ mm})^2(11\times10^{10}\text{ N/m}^2)}(1.05\text{ m}) = 5.29\times10^{-4}\text{ m}$$

$$A = \frac{\pi d^2}{4} = \pi R^2$$

One liter of fluid (1000 cm^3) in a flexible container is carried to the bottom of the sea, where the pressure is $2.6 \times 10^{+6}$ N/m^2 . What will be its volume there?

Let $B_{fluid} = 9.7 \times 10^9$

$$P = \frac{F}{A} = -B \frac{\Delta V}{V}$$

$$2.6 \times 10^6 \frac{N}{m^2} = -9.7 \times 10^9 \frac{\Delta V}{V}$$

$$\frac{2.6 \times 10^6 (1000 cm^3)}{9.7 \times 10^9} = \Delta V$$

$$=$$

$$2.6 \ cm^3 = \Delta V$$

$$V_f = V - \Delta V$$

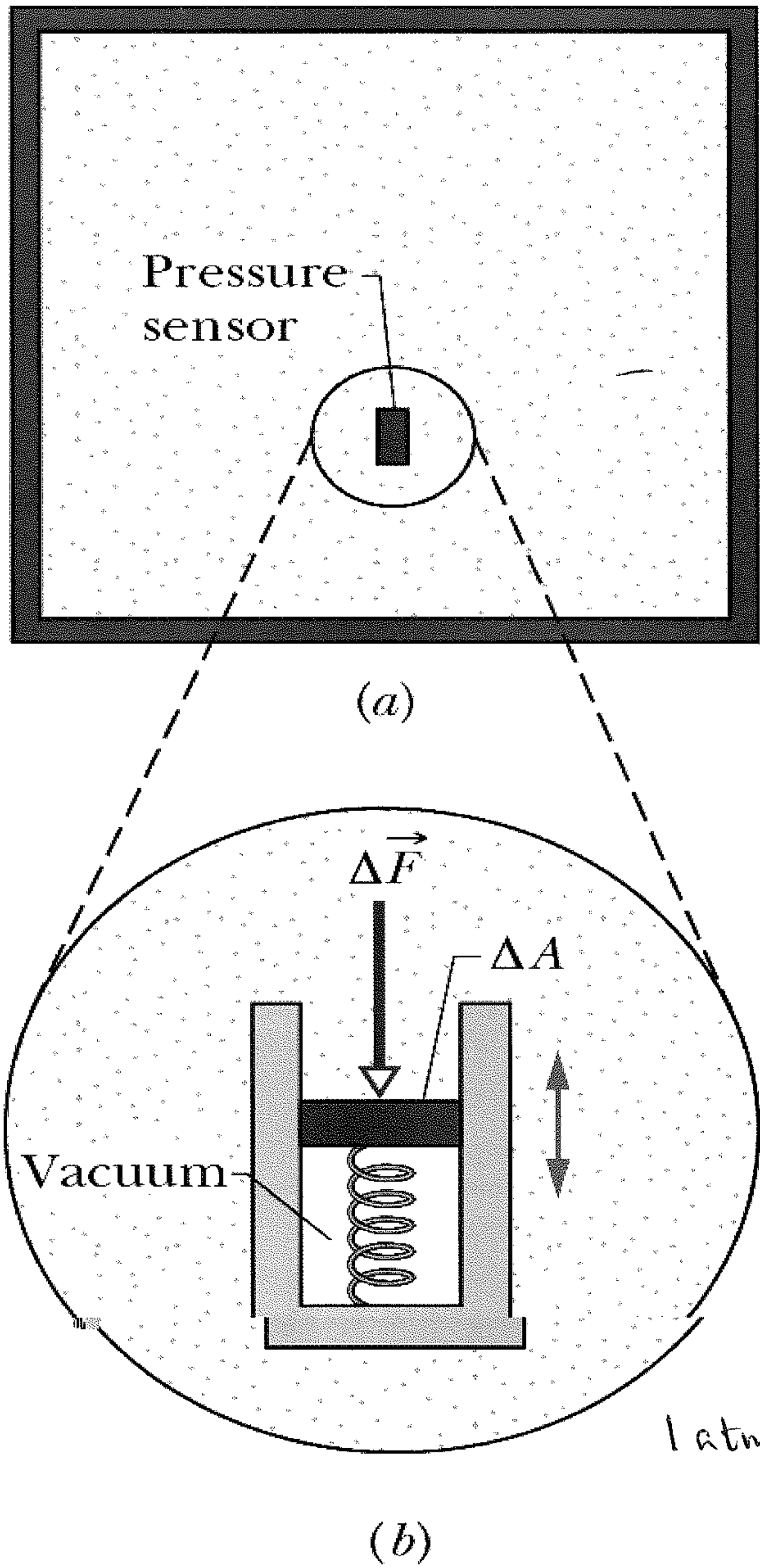
$$= 1000 \ cm^3 - 2.6 \ cm^3 \quad \sim 3 \ cm^3$$

$$\approx 997 \ cm^3$$

EXPERIENCE OF PRESSURE IN DAILY LIFE

SOME EXAMPLES

* DRIVE DOWN THE MOUNTAIN ROAD (AT EARDRUM)
* DIVE UNDER WATER
* INFLATE TYRES (e.g. CAR, BICYCLES)
* INFLATE RUBBER RAFTS
* INFLATE AIR MATTRESSES (e.g. AIR BED)
* OPEN PRESSURIZED CANS (PEPSI .....)
* COOKING WITH A PRESSURE COOKER
* SPRAYING (e.g PERFUMES, INSECTICIDES ...)
* METEREOLOGISTS REPORTING ATMOSPHERIC PRESSURE AND ITS IMPLICATION FOR WEATHER PREDICTION
* IN MEDICINE (e.g. MEASURING BLOOD PRESSURE)



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

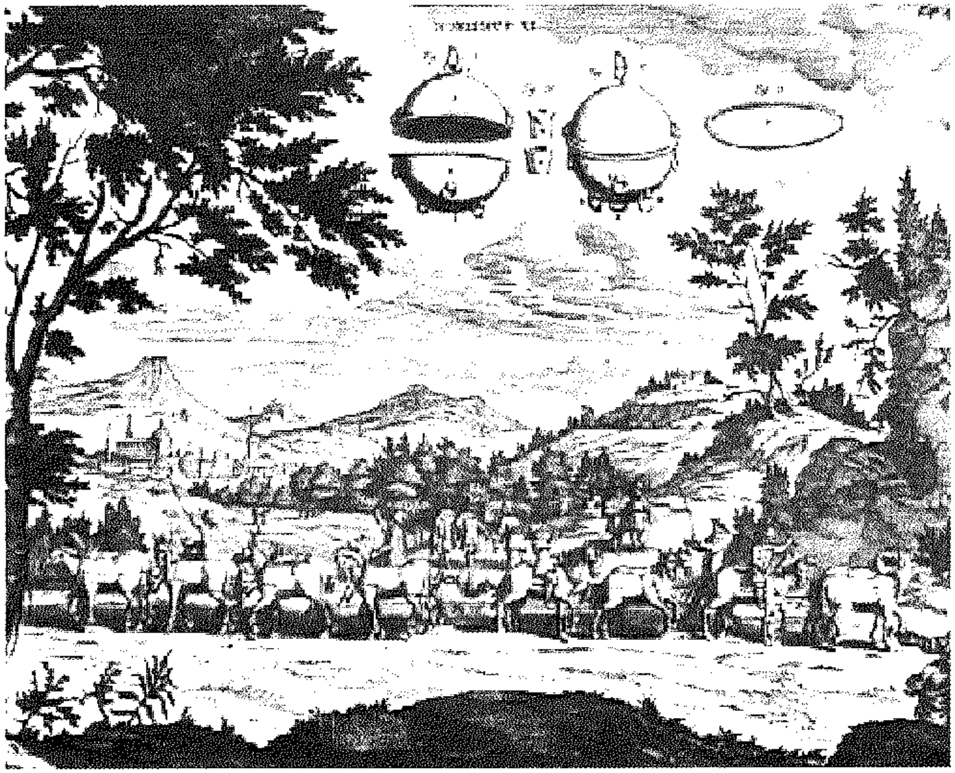
P - scalar

$[Pa] = \frac{1N}{m^2}$

$1\,atm = 1.01 \times 10^5\,Pa = 14.7\,lb/in^2$

$= 760\,torr$

$\frac{\text{Solids}}{\text{Force}} \longrightarrow$ Pressure / Fluids



The most renowned Otto von Guericke experiment, Magdeburg 1654

Some pressures	[Pa]
Center of the sun	2×10^{16}
Deepest ocean trench	1.1×10^{8}
Automobile tire	2×10^{5}
Atmosphere at sea level	1.0×10^{5}
Normal blood pressure	1.6×10^{4}
Best laboratory vacuum	10^{-12}

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

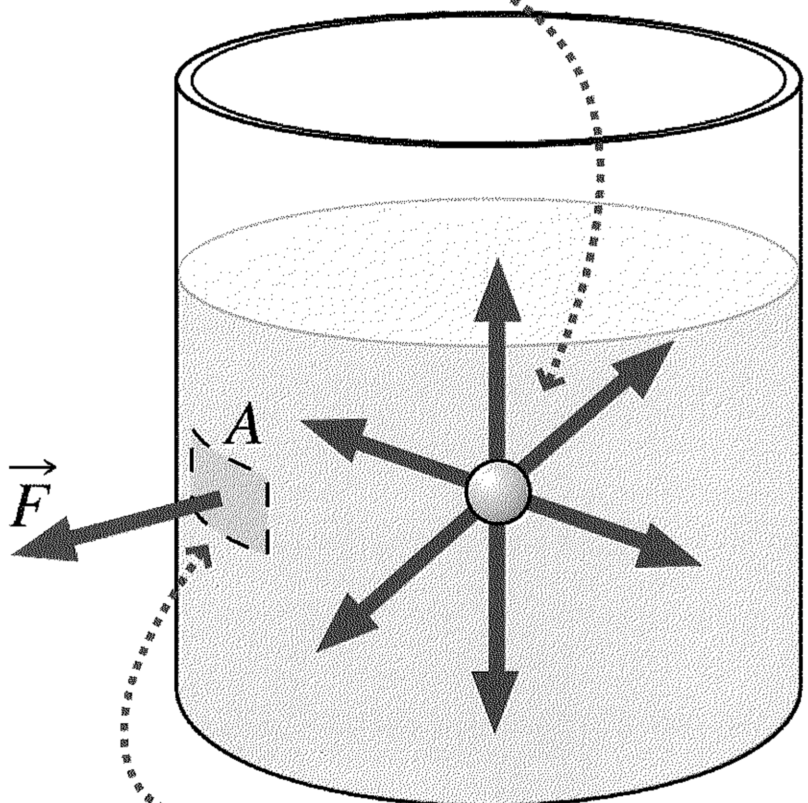
$$P = \Delta F/\Delta A \ [N/m^2]$$

$$1 \text{ atm} = 1.01 \times 10^5 \text{ Pa} = 760 \text{ torr} = 14.7 \text{ lb/in}^2$$

[psi]

Figure 10.4

The fluid exerts pressure internally as well as on the container. The internal pressure is the same in all directions.

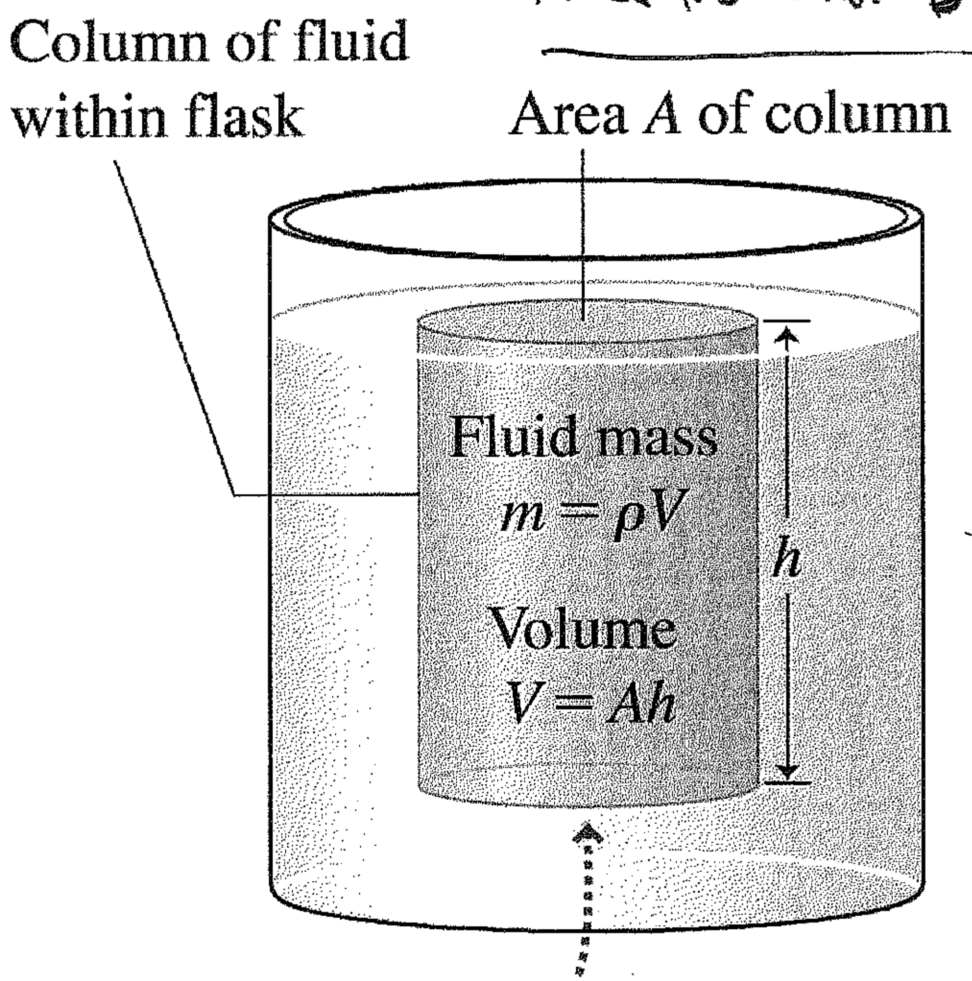


$\vec{F}$ is the force on the area A, so the pressure is $P = F/A$.

$P = \frac{F}{A} \left[\frac{N}{m^2}\right]$

Pressure and Dept

Figure 10.5



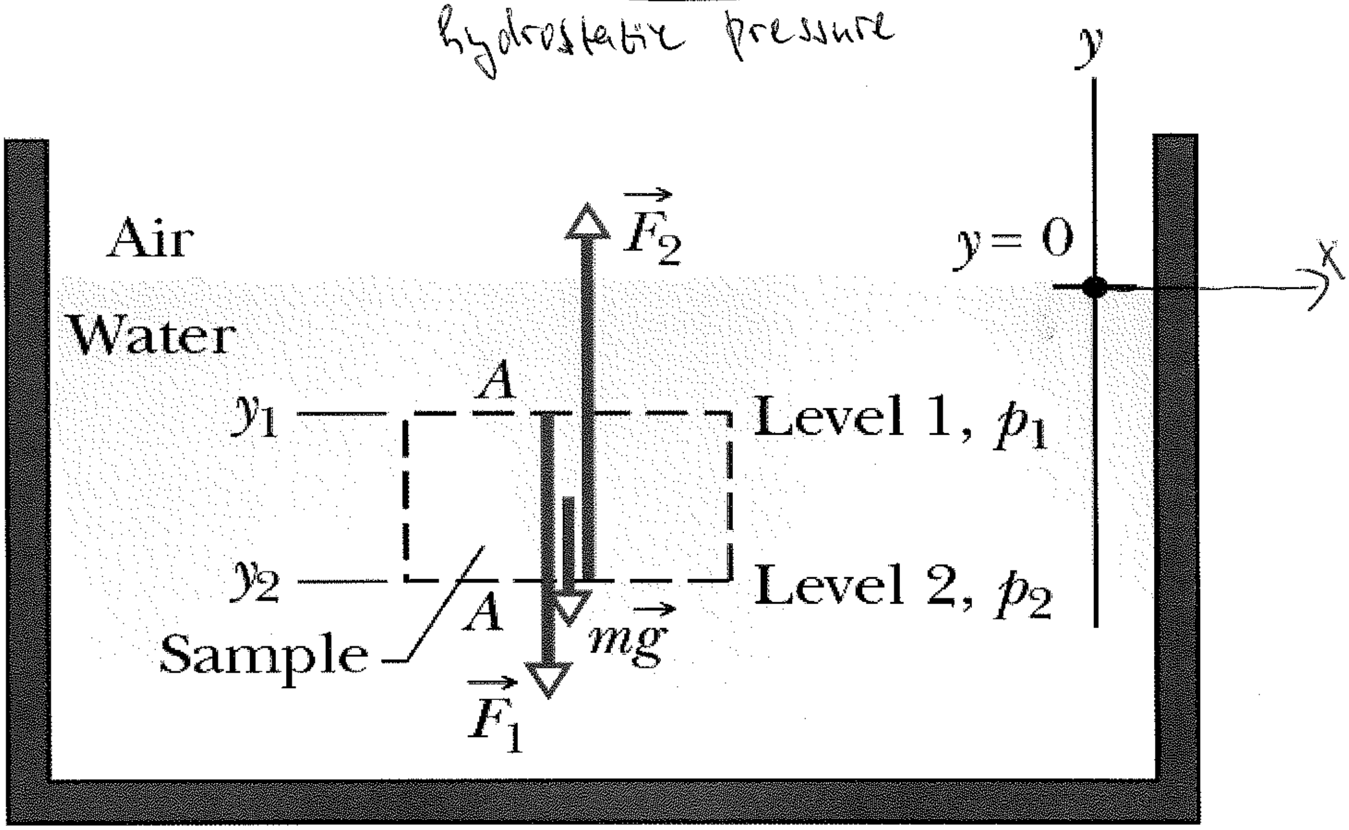
Pressure at bottom of column is due to weight of overlying fluid:

$$P = \frac{F}{A} = \frac{mg}{A} = \frac{\rho(A \cdot h) \cdot g}{A} = \rho \cdot g \cdot h$$

[PA]

Fluids at rest

hydrostatic pressure

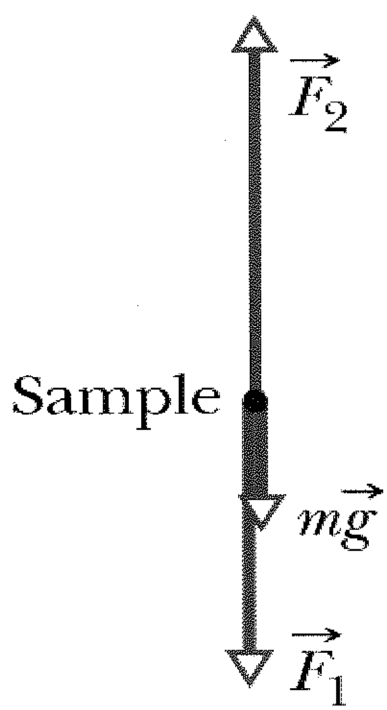


(a)

$$F_2 = F_1 + mg$$

$$F_1 = p_1 A, \quad m = \rho V$$

$$F_2 = p_2 A, \quad V = A(y_1 - y_2)$$



$$p_2 A = p_1 A + \rho A g (y_1 - y_2)$$

$$\boxed{p_2 = p_1 + \rho g (y_1 - y_2)}$$

if $y_1 = 0$, $p_1 = p_0$

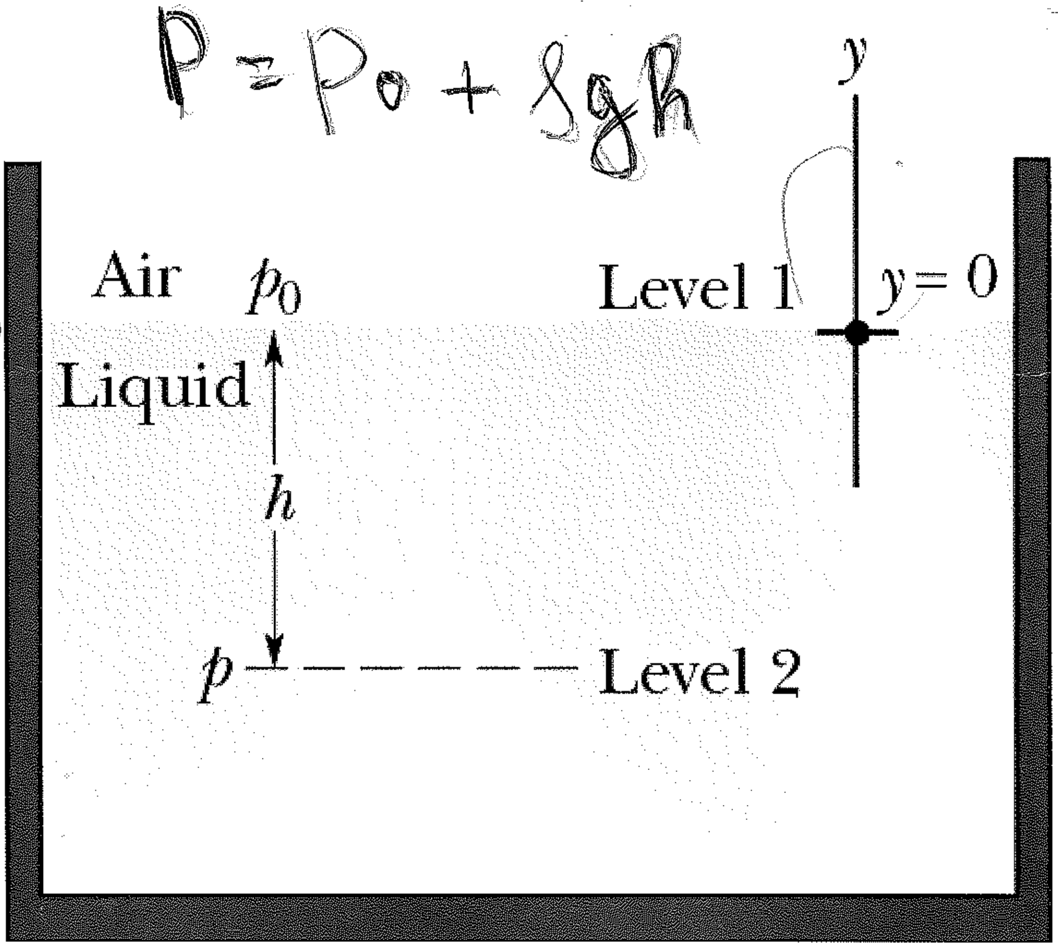
p is a scalar

p does not depend on x

(b)

$$\boxed{p = p_0 + \rho g h}$$

$P = P_0 + \rho g h$



P - Absolute pressure

$P = P_0 + \rho g h$

$P - P_0 = \rho g h$ gauge pressure

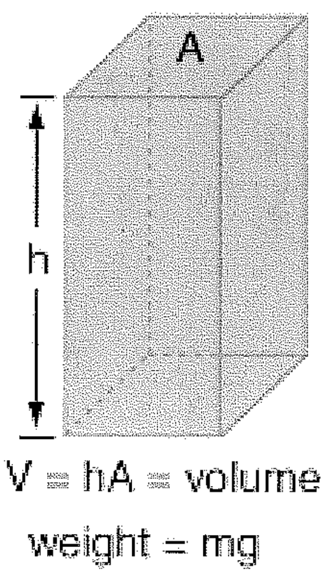
Static Fluid Pressure

The pressure exerted by a static fluid depends only upon the depth of the fluid, the density of the fluid, and the acceleration of gravity.

The pressure in a static fluid arises from the weight of the fluid and is given by the expression

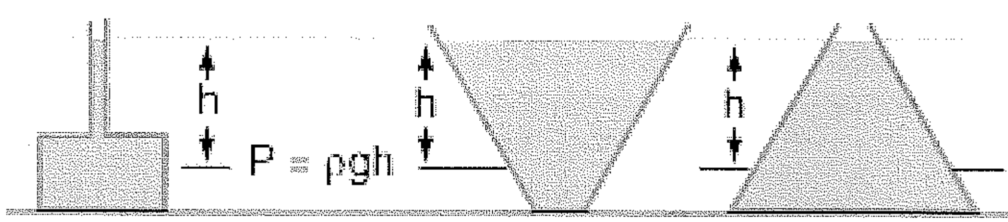
$$P_{\text{static fluid}} = \rho g h \quad \text{where} \quad \begin{aligned} \rho &= m/V = \text{fluid density} \\ g &= \text{acceleration of gravity} \\ h &= \text{depth of fluid} \end{aligned}$$

The pressure from the weight of a column of liquid of area A and height h is



Static fluid pressure does not depend on the shape, total mass, or surface area of the liquid.

$$\text{Pressure} = \frac{\text{weight}}{\text{area}} = \frac{mg}{A} = \frac{\rho V g}{A} = \rho g h$$



The most remarkable thing about this expression is what it does not include. The fluid pressure at a given depth does not depend upon the total mass or total volume of the liquid. The above pressure expression is easy to see for the straight, unobstructed column, but not obvious for the cases of different geometry which are shown.

3 m H_2O 25×15 m ; $F_{Bottom} = ?$

44. ORGANIZE AND PLAN The water exerts a force on the bottom of the pool equal to its pressure times the area of the bottom of the pool. The pressure can be calculated from Equation 10.4.

Known: $h = 3.0$ m; $A = (25\text{ m}) \times (15\text{ m}) = 3.8 \times 10^2\text{ m}^2$; $P_0 = 1$ atm; $\rho = 1000\text{ kg/m}^3$.

SOLVE The pressure at the bottom of the pool is:

$$P = P_0 + \rho g h = (1\text{ atm}) + (1000\text{ kg/m}^3)(9.80\text{ m/s}^2)(3.0\text{ m}) = 1.3 \times 10^5\text{ Pa}$$

The force is:

Area

$$F = PA = (1.3 \times 10^5\text{ Pa})(3.8 \times 10^2\text{ m}^2) = 4.9 \times 10^7\text{ N}$$

REFLECT At this relatively shallow depth, most of the pressure (and most of the force) still comes from the atmospheric pressure.

$h = ?$ so $P = 4$ atm

42. **ORGANIZE AND PLAN** A gauge pressure is the pressure difference from atmospheric pressure and equals the height of a column of liquid times the density of the liquid times g.

Known: $\Delta P = 4$ atm; $\rho = 1000$ kg/m^3.

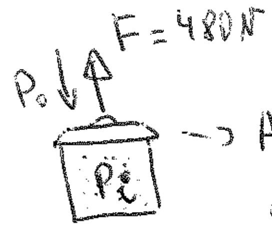
SOLVE The height of the water tower should be:

4×10^5 Pa

$$\Delta P = \rho g h$$

$$h = \frac{\Delta P}{\rho g} = \frac{(4\ \text{atm})}{(1000\ \text{kg/m}^3)(9.80\ \text{m/s}^2)} = 4 \times 10^1\ \text{m}$$

6P. An airtight container having a lid with negligible mass and an area of 77 cm^2 is partially evacuated. If a 480 N force is required to pull the lid off the container and the atmospheric pressure is 1.0×10^5 Pa, what is the air pressure in the container before it is opened? ssm



$\rightarrow A = 77\ cm^2$

$P_o = 1 \times 10^5\ Pa$

$\nearrow \frac{F}{A} = P_o - P_i$

6. The magnitude F of the force required to pull the lid off is $F = (p_o - p_i)A$, where p_o is the pressure outside the box, p_i is the pressure inside, and A is the area of the lid. Recalling that $1\,N/m^2 = 1\,Pa$, we obtain

$$p_i = p_o - \frac{F}{A} = 1.0 \times 10^5\ \text{Pa} - \frac{480\ \text{N}}{77 \times 10^{-4}\ \text{m}^2} = 3.8 \times 10^4\ \text{Pa}\ .$$

Steel $\downarrow$ d = ? so $\frac{\Delta V}{V} = -0.15\%$

43. ORGANIZE AND PLAN The fractional volume change due to compression forces is given by Equation 10.2. Since pressure is force per unit area we can use this equation (and the bulk modulus of steel from Table 10.2) to calculate the required pressure to compress the steel ball. The pressure at a certain depth is given by Equation 10.4, which we will rewrite to solve for the depth.

Known: $\Delta V/V = 0.015\%$; $P_0 = 1\text{ atm}$; $\rho = 1000\text{ kg/m}^3$; $B = 16\times10^{10}\text{ N/m}^2$.

SOLVE The required pressure to compress the steel ball is:

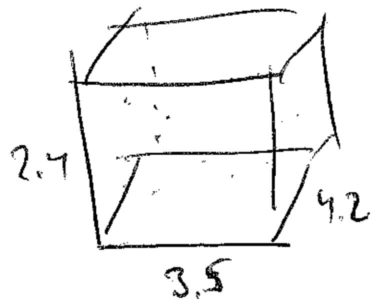
$$P = \frac{F}{A} = -B\frac{\Delta V}{V} = -\left(16\times10^{10}\text{ N/m}^2\right)\left(-0.015\%\right) = 2.4\times10^{7}\text{ N/m}^2$$

The ocean depth with this pressure is:

? 10^5 Pa

$$P = P_0 + \rho g h$$

$$h = \frac{P - P_0}{\rho g} = \frac{\left(2.4\times10^{7}\text{ N/m}^2\right) - \left(1\text{ atm}\right)}{\left(1000\text{ kg/m}^3\right)\left(9.80\text{ m/s}^2\right)} = 2.4\text{ km}$$



Air? $\rho_{air} = 1.21 \, kg/m^3$

$mg = (\rho V) g = (1.21 \, kg/m^3) \cdot (3.5 \times 4.2 \times 2.4) \cdot (9.8 \, m/s^2) =$

$= 418 \, N$ (110 cans of Pepsi)

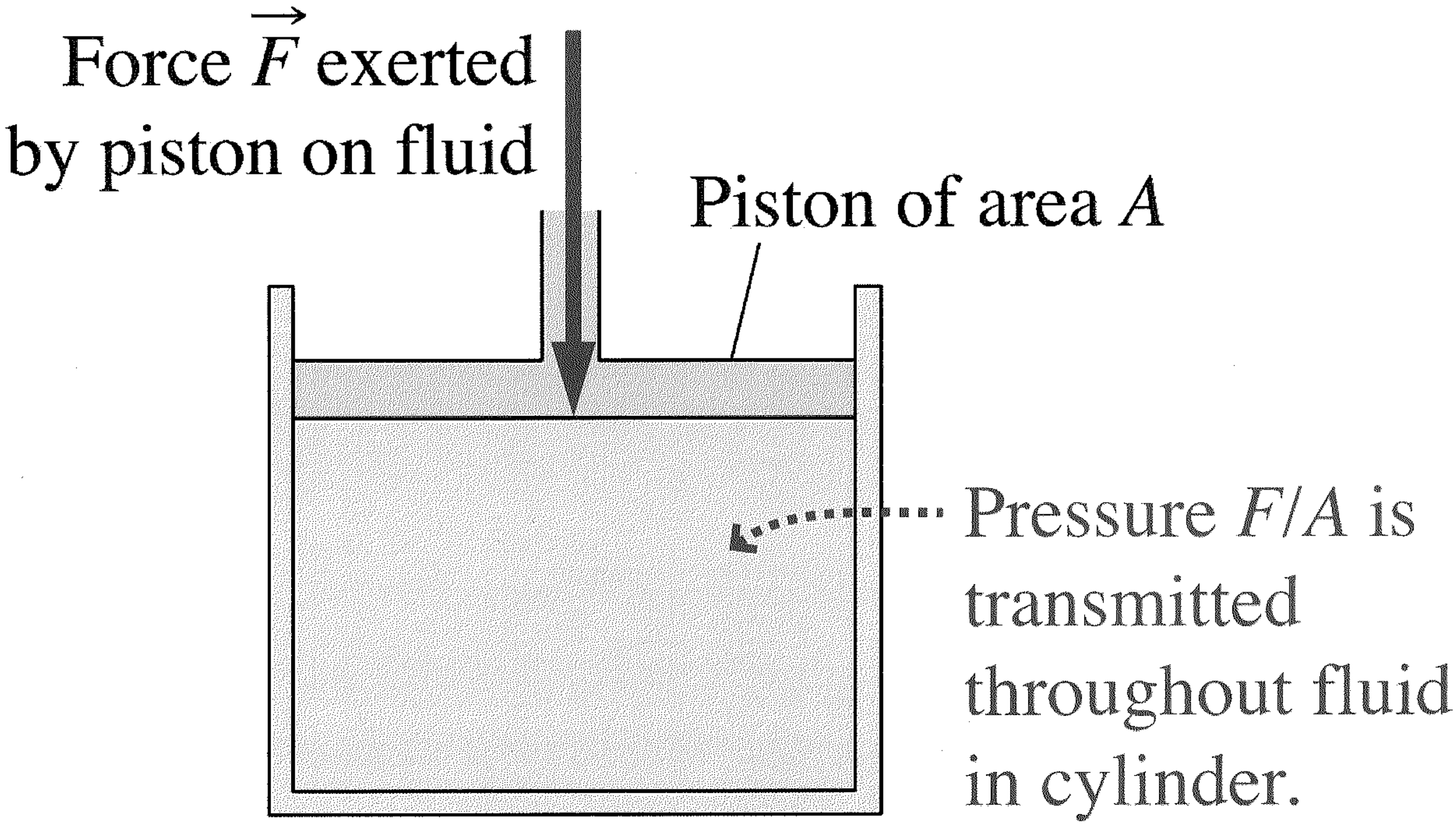
Force?

$F = p \cdot A = (3.5 \times 4.2)(1.01 \, atm \times 10^5 \, N/m^2)$

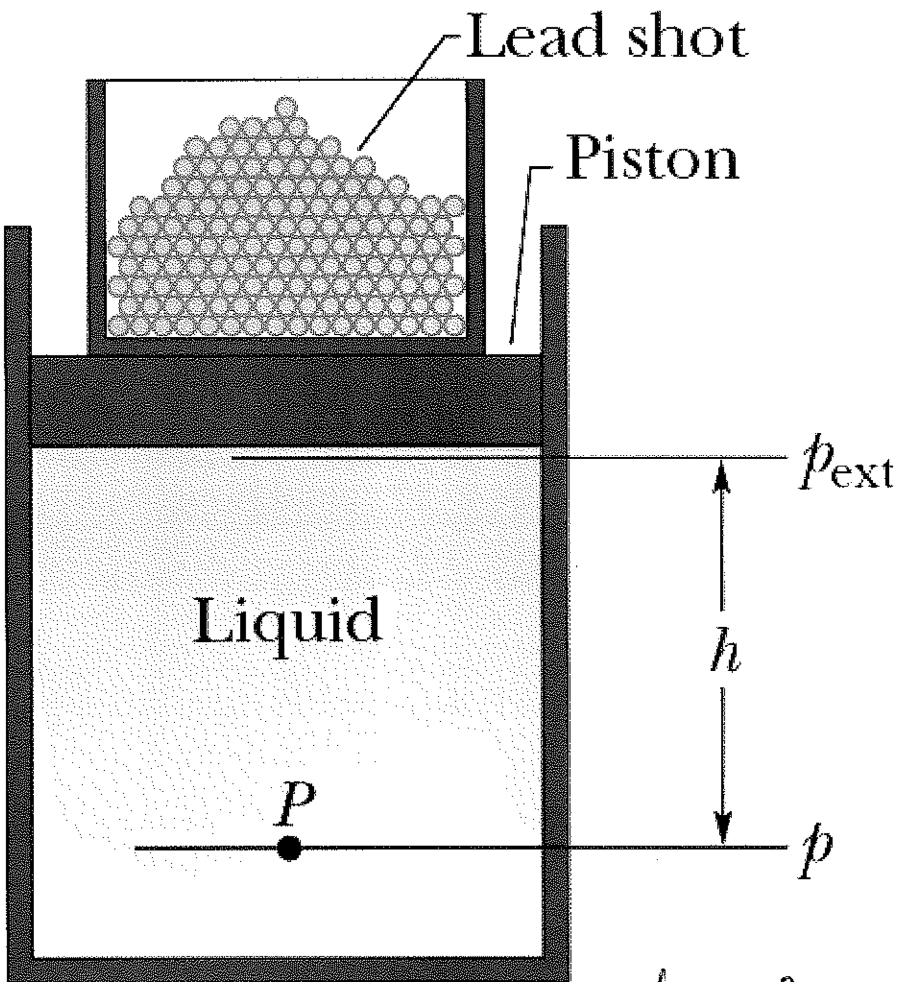
$= 1.5 \times 10^6 \, N$

Figure 10.6

Pascal's Principle (1652)



incompressible fluid



Pascal's principle (1652)

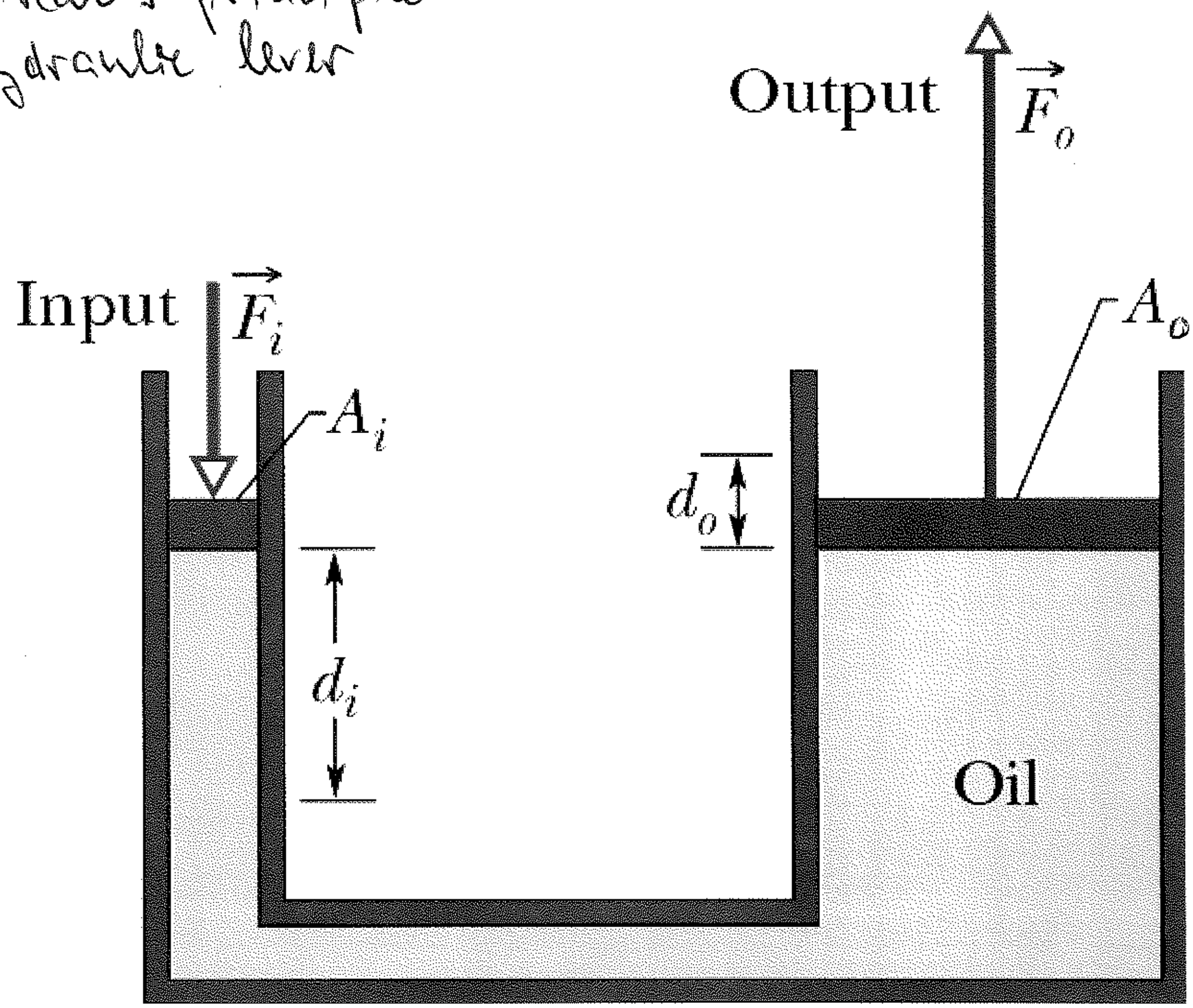
$$p = p_{ext} + \rho g h$$

if the fluid is incompressible

$$\Delta p = \Delta p_{ext}$$

A change in the p_{ext} is transmitted everywhere.

|| Pascal's principle
|| Hydraulic lever



$$\Delta p = \frac{F_{in}}{A_i} = \frac{F_{out}}{A_{out}}, \quad F_{out} = F_{in}\frac{A_o}{A_i} \quad \boxed{F_{out} > F_{in}}$$

Also $V = A_i d_i = A_o d_o$ (incompressible)

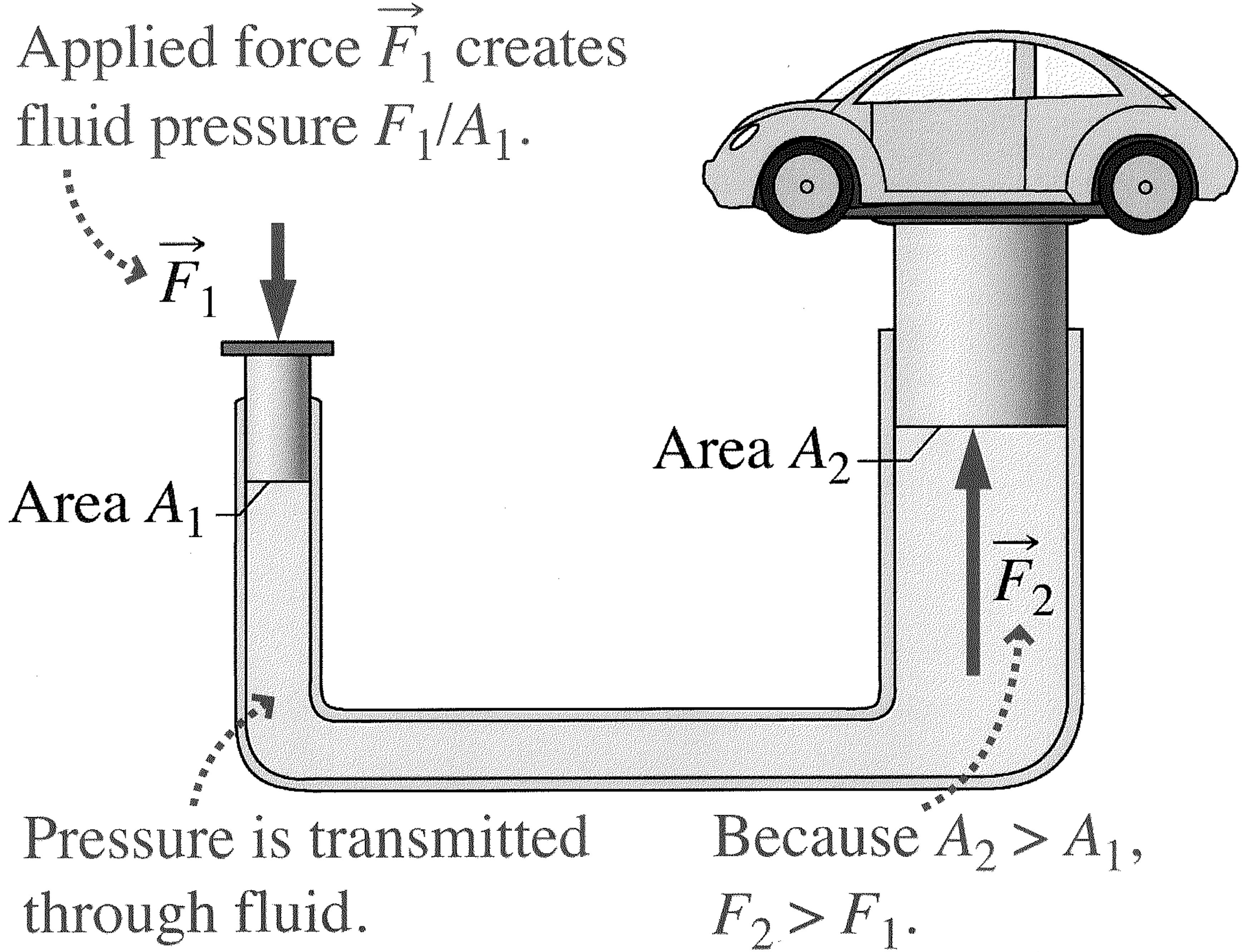
$$d_{out} = d_i \frac{A_i}{A_o} \quad \boxed{d_o < d_i}$$

Work $W = F_{out} \cdot d_o = \left(F_{in}\frac{A_o}{A_i}\right) d_i \left(\frac{A_i}{A_o}\right) = F_i d_i$

A force applied over a distance can be transformed to a greater force applied over a smaller distance.

Work is the same!

Figure 10.7



Applied force $\vec{F}_1$ creates fluid pressure F_1/A_1.
$\vec{F}_1$
Area A_1
Area A_2
$\vec{F}_2$
Pressure is transmitted through fluid.
Because $A_2 > A_1$, $F_2 > F_1$.

(F_2) F_{out} ? m_{out} ?

47. ORGANIZE AND PLAN The pressure on each piston is the air pressure plus the applied force on that piston divided by the piston area. The pressures on the two pistons are equal when the system is in equilibrium. Because the pistons are at the same height, the air pressure is the same on both pistons.

Known: $A_1 = 0.50\text{ m}^2$; $A_2 = 5.60\text{ m}^2$; $F_1 = 2.0\text{ kN}$.

SOLVE The system is in equilibrium when:

$$\Delta P_1 = \frac{F_1}{A_1} = \frac{F_2}{A_2} = \Delta P_2$$

This means that the larger piston can support a force:

$$F_2 = \frac{A_2}{A_1}F_1 = \frac{(5.60\text{ m}^2)}{(0.50\text{ m}^2)}(2.0\text{ kN}) = 22\text{ kN}$$

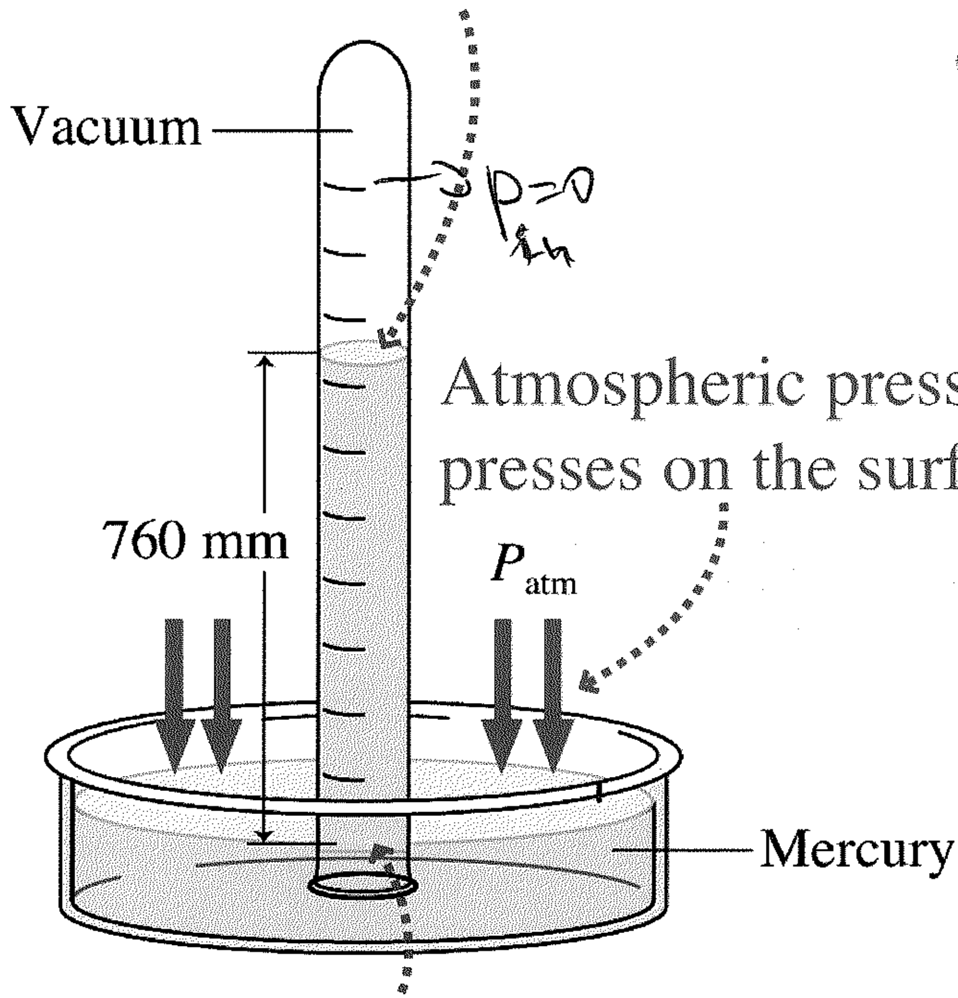
i.e., it can support a mass:

$$m_2 = \frac{F_2}{g} = \frac{(22\text{ kN})}{(9.80\text{ m/s}^2)} = 2.3\times 10^3\text{ kg} = 2300\text{ kg}$$

Pressure Gauges

Figure 10.8

A vacuum has zero pressure, so $P_0 = 0$ at the mercury's surface in the tube.

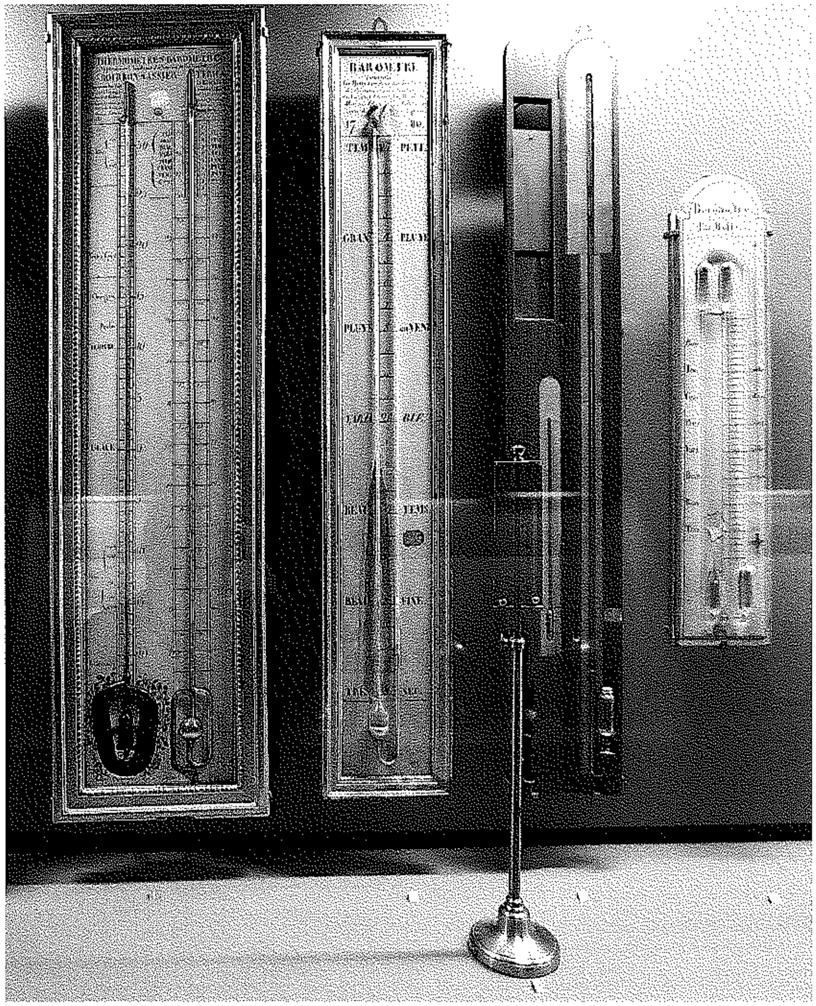


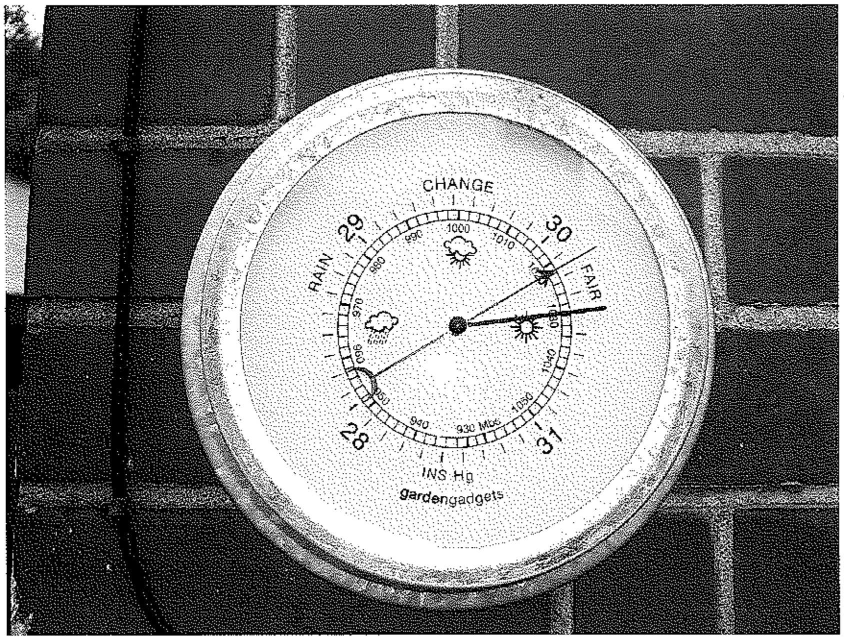
$P_{atm} = \rho g h + 0$

$h = \dfrac{P_{atm}}{\rho_{Hg} \cdot g} = 760\ mm$

$1\ mm(Hg) = torr$

. . . and pushes mercury up the tube until the mercury's weight balances the pressure force.




CHANGE
RAIN
FAIR
29
30
28
31
INS Hg
930 Mbs
gardengadgets