Fluids and pressure

Foundation Physics
Liquids and gases exist in abundance on earth. The existence of life is intimately related to the characteristics of matter in these phases. So consequently the physics of liquids and gases is not just another topic but is basic to life itself.

- A fluid is either a gas or a liquid
- Liquids are nearly incompressible whereas gas is easily compressed
Pressure

Definition:
Pressure $p$ of a force $F$ on an area $A$ is:

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

Units: $1 \frac{N}{m^2} = 1 \text{ pascal} = 1 \text{ Pa}$

Other pressure units:

- bar: $1 \text{ bar} = 1 \cdot 10^5 \text{ Pa}$
- atmosphere: $1 \text{ atm} = 1.01325 \cdot 10^5 \text{ Pa}$
- torr (=mm of mercury): $1 \text{ torr} = 133.32 \text{ Pa}$
Conversion Factors for Various Units of Pressure

<table>
<thead>
<tr>
<th>Conversion to N/m²</th>
<th>Conversion to atm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 atm = 1.013 × 10^5 N/m²</td>
<td>1.0 atm = 1.013 × 10^5 N/m²</td>
</tr>
<tr>
<td>1.0 dyn/cm² = 0.1 N/m²</td>
<td>1.0 atm = 1.013 × 10^6 dyn/cm²</td>
</tr>
<tr>
<td>1.0 kg/cm² = 9.8 × 10^4 N/m²</td>
<td>1.0 atm = 1.03 kg/cm²</td>
</tr>
<tr>
<td>1.0 lb/in.² = 6.90 × 10^3 N/m²</td>
<td>1.0 atm = 14.7 lb/in.²</td>
</tr>
<tr>
<td>1.0 mm Hg = 133 N/m²</td>
<td>1.0 atm = 760 mm Hg</td>
</tr>
<tr>
<td>1.0 cm Hg = 1.33 × 10^3 N/m²</td>
<td>1.0 atm = 76.0 cm Hg</td>
</tr>
<tr>
<td>1.0 cm water = 98.1 N/m²</td>
<td>1.0 atm = 1.03 × 10^3 cm water</td>
</tr>
<tr>
<td>1.0 bar = 1.000 × 10^5 N/m²</td>
<td>1.0 atm = 1.013 bar</td>
</tr>
</tbody>
</table>

Note that 1 Pa = 1 N/m²; 1 Torr = 1 mm Hg.

1 psi = 6.89 x 10^3 Pa
Pressure (force per area)

Weight: 1.01 x 10^5 N

Force on a strip dA:
\[ dF = \rho_w g (H - y) L dy \]

Total force on dam:
\[ F = \int_0^H \rho_w g (H - y) L dy = \frac{1}{2} \rho_w g L H^2 \]
What pressure is exerted by the tip of a scanning probe microscope with a load of 1 nN? Assume the tip is a 2 nm radius circle.
Stationary fluids

- Stationary fluids always exert forces perpendicular to surfaces whether the direction is up or down, left or right.
- The atmosphere exerts an equal and opposite force on the side of the wall.
Pressure is exerted by a gas on the walls of a container via collision of the gas molecules with the walls. If the same amount of gas at the same temperature occupies a larger volume, then its pressure decreases.

Question: what other factors can affect its pressure – explain?
Problem

- A pressure cooker is shaped like a can with a lid 25 cm in diameter. If the pressure in the cooker can reach 3.0 atm, how much force must the latches holding the lid onto the pot be designed to withstand?
Pascal’s Principle

‘Any pressure applied to a confined fluid will be transmitted undiminished to all parts of the fluid’

It is important to note that applied pressure and not force is transmitted.

The total pressure at the bottom of a lake is the sum of the pressure due to the weight of the water plus atmospheric pressure.
Properties of Liquids

• Liquids are practically incompressible

\[
\frac{\Delta V}{V} = -\kappa \cdot \Delta p
\]

\(\kappa\) is very small

\(\kappa\): bulk modulus of a substance measures the substance's resistance to uniform compression. The inverse of the bulk modulus gives a substance's compressibility.

• In equilibrium the pressure in a liquid at the same height is equal

\(p_1 = p_2\)
Hydraulic Press

\[ p_1 = p_2 \]
\[ \frac{F_1}{A_1} = \frac{F_2}{A_2} \]
\[ F_2 = F_1 \frac{A_2}{A_1} \]
We apply a force of 100 N on the master cylinder of diameter 2 cm and push the piston by 1 meter, how much does the 1000kg heavy car lift on the stand with a cylinder diameter of 19.8 cm?
The force \( F \) applied on the area \( A \) is due to the weight of the column of fluid above the area \( A \) and the depth \( h \).

\[
p_1 = \frac{F}{A} = \frac{mg}{A} = \frac{\rho \cdot A \cdot g \cdot h}{A} = \rho \cdot g \cdot h
\]

\( p_1 = \rho \cdot g \cdot h \) \quad \text{Pressure due to the weight of a fluid}

Example:
water column \( h = 10 \, m \), \( \rho = 10^3 \, \text{kg} \, / \, m^3 \)

\[
p_1 = \rho \cdot g \cdot h = 10^3 \cdot 9.81 \cdot 10 \approx 10^5 \, \text{Pa} \approx 1 \, \text{bar}
\]

\( p_{\text{tot}} = p_0 + p_1 \) \quad \text{The total pressure } p_{\text{tot}} \text{ is the pressure due to the weight of the fluid } p_1 \text{ plus atmospheric pressure } p_0.

\( p_0 \) is also named \textit{Gauge pressure} \( i.e \) the pressure above or below atmospheric pressure.
The three containers have the same floor space $A_1 = A_2 = A_3$. The force effective at the base is equal in all three containers.
a) Pressure due to the water alone

b) Total pressure due to the weight of the fluid and the atmospheric pressure
• (a) Calculate the pressure in Newton per square meter due to whole blood in an IV system, such as the one shown in the figure if $h=1.5$ m. (b) Noting that there is an open tube, so that atmospheric pressure is exerted on the blood in the bottle, calculate the total pressure exerted at the needle by the blood.

Needle inner diameter
0.25 mm
• To Be Covered: Pressure measurement & Flow

• Reading: Chapter 6
  ▪ Section 6.3
  ▪ Section 6.4
  ▪ Section 6.5
## Table 1. Dimensions of Medical Needles

<table>
<thead>
<tr>
<th>Gauge</th>
<th>Range of outside diameters (mm)</th>
<th>Minimum inside diameter of tubing (mm)</th>
<th>Normal-walled</th>
<th>Thinwalled</th>
<th>Extra-thinwalled</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>0.324</td>
<td>0.351</td>
<td>0.133</td>
<td>0.190</td>
<td>—</td>
</tr>
<tr>
<td>27</td>
<td>0.400</td>
<td>0.420</td>
<td>0.184</td>
<td>0.241</td>
<td>—</td>
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<tr>
<td>26</td>
<td>0.440</td>
<td>0.470</td>
<td>0.232</td>
<td>0.292</td>
<td>—</td>
</tr>
<tr>
<td>25</td>
<td>0.500</td>
<td>0.530</td>
<td>0.232</td>
<td>0.292</td>
<td>—</td>
</tr>
<tr>
<td>22</td>
<td>0.698</td>
<td>0.730</td>
<td>0.390</td>
<td>0.440</td>
<td>0.522</td>
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<tr>
<td>20</td>
<td>0.860</td>
<td>0.920</td>
<td>0.560</td>
<td>0.635</td>
<td>0.687</td>
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<tr>
<td>19</td>
<td>1.030</td>
<td>1.100</td>
<td>0.648</td>
<td>0.750</td>
<td>0.850</td>
</tr>
<tr>
<td>18</td>
<td>1.200</td>
<td>1.300</td>
<td>0.790</td>
<td>0.910</td>
<td>1.041</td>
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<tr>
<td>17</td>
<td>1.400</td>
<td>1.510</td>
<td>0.950</td>
<td>1.156</td>
<td>1.244</td>
</tr>
<tr>
<td>16</td>
<td>1.600</td>
<td>1.690</td>
<td>1.100</td>
<td>1.283</td>
<td>1.390</td>
</tr>
<tr>
<td>14</td>
<td>1.950</td>
<td>2.150</td>
<td>1.500</td>
<td>1.600</td>
<td>1.727</td>
</tr>
</tbody>
</table>

* Needle gauge selection is based on the commonly used medical products of large market share.  
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