Fluids
Pascal's Principle
Measuring Pressure
Fluid Dynamics

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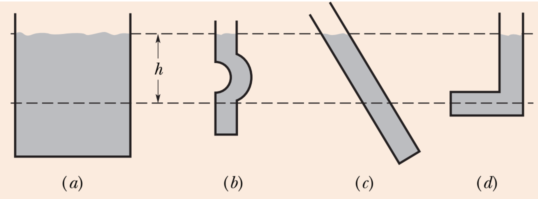
Last time

- liquid pressure: pressure and depth

Warm Up Question

The figure shows four containers of olive oil. Rank them according to the pressure at depth h, greatest first.[1]



A a, b, c, d

B a, d, c, b

C a, c, d, b

D All the same

[1] Halliday, Resnick, Walker, 9th ed, page 363.

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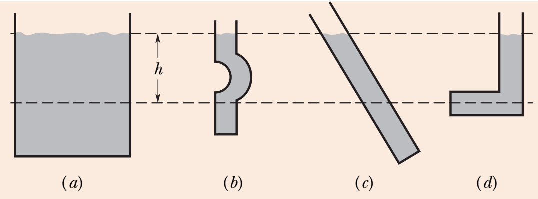

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Overview

- Pascal's principle
- measurements of pressure
- fluid dynamics

Pressure in a liquid

We have this expression for total pressure:

$$P_{\text{total}} = P_0 + \rho g h$$

What if the pressure at the surface of the liquid, P_0, was increased to P_1.

How would we expect this relation to change?

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$$P_{\text{total}} = P_1 + \rho g h$$

The *differences* in pressure between the different layers of liquid remain the same, but the pressure at each depth h increases.

Pascal's Law

This simple idea is captured by Pascal's Law.

Pascal's law applied to confined, incompressible fluids.

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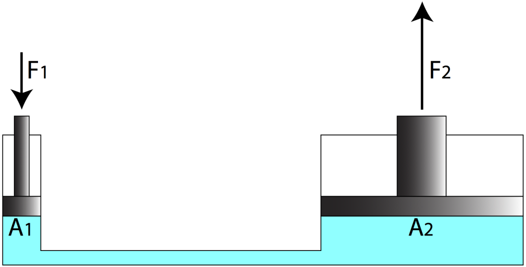
Pascal's Law

A change in pressure applied to one part of an (incompressible) fluid is transmitted undiminished to every point of the fluid.

This does *not* mean that the pressure is the same at every point in the fluid.

It means that if the pressure is increased at one point in the fluid, it increases by the same amount at all other points.

Pascal's Principle



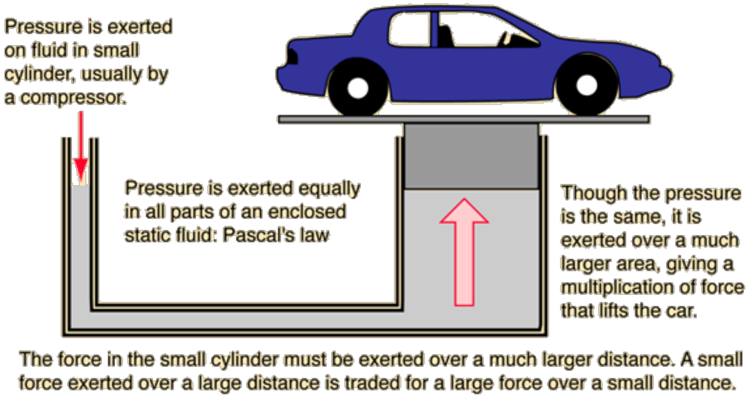
Since the changes in pressures at the left end and the right end are the same:

$$\begin{aligned} \Delta P_1 &= \Delta P_2 \\ \frac{F_1}{A_1} &= \frac{F_2}{A_2} \end{aligned}$$

Since $A_2 > A_1$, $F_2 > F_1$.

Hydraulic Lift

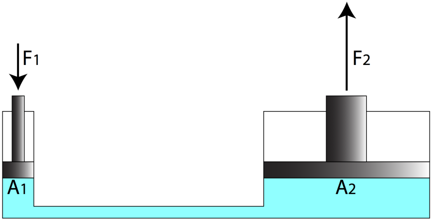
This has applications:



[1] Figure from hyperphysics.phy-astr.gsu.edu.

Question

If a pair of pistons are connected on either end of a hydraulic tube. The first has area 0.2 m^2 and the second has an area of 4 m^2.



A force of 30 N is applied the first piston. What is the force exerted by the second piston on a mass that rests on it?

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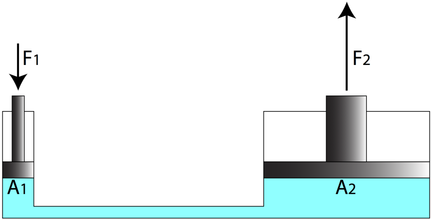

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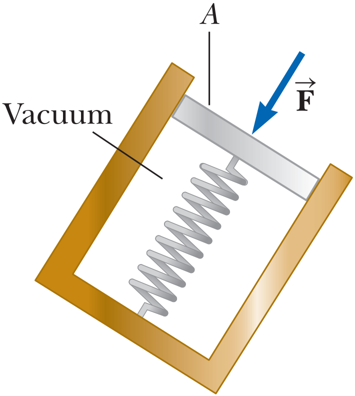
If the first piston is depressed a distance of 1 m by the 30 N force, how far does the second piston rise?

Measuring Pressure

Pressure in a fluid could be measured using a device like this:

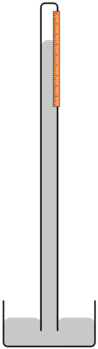


The pressure is proportional to the compression of the spring.

[1] Diagram from Serway & Jewett, 9th ed.

Barometers

Barometers are devices for measuring local atmospheric pressure.

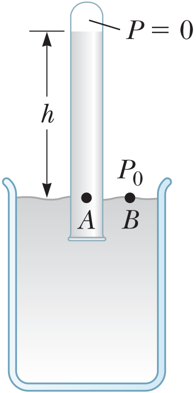


Typically, simple barometers are filled with mercury, which is very dense.

The weight of the mercury in the tube exerts the same pressure as the surrounding atmosphere. On low pressure days, the level of the mercury drops. On high pressure days it rises.

Mercury Barometer

The pressure at points A and B is the same.



The pressure at B is P_0.

Above the mercury in the tube is a vacuum, so pressure at A is $\rho_{Hg} g h$.

$(\rho_{Hg} = 13.6 \text{ kg/m}^3)$

Therefore, $P_0 = \rho_{Hg} g h$.

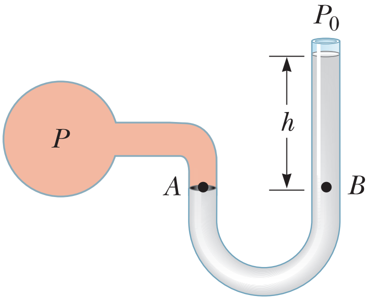
$$h \propto P_0$$

Pressure is sometimes quoted in "inches of mercury".

[1] Diagrams from Serway & Jewett, 9th ed.

Manometer

The pressure being measured, P, can be compared to atmospheric pressure P_0 by measuring the height of the incompressible fluid in the U-shaped tube.



If h is positive, $P > P_0$, if “negative”, $P < P_0$.

$P - P_0$ is called the **gauge pressure**.

Fluid Dynamics

When fluids are in motion, their behavior can be very complex.

We will only consider smooth, **laminar** flow.

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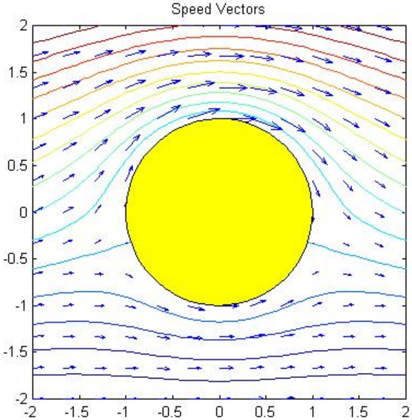
We will only consider smooth, **laminar** flow.

Laminar flow is composed of **streamlines** that do not cross or curl into vortices.

Streamline

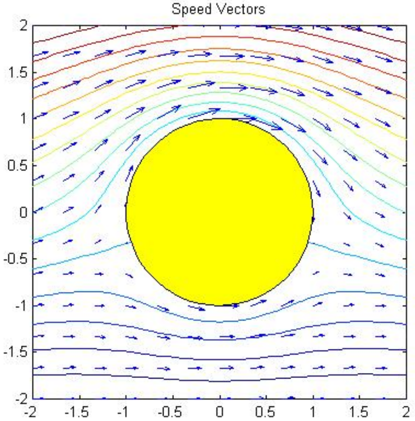
The lines traced out by the velocities of individual particles over time. Streamlines are always tangent to the velocity vectors in the flow.

Fluid Dynamics



[1]Image by Dario Isola, using MatLab.

Fluid Dynamics



A diagram of streamlines can be compared to Faraday's representation of the electric field with field lines. In fluids, the vector field is instead a field of velocity vectors in the fluid at every point in space and time, and streamlines are the field lines.

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Fluid Dynamics

We will make some simplifying assumptions:

1. the fluid is **nonviscous**, *ie.* not sticky, it has no internal friction between layers
2. the fluid is **incompressible**, its density is constant
3. the flow is **laminar**, *ie.* the streamlines are constant in time
4. the flow is **irrotational**, there is no curl

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In real life no fluids actually have the second property, and almost none have the first.

Flows can have the second two properties, in the right conditions.

Summary

- Pascal's principle
- measurements of pressure
- introduced fluid dynamics

Test Wednesday, April 22, in class. (TBC)