Engineering Physics 2

Midterm – 2

Fluids

- A fluid is any substance that can flow; we use the term for both liquids and gases. We usually think of a gas as easily compressed and a liquid as nearly incompressible, although there are exceptional cases.

- An important property of any material is its *density*, defined as its **mass** per unit **volume**.

$$\rho = \frac{m}{V} \qquad \text{(definition of density)}$$

Fluids

Material	Density (kg/m^3)*	Material	Density (kg/m^3)*
Air (1 atm, 20°C)	1.20	Iron, steel	7.8×10^3
Ethanol	0.81×10^3	Brass	8.6×10^3
Benzene	0.90×10^3	Copper	8.9×10^3
Ice	0.92×10^3	Silver	10.5×10^3
Water	1.00×10^3	Lead	11.3×10^3
Seawater	1.03×10^3	Mercury	13.6×10^3
Blood	1.06×10^3	Gold	19.3×10^3
Glycerine	1.26×10^3	Platinum	21.4×10^3
Concrete	2×10^3	White dwarf star	10^{10}
Aluminum	2.7×10^3	Neutron star	10^{18}

Fluids

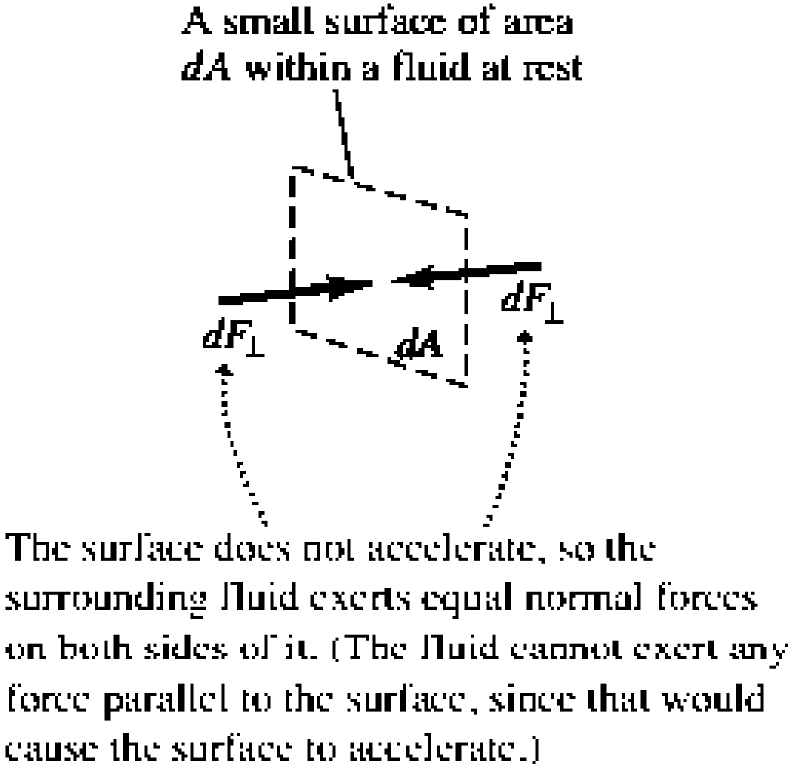
Practice:

1. Find the mass and weight of the air at 20°C in a living room with a 4.0 m × 5.0 m floor and a ceiling 3.0 m high, and the mass and weight of an equal volume of water.

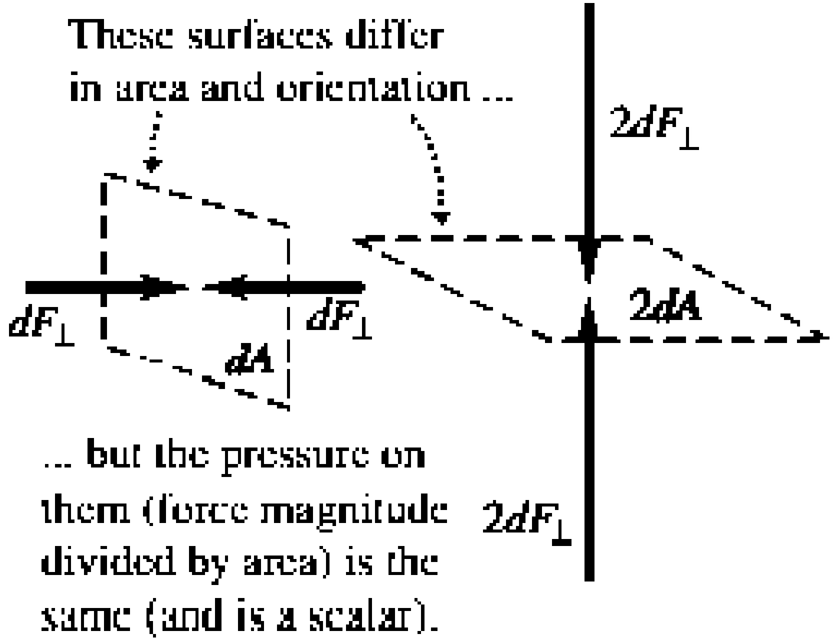
Ans: mass of air = 72 kg , weight of air = 700 N , mass of water 6.0 x 10^4 kg, weight of air = 5.9 x 10^5 N

Fluids

- Pressure in Fluids



$$p = \frac{F_\perp}{A}$$



Fluids

$$1 \text{ pascal} = 1 \text{ Pa} = 1 \text{ N/m}^2$$

Atmospheric pressure p_a is the pressure of the earth's atmosphere, the pressure at the bottom of this sea of air in which we live. This pressure varies with weather changes and with elevation. Normal atmospheric pressure at sea level (an average value) is 1 *atmosphere* (atm), defined to be exactly 101,325 Pa. To four significant figures,

$$\begin{aligned}(p_a)_{av} &= 1 \text{ atm} = 1.013 \times 10^5 \text{ Pa} \\ &= 1.013 \text{ bar} = 1013 \text{ millibar} = 14.70 \text{ lb/in.}^2\end{aligned}$$

Fluids

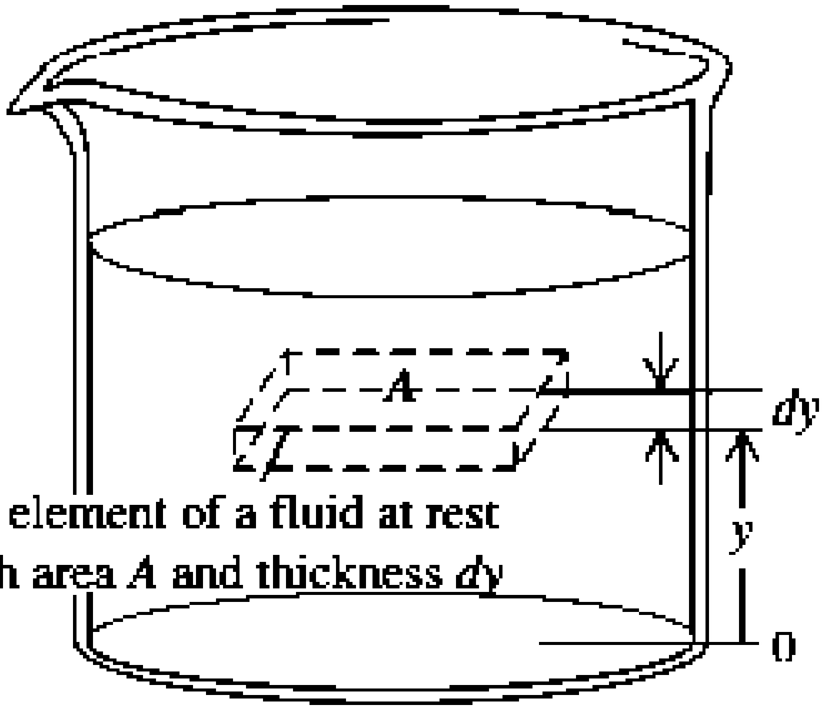
Practice:

2. In the room described in item no. 1, what is the total downward force on the floor due to an air pressure of 1 atm?

Ans: 2.0 x 10^6 N

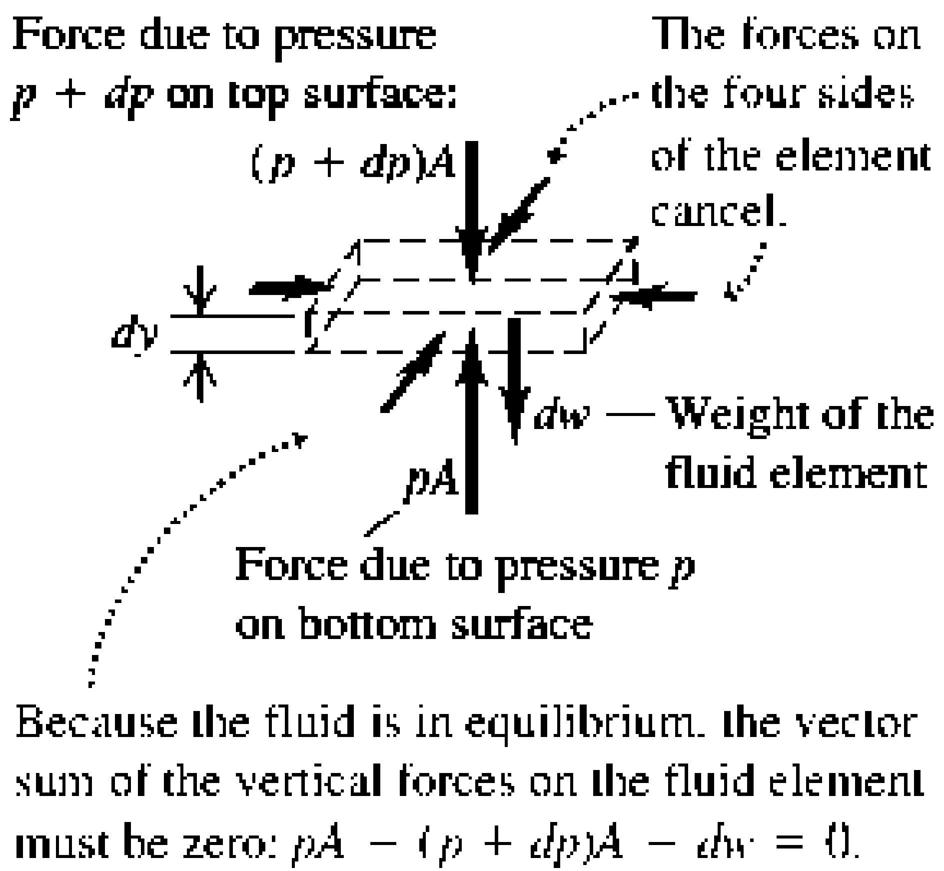
Fluids

The bottom and top surfaces each have area A, and they are at elevations y and $y + dy$ above some reference level where $y = 0$. The volume of the fluid element is $dV = A\,dy$, its mass is $dm = \rho\,dV = \rho A\,dy$, and its weight is $dw = dm\,g = \rho g A\,dy$.



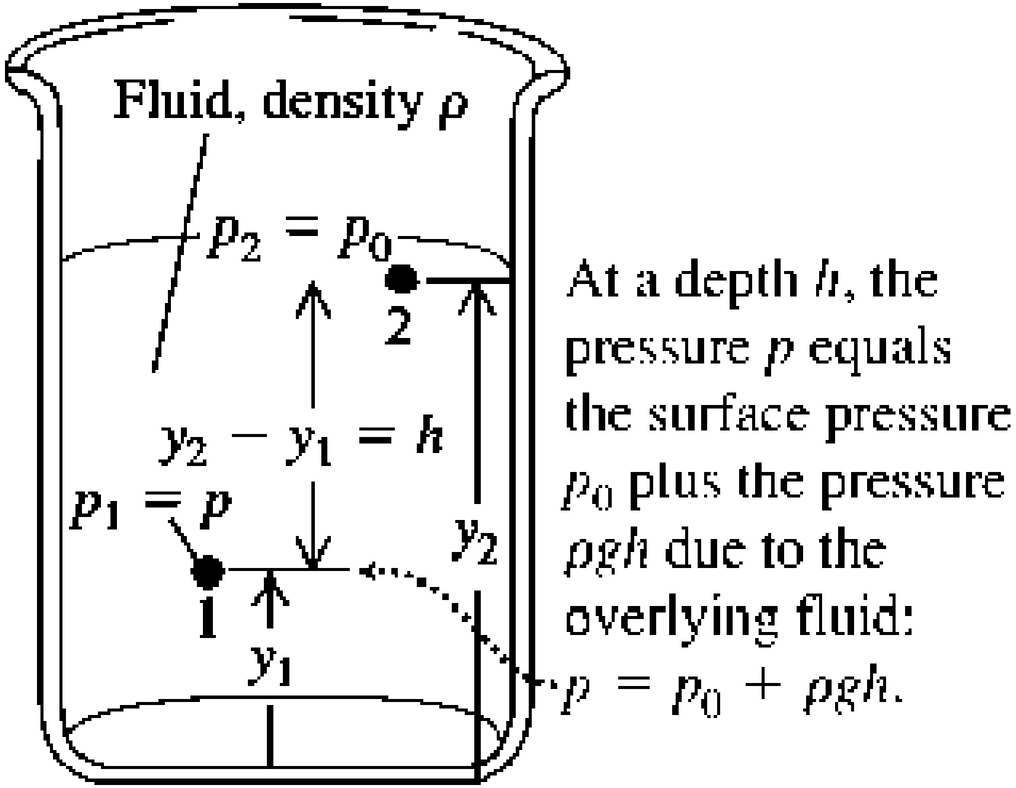
An element of a fluid at rest with area A and thickness dy

Fluids



Force due to pressure
$p + dp$ on top surface:
$(p + dp)A$
The forces on
the four sides
of the element
cancel.
dy
dw — Weight of the
fluid element
pA
Force due to pressure p
on bottom surface
Because the fluid is in equilibrium, the vector sum of the vertical forces on the fluid element must be zero: $pA - (p + dp)A - dw = 0$.

Fluids



Pressure difference between levels 1 and 2:

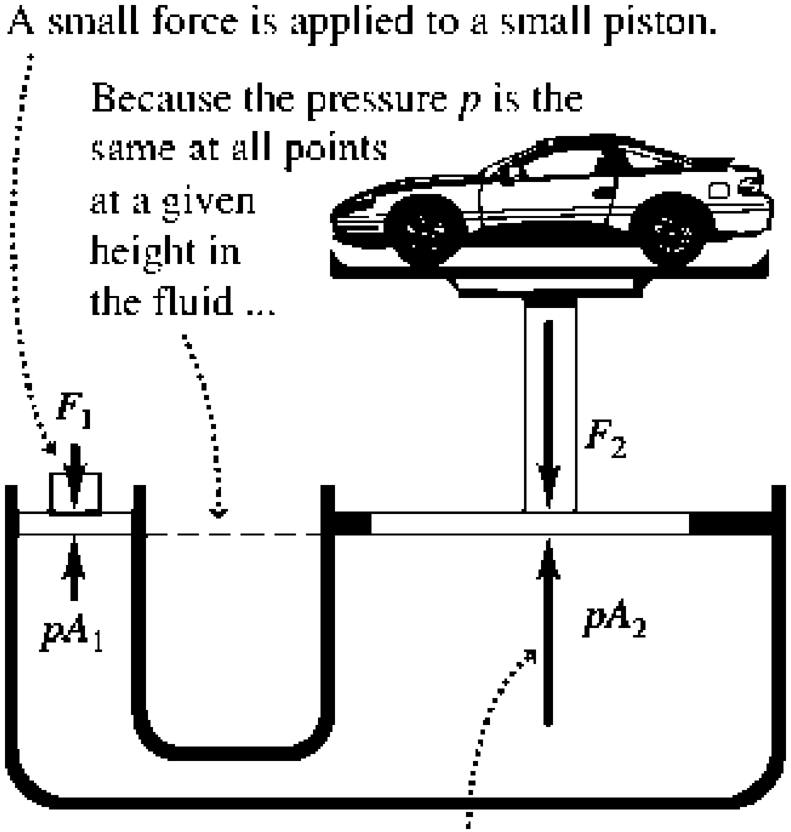
$$p_2 - p_1 = -\rho g(y_2 - y_1)$$

The pressure is greater at the lower level.

Fluids

- Pascal's law: Pressure applied to an enclosed fluid is transmitted undiminished to every portion of the fluid and the walls of the containing vessel.

$$p = \frac{F_1}{A_1} = \frac{F_2}{A_2} \qquad \text{and} \qquad F_2 = \frac{A_2}{A_1} F_1$$



Fluids

If the pressure inside a car tire is equal to atmospheric pressure, the tire is flat. The pressure has to be *greater* than atmospheric to support the car, so the significant quantity is the *difference* between the inside and outside pressures.

The excess pressure above atmospheric pressure is usually called **gauge pressure,** and the total pressure is called **absolute pressure.**

Fluids

Practice:

3. Water stands 12.0 m deep in a storage tank whose top is open to the atmosphere. What are the absolute and gauge pressures at the bottom of the tank?

Ans: absolute pressure (p) = 2.19 x 10^5 Pa or 2.16 atm
gauge pressure (p - po) = 1.18 x 10^5 Pa or 1.16 atm

Fluids

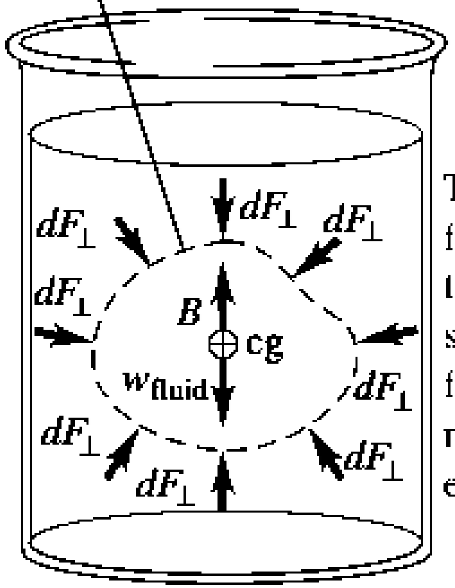
- **Buoyancy** is a familiar phenomenon: A body immersed in water seems to weigh less than when it is in air. When the body is less dense than the fluid, it floats. The human body usually floats in water, and a helium-filled balloon floats in air.

***Archimedes's principle**: When a body is completely or partially immersed in a fluid, the fluid exerts an upward force on the body equal to the weight of the fluid displaced by the body*

Fluids

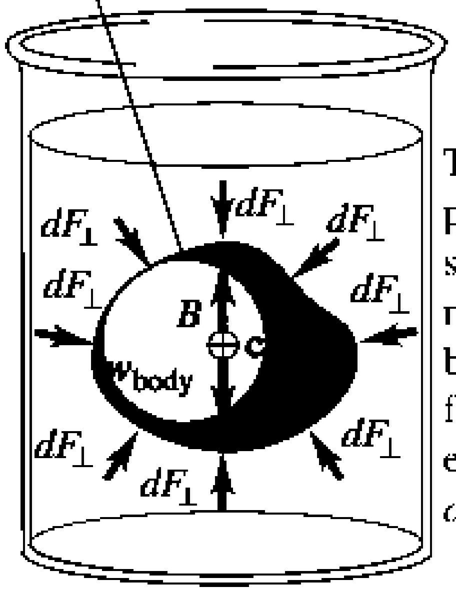
Archimedes's principle.

(a) Arbitrary element of fluid in equilibrium



The forces on the fluid element due to pressure must sum to a buoyant force equal in magnitude to the element's weight.

(b) Fluid element replaced with solid body of the same size and shape



The forces due to pressure are the same, so the body must be acted upon by the same buoyant force as the fluid element, *regardless of the body's weight.*

Fluids

Practice:

4. A 15.0-kg solid gold statue is raised from the sea bottom .What is the tension in the hoisting cable (assumed massless) when the statue is

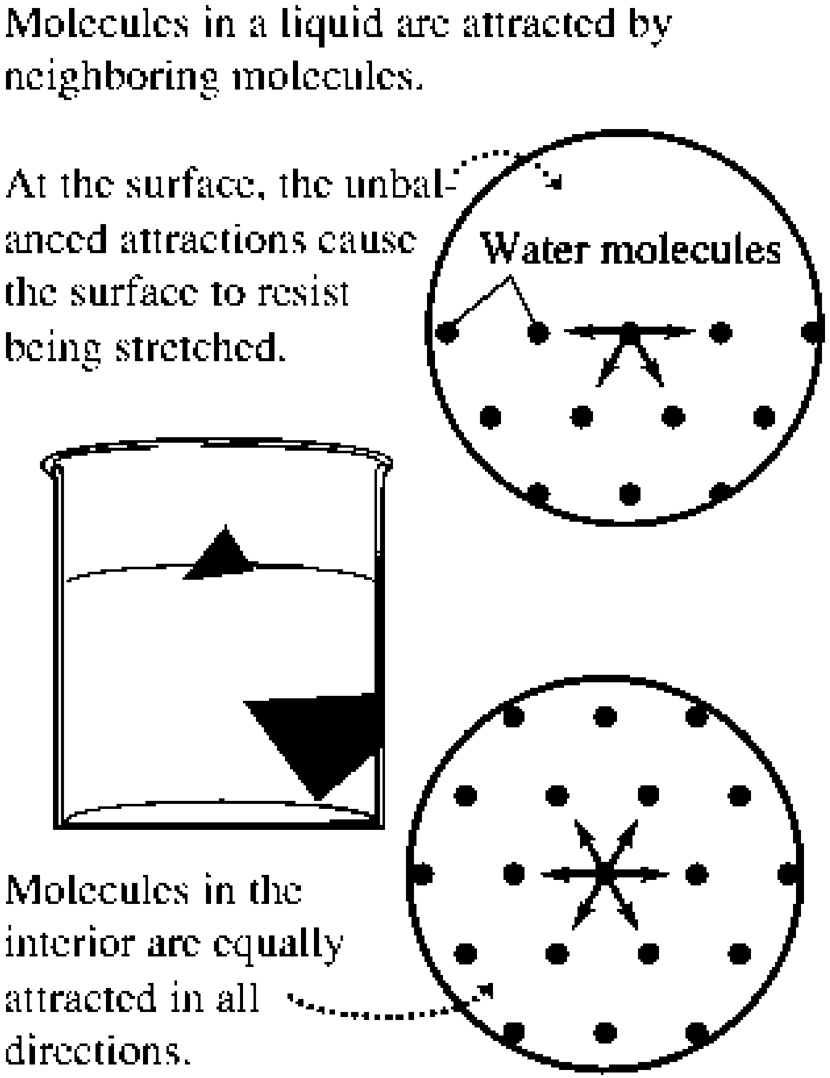
(a) at rest and completely underwater and

(b) at rest and completely out of the water?

Ans: a. T = 139 N ; b. T = 147 N

Fluids

- *An object less dense than water, such as an air-filled beach ball, floats with part of its volume below the surface. Conversely, a paper clip can rest atop a water surface even though its density is several times that of water. This is an example of* ***surface tension****.*



Fluids

An **ideal fluid** is a fluid that is incompressible (that is, its density cannot change) and has no internal friction (called **viscosity**). Liquids are approximately incompressible in most situations, and we may also treat a gas as incompressible if the pressure differences from one region to another are not too great.

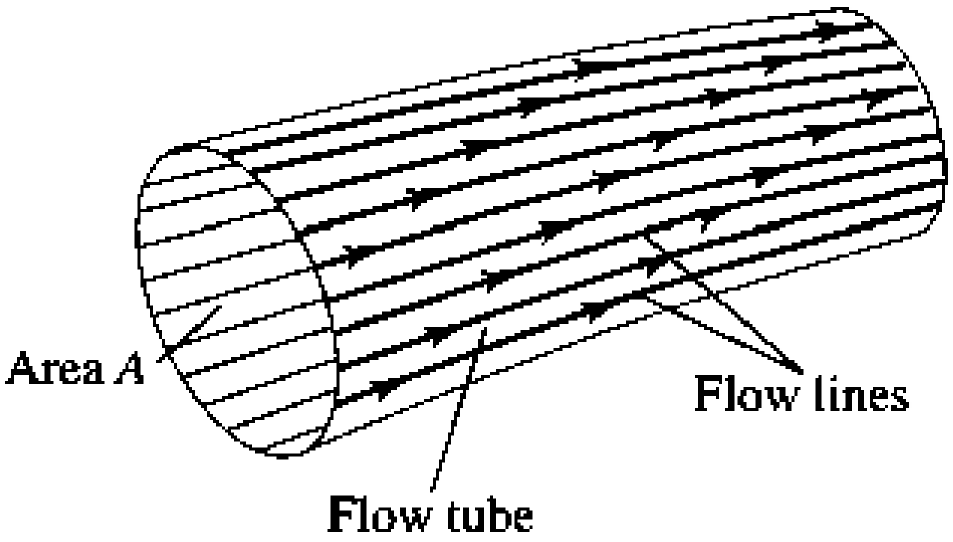
The path of an individual particle in a moving fluid is called a **flow line**. If the overall flow pattern does not change with time, the flow is called **steady flow**.

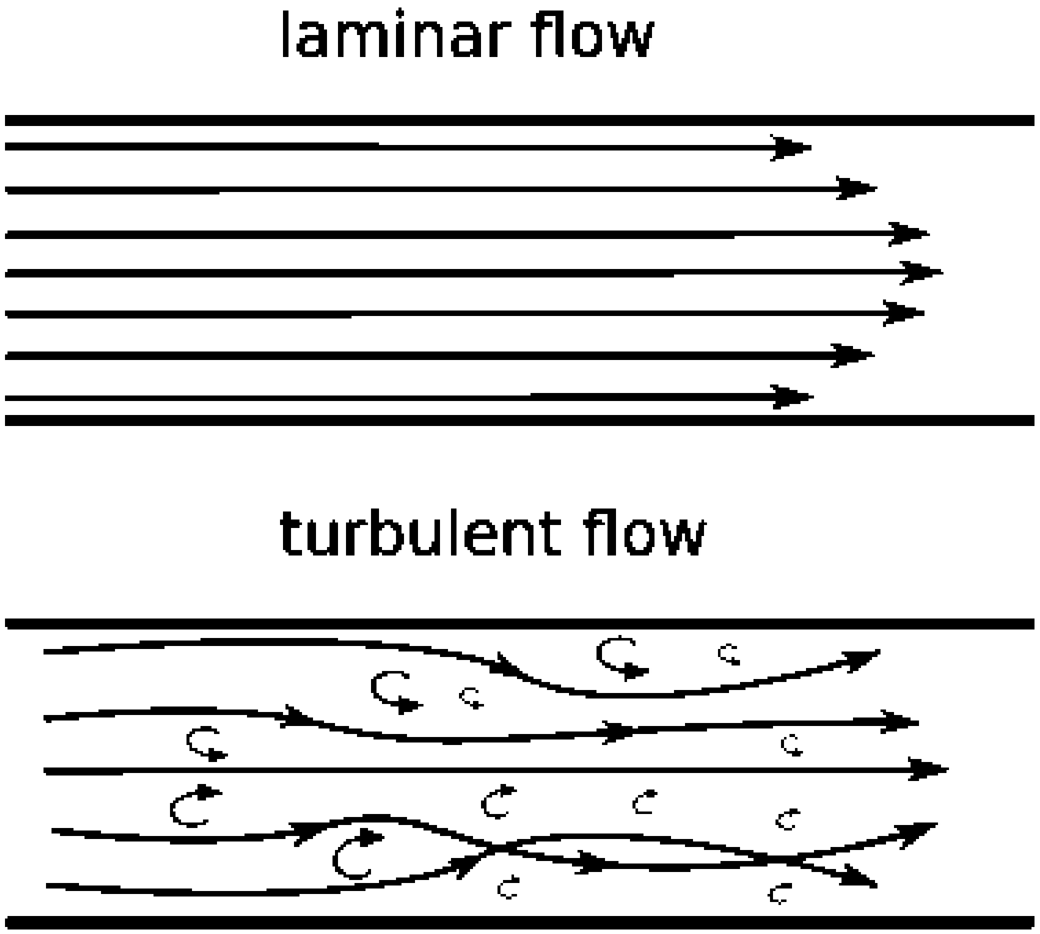
Fluids

A **streamline** is a curve whose tangent at any point is in the direction of the fluid velocity at that point. When the flow pattern changes with time, the streamlines do not coincide with the flow lines. We will consider only steady-flow situations, for which flow lines and streamlines are identical.

These patterns are typical of **laminar flow**, in which *adjacent layers of fluid slide smoothly past each other and the flow is steady*. (A lamina is a thin sheet.) *At sufficiently high flow rates, or when boundary surfaces cause abrupt changes in velocity, the flow can become irregular and chaotic*. This is called **turbulent flow.**

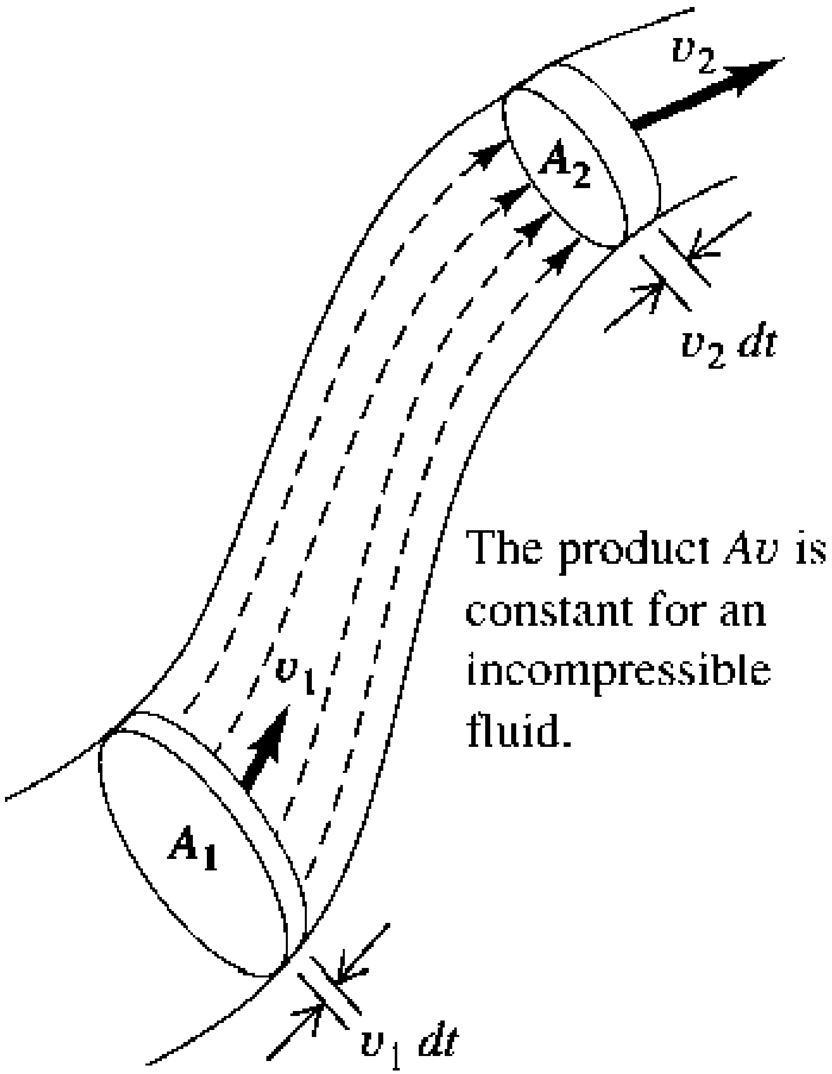
Fluids





Fluids

The mass of a moving fluid doesn't change as it flows. This leads to an important quantitative relationship called the continuity equation. Consider a portion of a flow tube between two stationary cross sections with areas A1 and A2

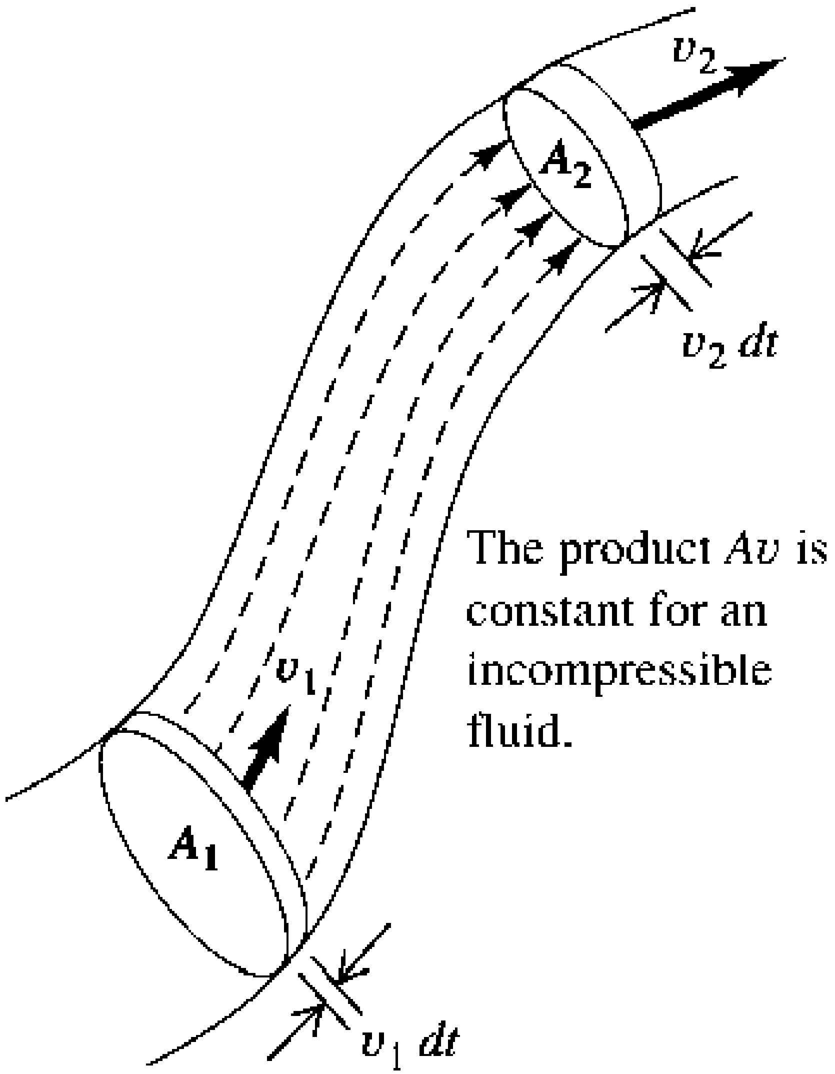


$$A_1 v_1 = A_2 v_2 \qquad \text{(continuity equation, incompressible fluid)}$$

Fluids

$$\frac{dV}{dt} = Av \qquad \text{(volume flow rate)}$$

The mass flow rate is $\rho \; dV/dt$



$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \qquad \text{(continuity equation, compressible fluid)}$$

Fluids

Practice:

5. Incompressible oil of density is pumped through a cylindrical pipe at a rate of 9.5 liters per second.

(a) The first section of the pipe has a diameter of 8.0 cm. What is the flow speed of the oil? What is the mass flow rate?

(b) The second section of the pipe has a diameter of 4.0 cm. What are the flow speed and mass flow rate in that section?

Ans: a. v1= 1.9 m/s , mass flow rate = 8.1kg/s ; b. v2 = 7.6 m/s , mass flow rate = 8.1kg/s