Physics 1501

Fall 2008

Mechanics, Thermodynamics, Waves, Fluids

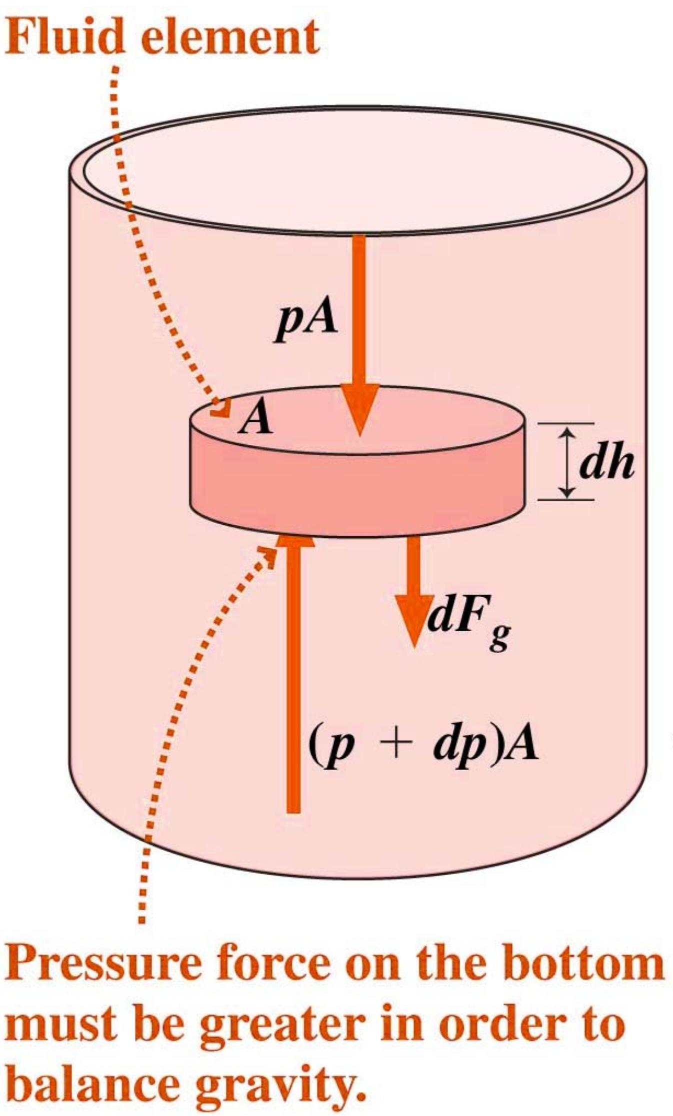
Lecture 27: Fluid motion II

Recap: hydrostatic equilibrium

- In the presence of gravity, pressure in a static fluid increases with depth.
  - This allows an upward pressure force to balance the downward gravitational force.
  - This condition is **hydrostatic equilibrium.**
  - Details depend on the nature of the fluid.
    - **Incompressible fluids** like liquids have constant density; for them, pressure as a function of depth *h* is

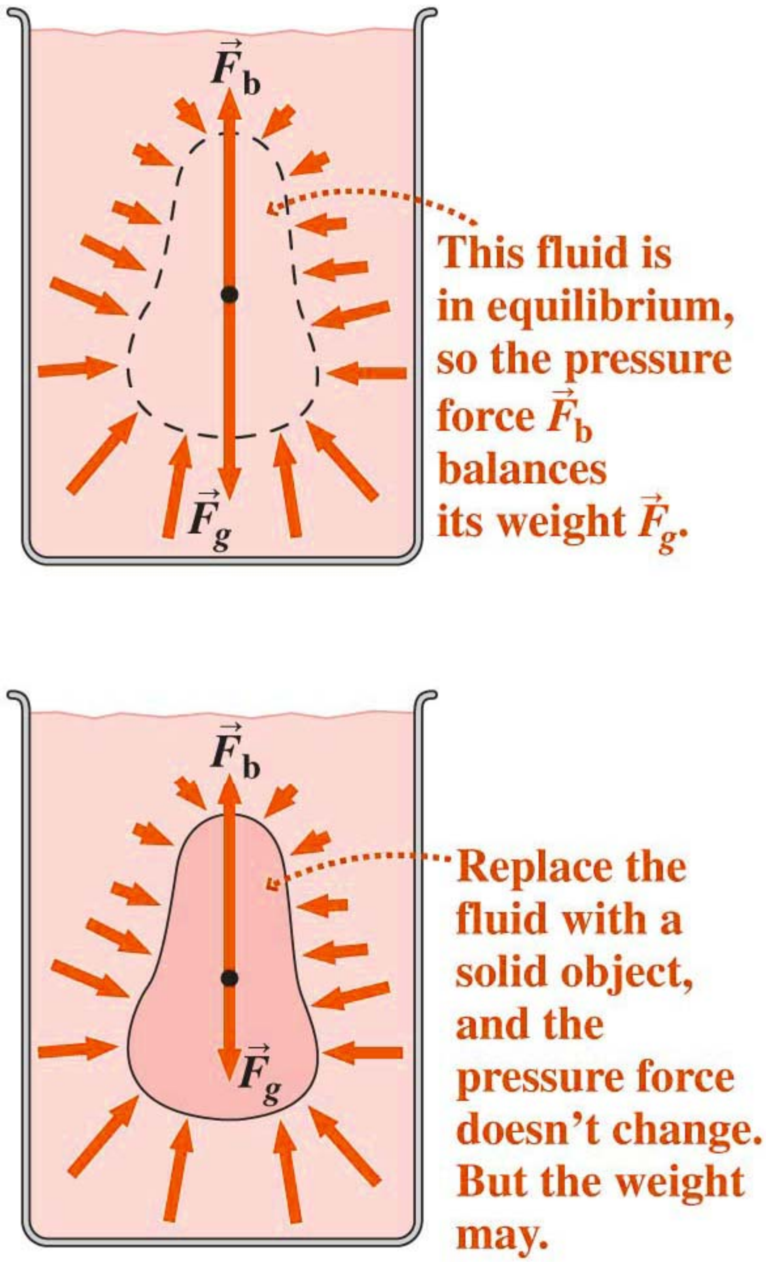
$$p = p_0 + \rho g h$$

where p_0 is the pressure at the surface.



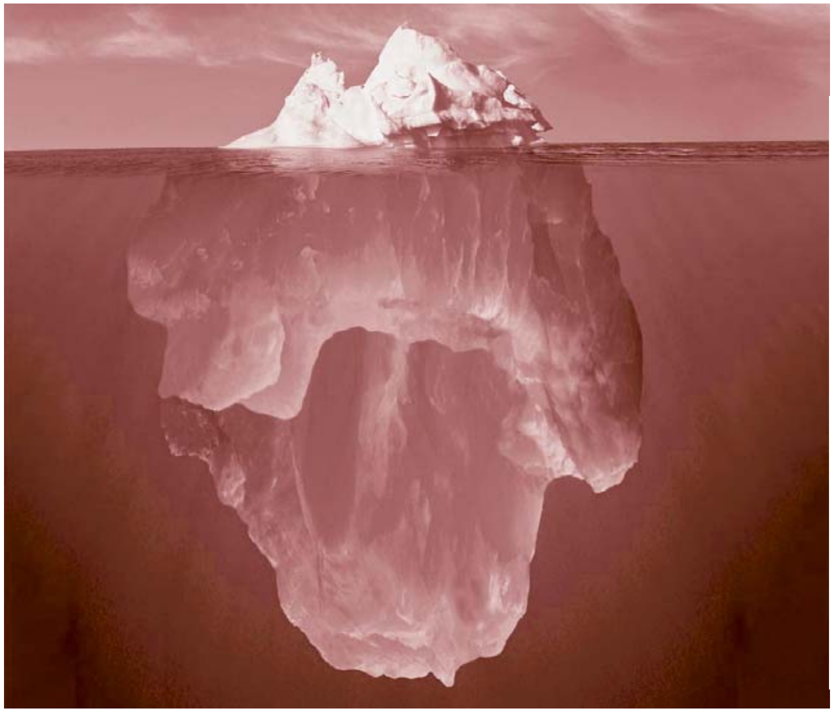
Recap: buoyancy

- When a fluid is in hydrostatic equilibrium, the force due to pressure differences on an arbitrary volume of fluid exactly balances the weight of the fluid.
- Replacing the fluid with an object of the same shape doesn't change the force due to the pressure differences.
  - Therefore the object experiences an upward force equal to the weight of the original fluid.
  - This is the **buoyancy force.**
  - **Archimedes' principle** states that the buoyancy force is equal to the weight of the displaced fluid.



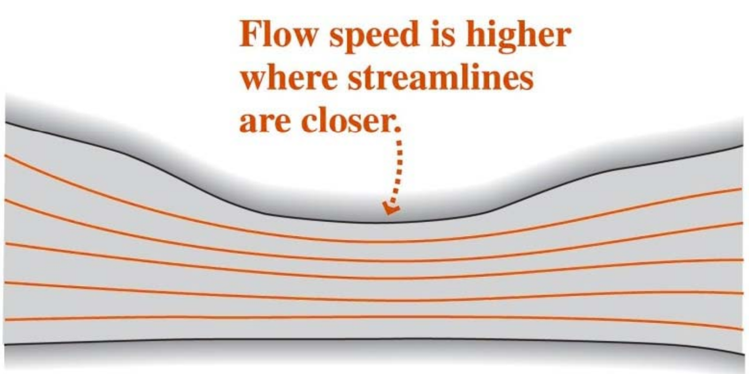
Recap: floating and sinking

- If a submerged object is less dense than a fluid, then the buoyancy force is greater than its weight, and the object rises.
  - In a liquid, it eventually reaches the surface.
    - Then the object floats at a level such that the buoyancy force equals its weight.
    - That means the submerged portion displaces a weight of liquid equal to the weight of the object.
  - In the atmosphere, a buoyant object like a balloon rises to a level where its density is equal to that of the atmosphere.
    - This is **neutral buoyancy**.



Fluid dynamics

- Moving fluids are characterized by their flow velocity as a function of position and time.
  - In **steady flow**, the velocity at a given point is independent of time.
    - Steady flows can be visualized with **streamlines** which are everywhere tangent to the local flow direction.
      - The density of streamlines reflects the flow speed.



Streamlines in an automobile wind-tunnel test

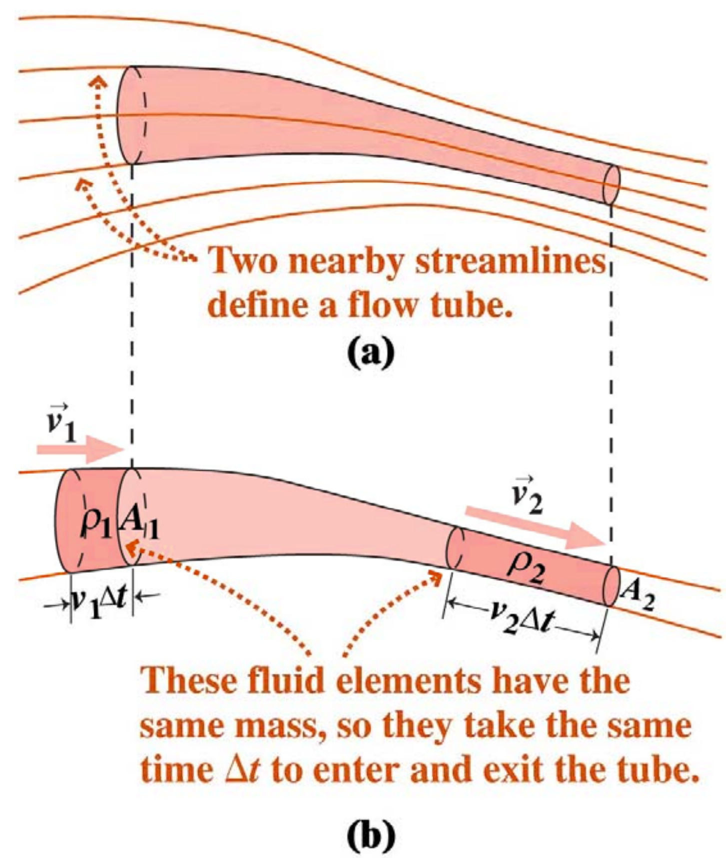
  - In **unsteady flow**, the fluid velocity at a given point varies with time.
    - Unsteady flows are more difficult to treat.

The continuity equation

- The **continuity equation** expresses conservation of mass in a moving fluid.
  - It follows from considering a **flow tube**, usually an imaginary tube bounded by nearby streamlines.
    - The flow tube may also be an actual physical tube or pipe.
- The continuity equation reads

  $$\rho v A = \text{constant}$$

  - Here ρ is the density, v the flow speed, and A the cross-sectional area; the quantities are evaluated at points along the same flow tube.
  - The quantity $\rho v A$ is the mass flow rate.
  - For incompressible fluids, density is constant and the continuity equation reduces to vA = constant.
    - Here vA is the volume flow rate.

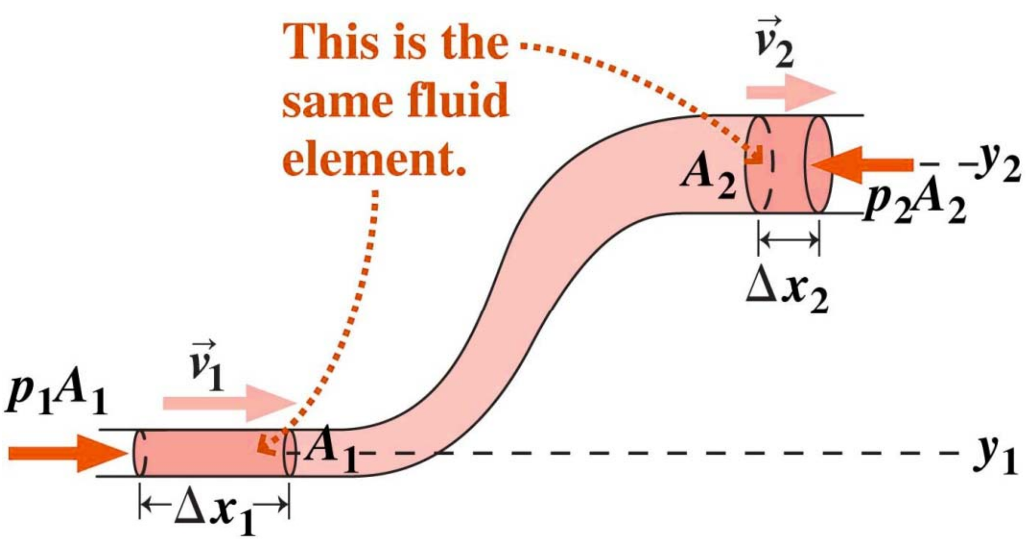


Bernoulli's equation

- Considering the work done as a fluid moves along a stream tube leads to **Bernoulli's equation**, a statement of energy conservation in a fluid.
  - Neglecting fluid friction (viscosity) and in the absence of mechanical pumps and turbines that add or remove energy from the fluid, Bernoulli's equation reads

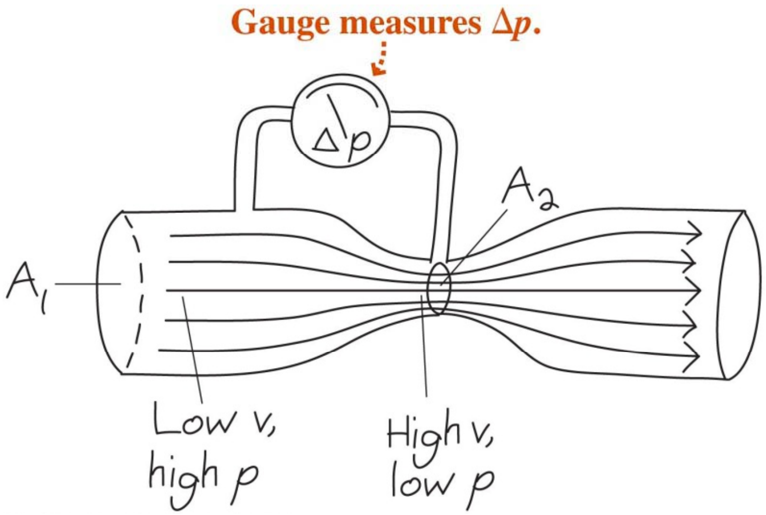
$$p + \tfrac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

where the quantities are evaluated along a flow tube.

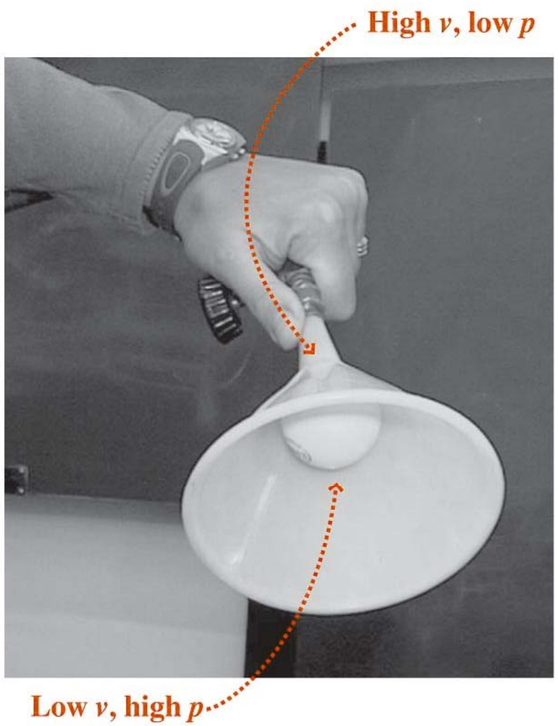


The Bernoulli effect

- For flows that don't involve height differences, Bernoulli's equation shows that higher flow speeds are accompanied by lower pressures, and vice versa.
  - This is the **Bernoulli effect.**



The venturi flow meter is one application of the Bernoulli effect. Measuring the pressure difference between the constriction and the unconstricted pipe gives a measure of the flow speed.



The ping-pong ball is supported by the downward flowing air in the inverted funnel, because of the higher pressure of the slower-moving air beneath the ball.

question

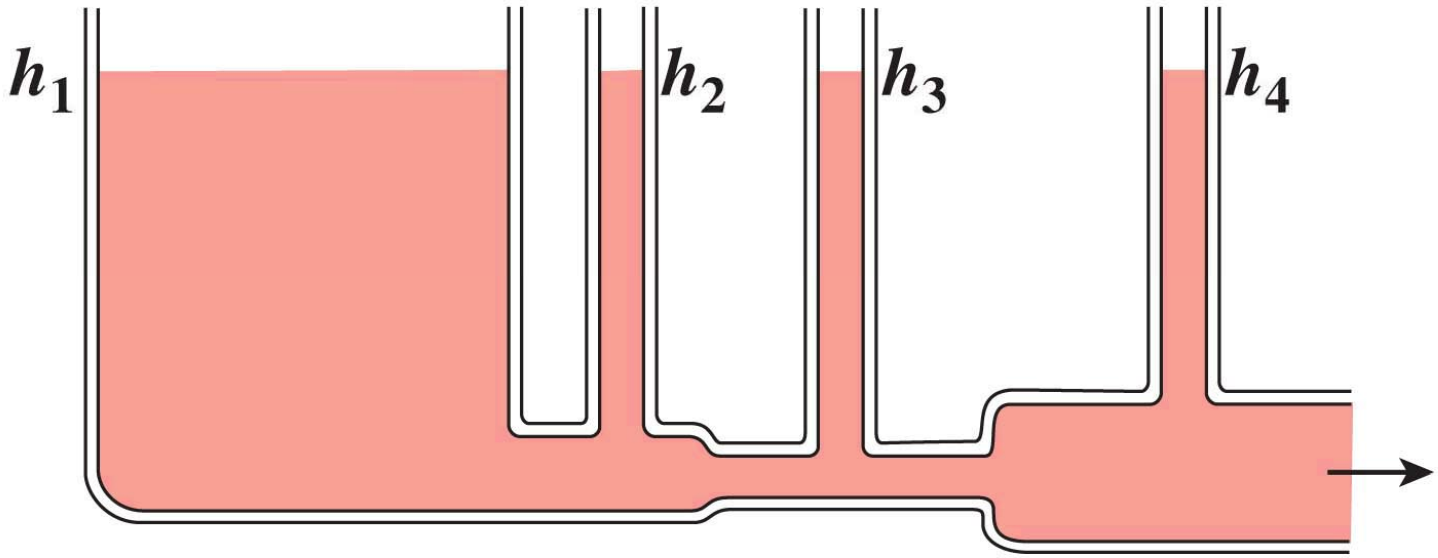
A large tank is filled with liquid to the level h_1 shown in the figure. It drains through a small pipe whose diameter varies. Emerging from each section of pipe are small tubes open to the atmosphere. Which of the tubes has the second-lowest liquid level when the liquid is flowing?

A. h_1

B. h_2

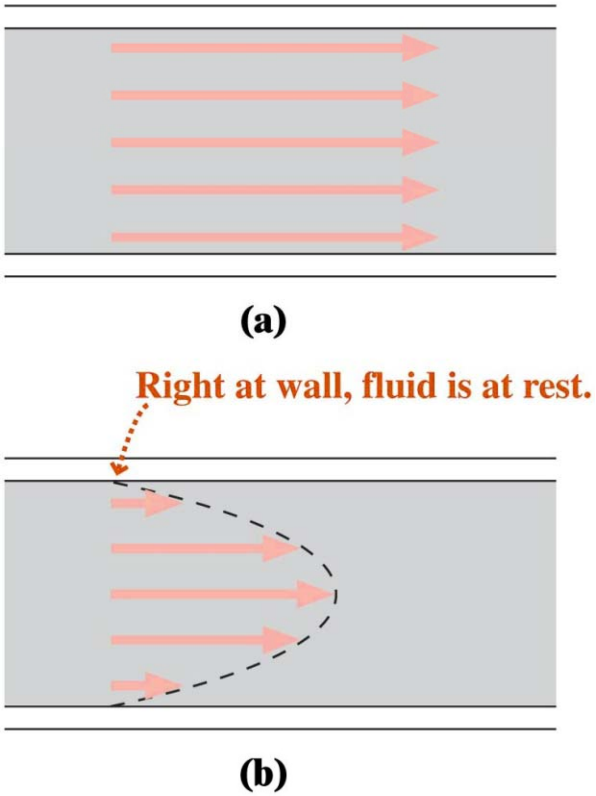
C. h_3

D. h_4



Viscosity and turbulence

- **Viscosity** is fluid friction.
  - It's associated with the transfer of momentum by molecules moving perpendicular to the fluid flow.
  - It also occurs where a fluid contacts pipe walls, river banks, and other material containers.
  - Viscosity dissipates flow energy.
- **Turbulence** is complex, chaotic, time-dependent fluid motion.



Without viscosity, flow in a pipe would be uniform. Viscous drag at the pipe walls introduces a parabolic flow profile.

Summary

- Fluid is matter that flows readily under the influence of external forces.
- Fluid is characterized by pressure, density, and flow velocity.
- Hydrostatic equilibrium characterizes stationary fluids under the influence of gravity.
  - Objects submerged in a fluid in hydrostatic equilibrium are subject to an upward buoyant force, equal to the weight of the displaced fluid.
  - Objects floating at the surface of a liquid displace a volume of water whose weight equals that of the object.
- Moving fluids conserve matter and, under appropriate circumstances, energy as well.
  - The continuity equation describes the conservation of matter.
  - Bernoulli's equation describes conservation of energy.
    - The Bernoulli effect describes the tradeoff between flow speed and pressure.
    - Where pressure is high, flow speed is low, and vice versa.
  - Viscosity and turbulence are more complicated aspects of fluid behavior.