Physics 2A
Chapter 13: Fluids

"*Keep in mind that neither success nor failure is ever final*." – Roger Ward Babson

"Our greatest glory is not in never failing, but in rising up every time we fail."
Ralph Waldo Emerson

"If you continue to do what you've always done, you'll continue to get what you've always got."
Yogi Berra

"Defeat is not defeat unless accepted as a reality in your own mind." – Bruce Lee

Reading: pages 405 – 431 (skip section 13.7)

Outline:

⇒ mass density
⇒ pressure
 definition
 pressure in a fluid
 atmospheric pressure
 nothing in physics sucks!
 pressure units
⇒ Pascal's principle (read on your own)
⇒ Bouyancy
 buoyant force
 Archimedes' principle
 float or sink?
⇒ fluids in motion
 ideal fluid (PowerPoint)
 equation of continuity
 Bernoulli's principle (Bernoulli effect)
 applications of Bernoulli's principle
 Bernoulli's equation

Problem Solving

Some problems require you to know the definitions of pressure and density. Remember that if the pressure is uniform and the surface is a plane, then $P = F/A$. If there are several surfaces, you may need to sum the forces vectorially to obtain the net force. Remember that each force is perpendicular to the surface on which it acts.

To calculate the pressure at depth d in a static incompressible fluid, use $p = p_0 + \rho g d h$, where p is the pressure at depth d, p_0 is the pressure at the top of the fluid, and ρ is the density of the fluid.

Two fundamental Archimedes' principle problems involve finding the buoyant force on an object, either floating or completely submersed in an incompressible fluid, and deciding if an object floats or sinks. These and many other Archimedes' law problems start with the equations $F_g = mg = (\rho g)V$ for the force of gravity and $F_b = \rho_f gV_f$ for the buoyancy, where ρ is the density of the object, ρ_f is the density of the fluid in which it is wholly or partially immersed, V is the volume of the object, and V_f is the volume of fluid displaced. If the object is floating with no other forces acting, then $\rho V = \rho_f V_f$.

For a fluid in motion, the volume flow rate gives the volume of fluid that passes a cross section per unit time and is given by Av, where A is the cross-sectional area of the tube and v is the fluid speed.

Bernoulli's equation is used to solve some problems. It relates conditions (density, fluid speed, pressure, and height above Earth) at one point in the steady flow of a nonviscous, incompressible fluid to conditions at another point. If you are given all but one of these quantities you can use Bernoulli's equation to solve for the unknown quantity.

Questions and Example Problems from Chapter 13

Question 1
A closed tank is completely filled with water. A valve is then opened at the bottom of the tank and water begins to flow out. When the water stops flowing, will the tank be completely empty, or will there still be a noticeable amount of water in it? Explain your answer.

Question 2
A steel beam is suspended completely under water by a cable that is attached to one end of the beam, so it hangs vertically. Another identical beam is also suspended completely under water, but by a cable that is attached to the beam so it hangs horizontally. Which beam, if either, experiences the greater buoyant force? Provide a reason for your answer. Neglect any change in water density with depth.

SUMMARY

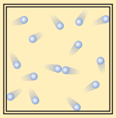
The goal of Chapter 13 has been to understand the static and dynamic properties of fluids.

GENERAL PRINCIPLES

Fluid Statics

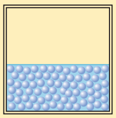
Gases

- Freely moving particles
- Compressible
- Pressure mainly due to particle collisions with walls



Liquids

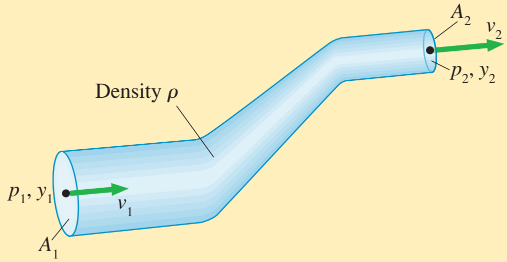
- Loosely bound particles
- Incompressible
- Pressure due to the weight of the liquid
- Hydrostatic pressure at depth d is $p = p_0 + \rho g d$
- The pressure is the same at all points on a horizontal line through a liquid (of one kind) in hydrostatic equilibrium



Fluid Dynamics

Ideal-fluid model

- Incompressible
- Smooth, laminar flow
- Nonviscous



Equation of continuity

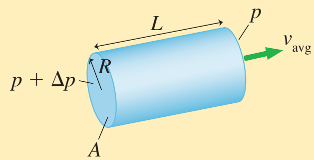
Volume flow rate $Q = \dfrac{\Delta V}{\Delta t} = v_1 A_1 = v_2 A_2$

Bernoulli's equation is a statement of energy conservation:

$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$

Poiseuille's equation governs viscous flow through a tube:

$$Q = v_{avg} A = \frac{\pi R^4 \Delta p}{8 \eta L}$$



IMPORTANT CONCEPTS

Density $\rho = m/V$, where m is mass and V is volume.

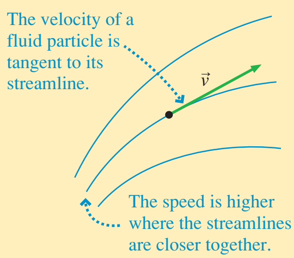
Pressure $p = F/A$, where F is force magnitude and A is the area on which the force acts.

- Pressure exists at all points in a fluid.
- Pressure pushes equally in all directions.
- Gauge pressure $p_g = p - 1$ atm.

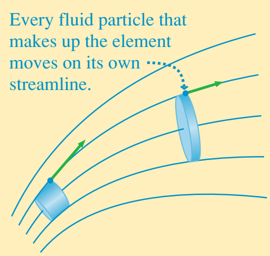
Viscosity η is the property of a fluid that makes it resist flowing.

Representing fluid flow

Streamlines are the paths of individual fluid particles.



Fluid elements contain a fixed volume of fluid. Their shape may change as they move.

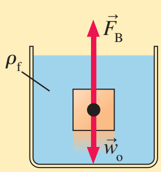


APPLICATIONS

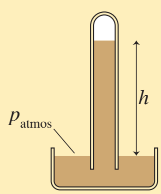
Buoyancy is the upward force of a fluid on an object immersed in the fluid.

Archimedes' principle: The magnitude of the buoyant force equals the weight of the fluid displaced by the object.

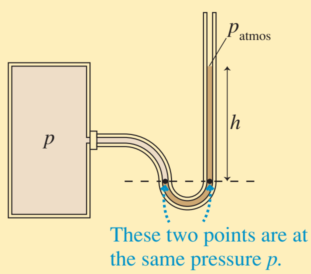
Sink:	$\rho_{avg} > \rho_f$	$F_B < w_o$
Float:	$\rho_{avg} < \rho_f$	$F_B > w_o$
Neutrally buoyant:	$\rho_{avg} = \rho_f$	$F_B = w_o$



Barometers measure atmospheric pressure. Atmospheric pressure is related to the height of the liquid column by $p_{atmos} = \rho g h$.



Manometers measure pressure. The pressure at the closed end of the tube is $p = 1\text{ atm} + \rho g h$.



Problem 1
A pirate in a movie is carrying a chest (0.30 m × 0.30 m × 0.20 m) that is supposed to be filled with gold. To see how ridiculous this is, determine the weight (in newtons) of the gold. To judge how large this weight is, remember that 1 N = 0.225 lb.

Problem 2
An airtight box has a removable lid of area 1.3×10^{-2} m^2 and negligible weight. The box is taken up a mountain where the air pressure outside the box is 0.85×10^5 Pa. The inside of the box is completely evacuated. What is the magnitude of the force required to pull the lid off the box?

Problem 3
High-heeled shoes can cause tremendous pressure to be applied to a floor. Suppose that the radius of a heel is 6.00×10^{-3} m. At times during a normal walking motion, nearly the entire body weight acts perpendicular to the surface of the heel. Find the pressure that is applied to the floor under the heel because of the weight of a 50.0 kg woman.

Problem 4
At a depth of 10.9 km, the Challenger Deep in the Marianas Trench of the Pacific Ocean is the deepest site in any ocean. Yet, in 1960, Donald Walsh and Jacques Piccard reached the Challenger Deep in the bathyscaphe *Triete*. Assuming that seawater has a uniform density of 1024 kg/m^3, calculate the force the water would exert at a depth of 10.9 km on a round observation window of diameter 25 cm.

Problem 5
At a given instant, the blood pressure in the heart is 1.6×10^4 Pa. If an artery in the brain is 0.45 m above the heart, what is the pressure in the artery? Ignore any pressure changes due to blood flow.

Problem 6
A solid block is attached to a spring scale. When the block is suspended in air the scale reads 20.0 N; when it is completely immersed in water the scale reads 17.7 N. What is the (a) volume and (b) density of the block?

Problem 7
Only a small part of an iceberg protrudes above the water, while the bulk lies below the surface. The density of ice is 917 kg/m^3 and that of seawater is 1025 kg/m^3. Find the percentage of the iceberg's volume that lies below the surface.

Problem 8

A water line with an internal radius of 6.5×10^{-3} m is connected to a shower head that has 12 holes. The speed of the water in the line is 1.2 m/s. (a) What is the volume flow rate in the line? (b) At what speed does the water leave one of the holes (effective hole radius = 4.6×10^{-4} m) in the head?

Problem 9

Water flows through a pipe of radius 8.0 cm with a speed of 10.0 m/s. It then enters a smaller pipe of radius 3.0 cm. What is the speed of the water as it flows through the smaller pipe? Assume that the water is incompressible.

Problem 10
An airplane has an effective wing surface area of 16 m^2 that is generating the lift force. In level flight the air speed over the top of the wings is 62.0 m/s, while the air speed beneath the wings is 54.0 m/s. What is the weight of the plane?

Problem 11
Suppose that a 15 m/s wind is blowing across the roof of your house. The density of air is 1.29 kg/m^3. (a) Determine the reduction in pressure (below atmospheric pressure of stationary air) that accompanies this wind. (b) Explain why some roofs are "blown outward" during high winds.