Chapter 15 Fluid

- **Density**
- **Pressure**
- **Static Equilibrium in Fluids: Pressure and Depth**
- **Archimedes' Principle and Buoyancy**
- **Applications of Archimedes' Principle**

Units of Chapter 15

- **Fluid Flow and Continuity**
- **Bernoulli's Equation**
- **Applications of Bernoulli's Equation**
- **Viscosity and Surface Tension (optional)**

15-1 Density

The density of a material is its mass per unit volume:

Definition of Density, ρ

$$\rho = M/V$$

SI unit: kg/m^3

TABLE 15–1
Densities of Common Substances

Substance	Density (kg/m^3)
Gold	19,300
Mercury	13,600
Lead	11,300
Silver	10,500
Iron	7860
Aluminum	2700
Ebony (wood)	1220
Ethylene glycol (antifreeze)	1114
Whole blood (37 °C)	1060
Seawater	1025
Freshwater	1000
Olive oil	920
Ice	917
Ethyl alcohol	806
Cherry (wood)	800
Balsa (wood)	120
Styrofoam	100
Oxygen	1.43
Air	1.29
Helium	0.179

15-2 Pressure

Pressure is force per unit area:

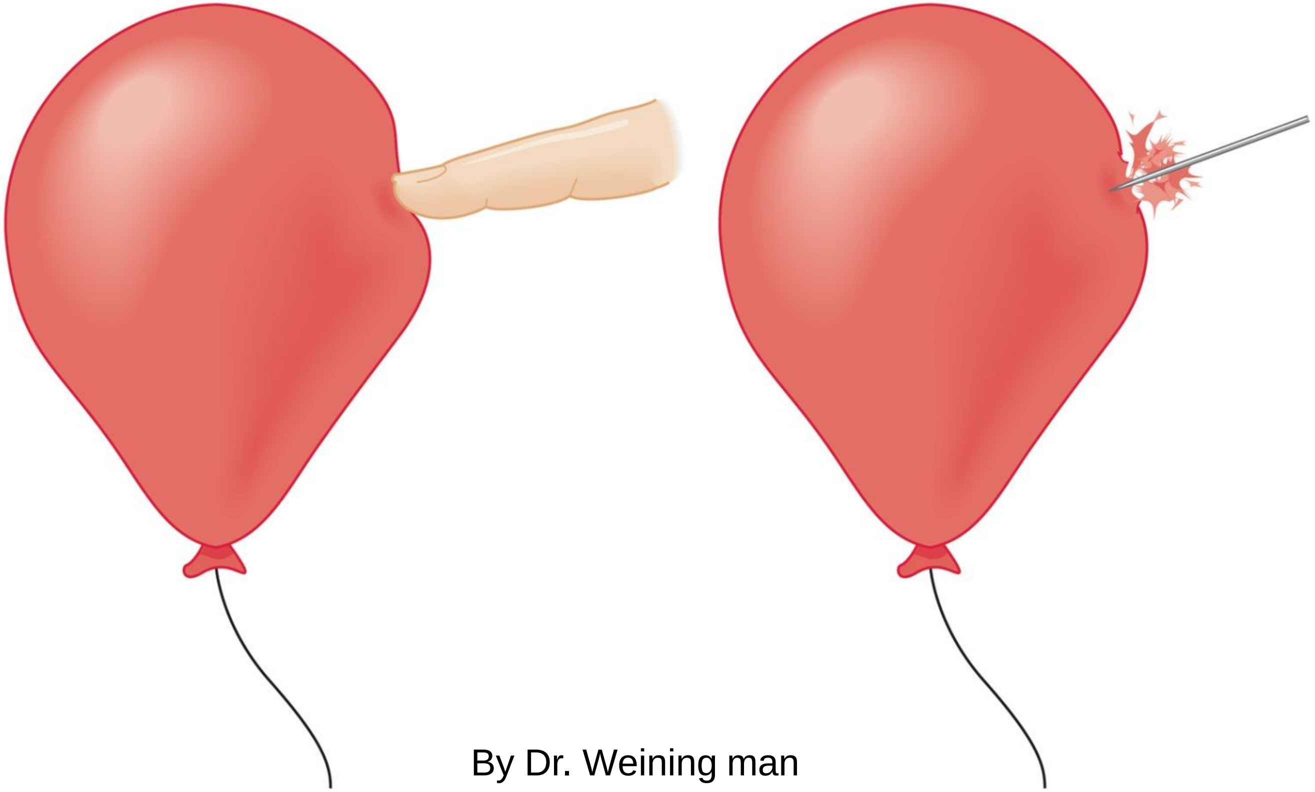
Definition of Pressure, *P*

$$P = F/A$$

SI unit: N/m^2

15-2 Pressure

The same force applied over a smaller area results in greater pressure – think of poking a balloon with your finger and then with a needle.



15-2 Pressure

Atmospheric pressure is due to the weight of the atmosphere above us.

Atmospheric Pressure, P_{at}

$$P_{at} = 1.01 \times 10^5\ \mathrm{N/m^2}$$

SI unit: $\mathrm{N/m^2}$

The pascal (Pa) is 1 $\mathrm{N/m^2}$. Pressure is often measured in pascals.

15-2 Pressure

There are a number of different ways to describe atmospheric pressure.

In pascals: $P_{\mathrm{at}} = 101\ \mathrm{kPa}$

In pounds per square inch: $P_{\mathrm{at}} = 14.7\ \mathrm{lb/in^2}$

In bars:

$$1\ \mathrm{bar} = 10^5\ \mathrm{Pa} \approx 1\ P_{\mathrm{at}}$$

15-2 Pressure

Since atmospheric pressure acts uniformly in all directions, we don’t usually notice it.

Therefore, if you want to, say, add air to your tires to the manufacturer’s specification, you are not interested in the total pressure. What you are interested in is the gauge pressure – how much more pressure is there in the tire than in the atmosphere?

$$P_{\mathrm{g}} = P - P_{\mathrm{at}}$$

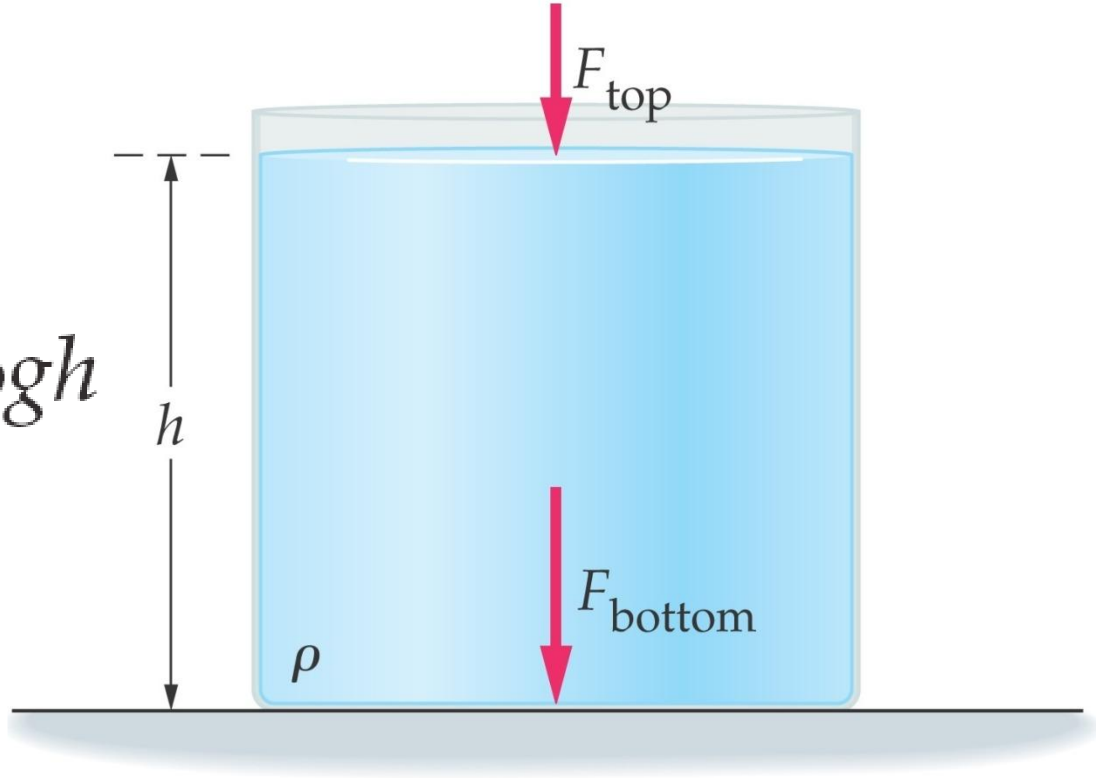
Also the blood pressure that we often talk about is how much more pressure is there in than in the atmosphere?

15-3 Static Equilibrium in Fluids: Pressure and Depth

The increased pressure as an object descends through a fluid is due to the increasing mass of the fluid above it.

$$F_{top} = P_{at} A$$

$$P_{bottom} = P_{at} + \rho g h$$

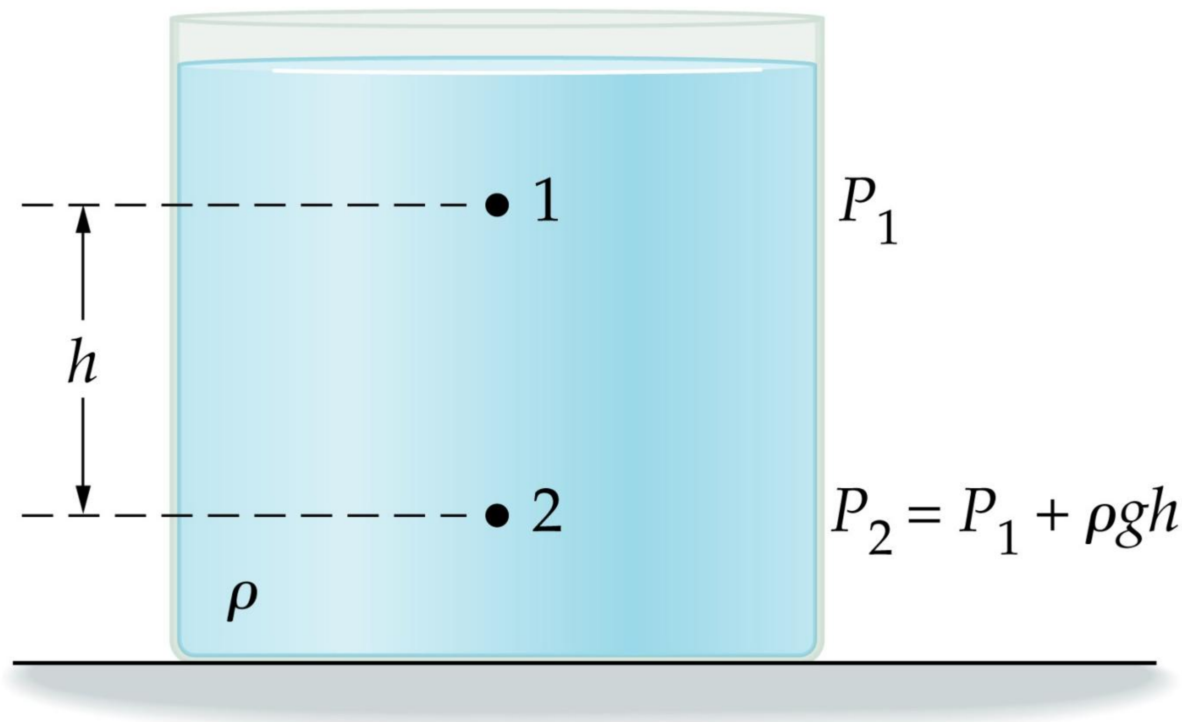


(a)

15-3 Static Equilibrium in Fluids: Pressure and Depth

Dependence of Pressure on Depth

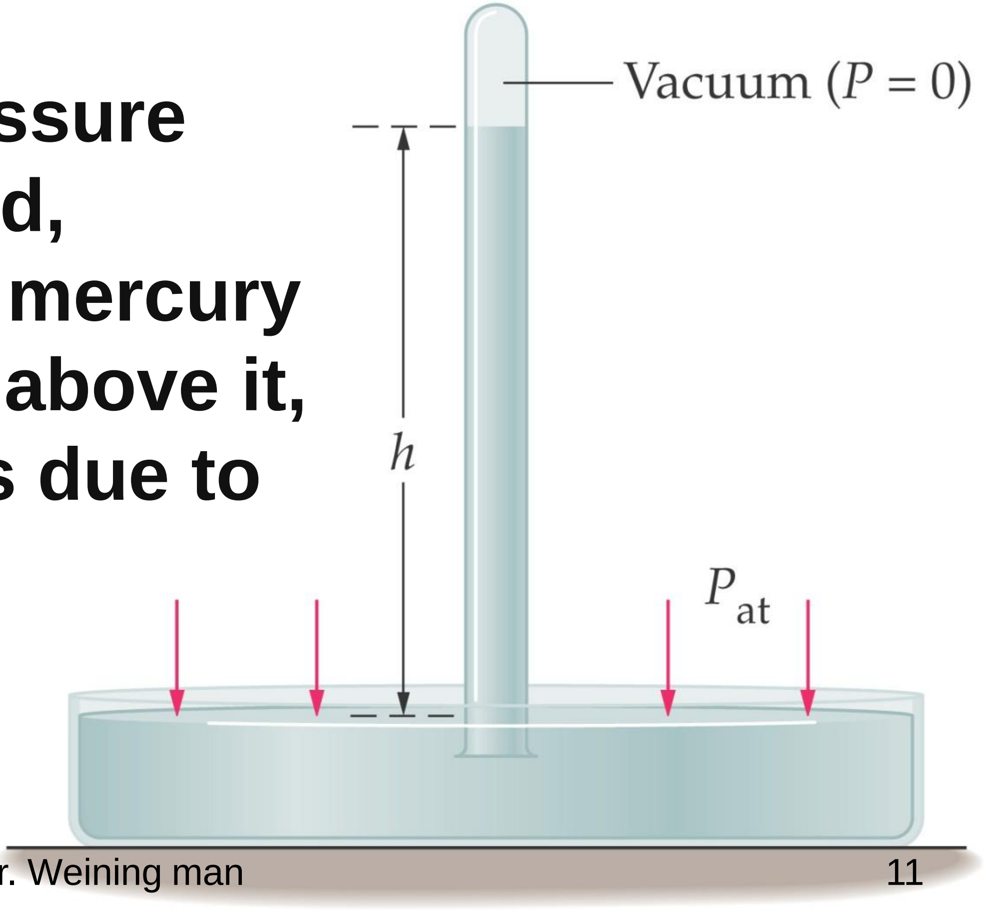
$$P_2 = P_1 + \rho g h$$



(b)

15-3 Static Equilibrium in Fluids: Pressure and Depth

A barometer compares the pressure due to the atmosphere to the pressure due to a column of fluid, typically mercury. The mercury column has a vacuum above it, so the only pressure is due to the mercury itself.



15-3 Static Equilibrium in Fluids: Pressure and Depth

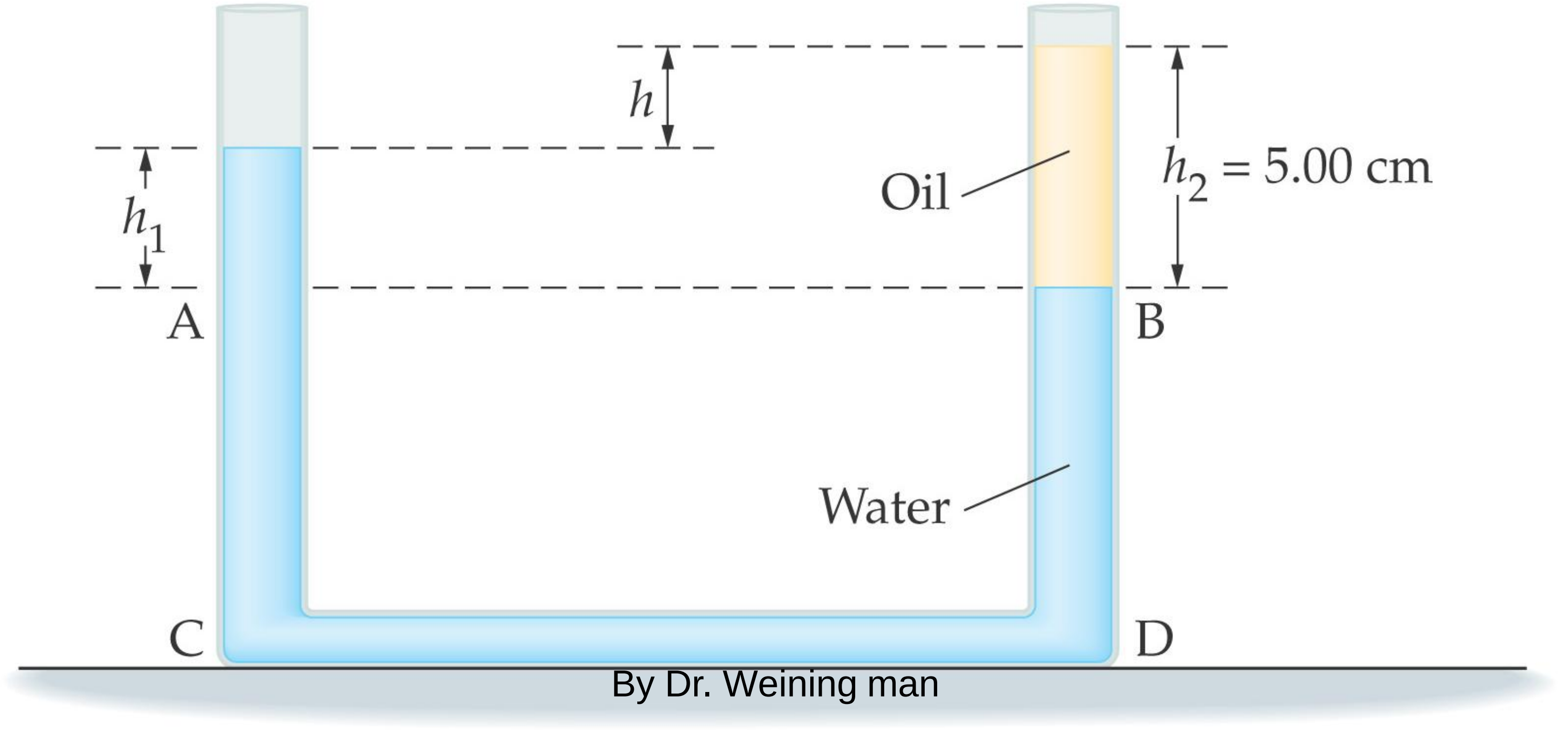
This leads to the definition of atmospheric pressure in terms of millimeters of mercury:

$$1 \text{ atmosphere} = P_{\text{at}} = 760 \text{ mmHg}$$

In the barometer, the level of mercury is such that the pressure due to the column of mercury is equal to the atmospheric pressure.

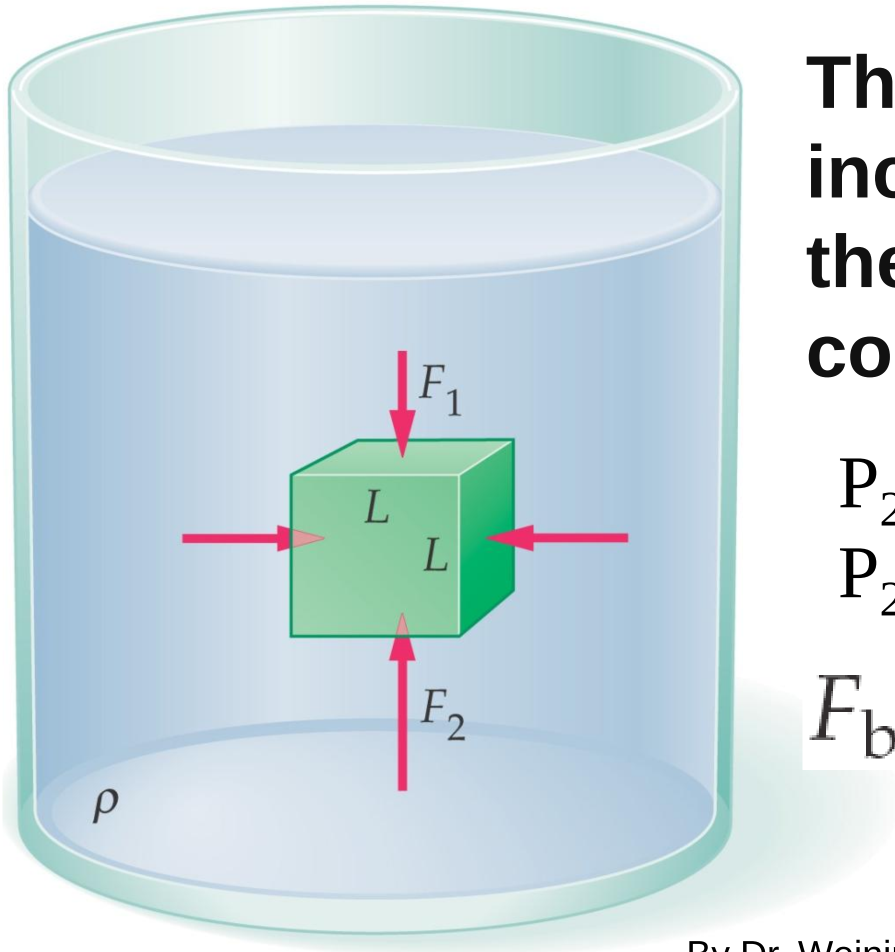
15-3 Static Equilibrium in Fluids: Pressure and Depth

This is true in any container where the fluid can flow freely – the pressure will be the same at the same height.



15-4 Archimedes' Principle and Buoyancy

A fluid exerts a net upward force on any object it surrounds, called the buoyant force.



This force is due to the increased pressure at the bottom of the object compared to the top.

$P_2 > P_1$;

$P_2 - P_1 = \rho \, g \, L$

$$F_b = F_2 - F_1 = \rho g L^3$$

15-4 Archimedes' Principle and Buoyancy

Archimedes' Principle: An object completely immersed in a fluid experiences an upward buoyant force equal in magnitude to the weight of fluid displaced by the object.

Buoyant Force When a Volume *V* Is Submerged in a Fluid of Density ρ

$$F_b = \rho g V$$

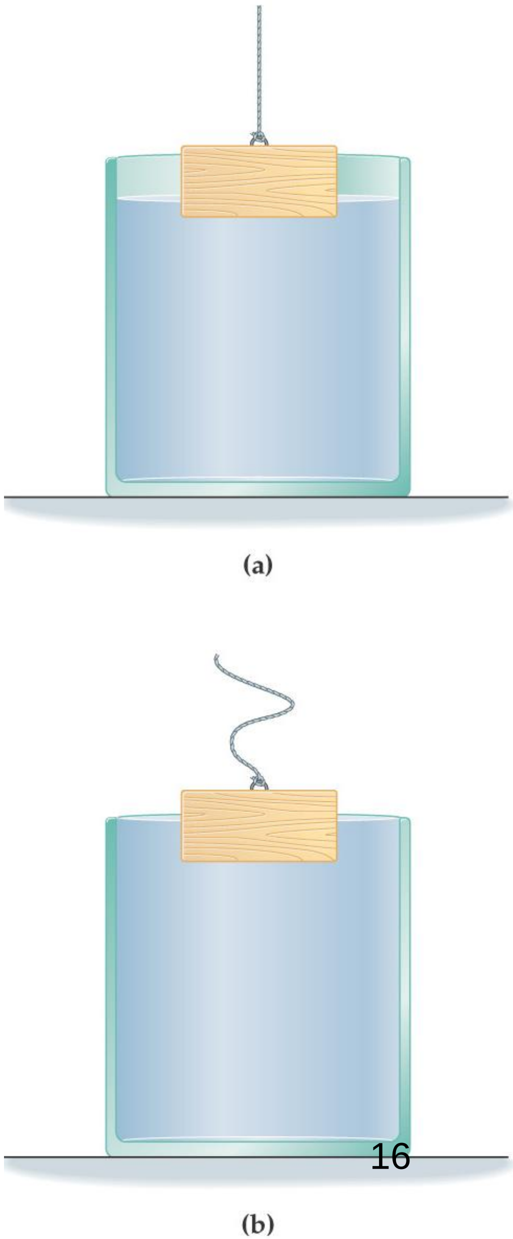
SI unit: N

Here the Volume is the volume submerged in Fluid.

15-5 Applications of Archimedes' Principle

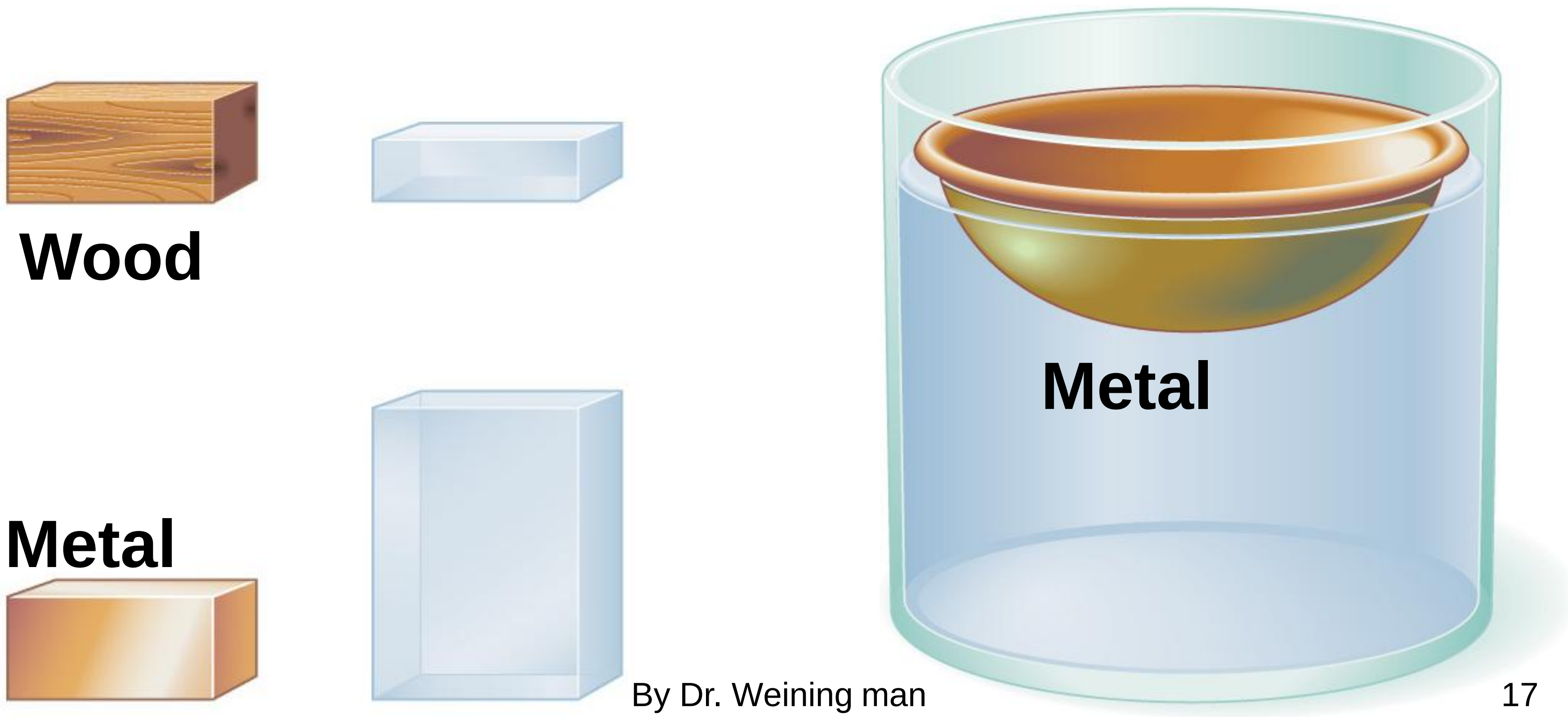
An object floats, when the buoyancy force is equal to its weight.

An object floats, when it displaces an amount of fluid equal to its weight.



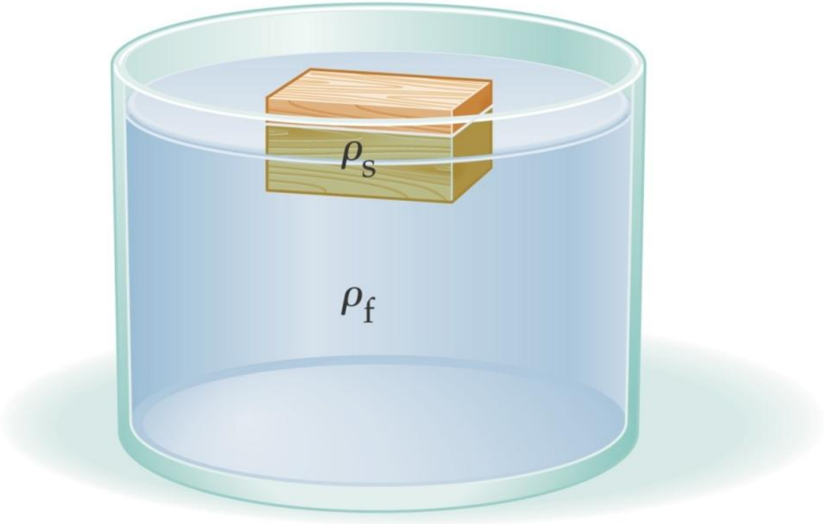
15-5 Applications of Archimedes' Principle

An object made of material that is denser than water can float only if it has indentations or pockets of air that make its average density less than that of water.



15-5 Floating object

The fraction of an object that is submerged when it is floating depends on the densities of the object and of the fluid.



1, Analyze forces:

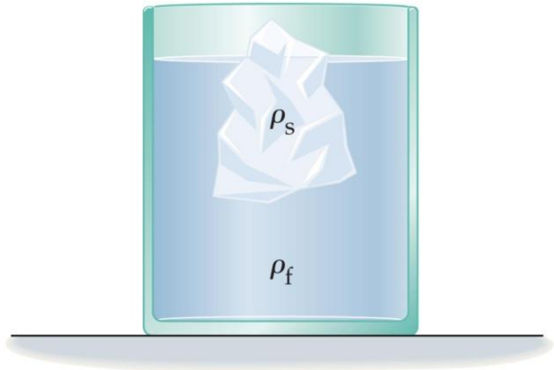
2, F_b=mg;

$$F_b = \rho_{fluid} V_{sub} g$$

$$mg = \rho_{object} V_{object} g$$

$$\rho_{fluid} V_{sub} = \rho_{object} V_{object}$$

$$V_{sub} = \rho_{object} V_{object} / \rho_{fluid}$$



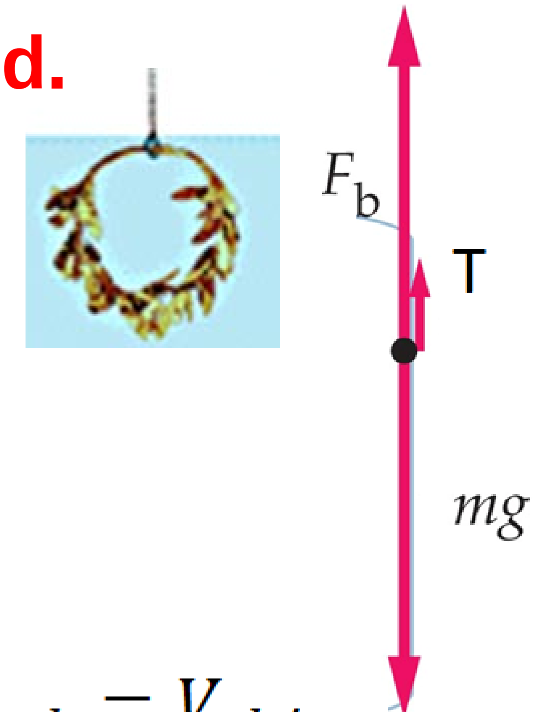
Ice density = 0.9 water density

$V_{sub}/V = \rho_{ice}/\rho_{water}$ =0.9

That's why "The tip of a iceberg" means a very small portion

15-5 When buoyancy force is not equal to the object's mg

To measure apparent weight in liquid.



1, Analyze forces:

2, $F_b + T = mg$;

By comparing Tension and mg, you can find buoyancy force.

3. $F_b = \rho_{fluid} V_{sub} g$

If it is completely submerged in, $V_{sub} = V_{object}$

You can find the volume if a irregular shaped object.

4, $mg = \rho_{object} V_{object} g$

To use the volume of the object, you can find its density using its real mg.

15-5 When buoyancy force is not equal to the object's mg

Object sinking or raising down in fluid

They are completely submerged in, V_{sub}=V

1, Analyze forces:

2, F_b – mg = ma; (raising) mg – F_b = ma; (sinking)

By comparing buoyancy force and mg, you can find net force and acceleration.

$$mg = \rho_{object} V_{object} g$$

$$F_b = \rho_{fluid} V_{sub} g \qquad V_{sub} = V_{object} = V$$

Plug F_b and mg in to step 2 and get net force.

a = net force / m ; a = net force / (ρ_{object}V)

Notice that V cancels, a is only determined by fluid and object density as well as g.

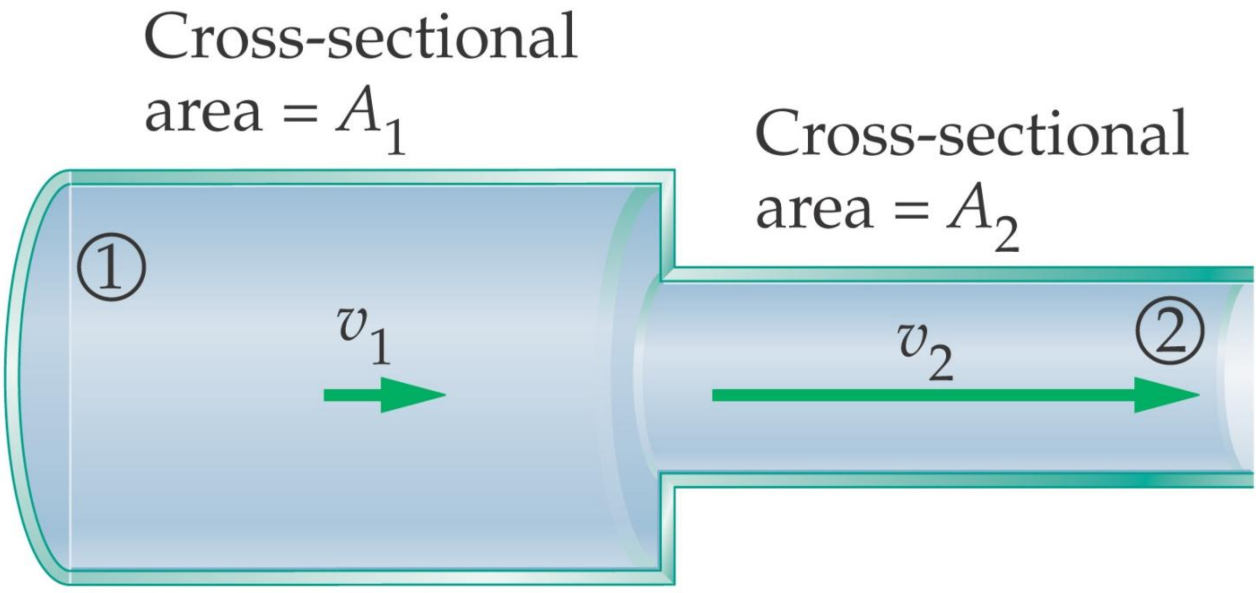
By Dr. Weining man

15-6 Fluid Flow and Continuity

Continuity tells us that whatever the volume of fluid in a pipe passing a particular point per second, the same volume must pass every other point in a second. The fluid is not accumulating or vanishing along the way.

This means that where the pipe is narrower, the flow is faster, as everyone who has played with the spray from a drinking fountain well knows.

15-6 Fluid Flow and Continuity



Equation of Continuity

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

15-6 Fluid Flow and Continuity

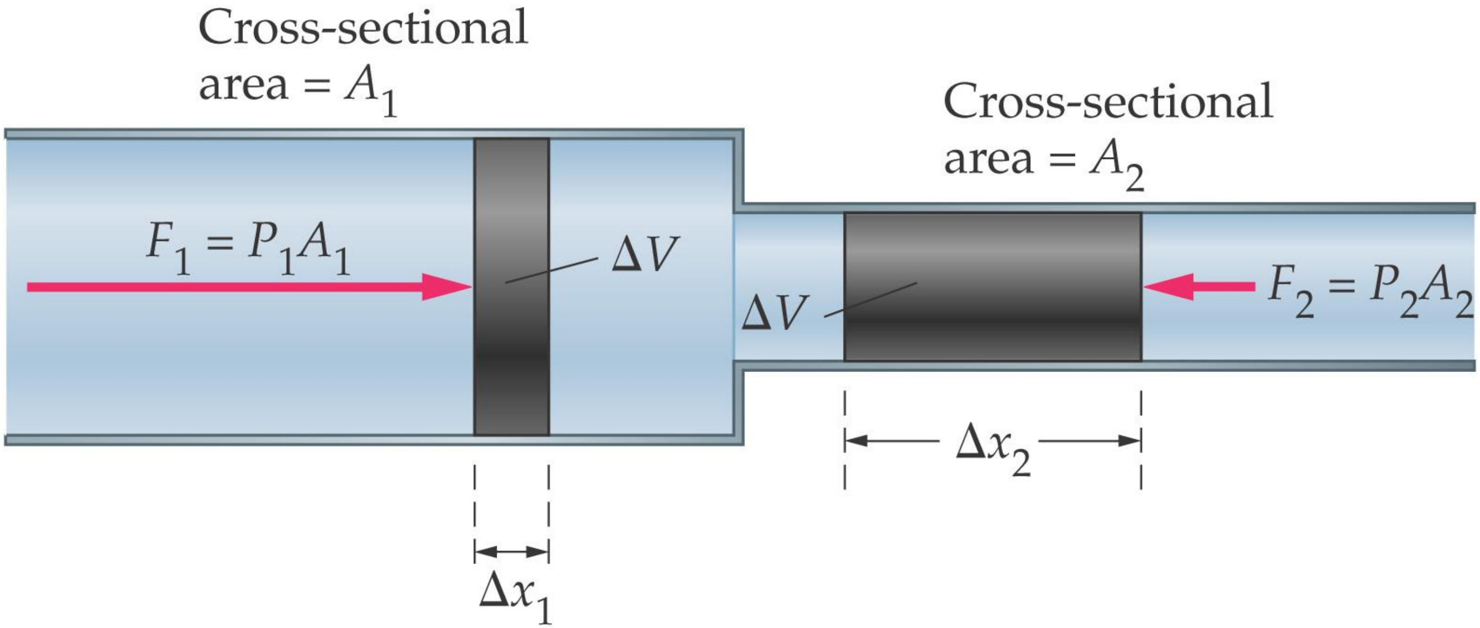
Most gases are easily compressible; most liquids are not. Therefore, the density of a liquid may be treated as constant, but not that of a gas.

Equation of Continuity for an Incompressible Fluid

$$A_1 v_1 = A_2 v_2$$

15-7 Bernoulli's Equation

When a fluid moves from a wider area of a pipe to a narrower one, its speed increases; therefore, work has been done on it.



$$\Delta W_{\text{total}} = (P_1 - P_2)\Delta V$$

15-7 Bernoulli's Equation

The kinetic energy of a fluid element is:

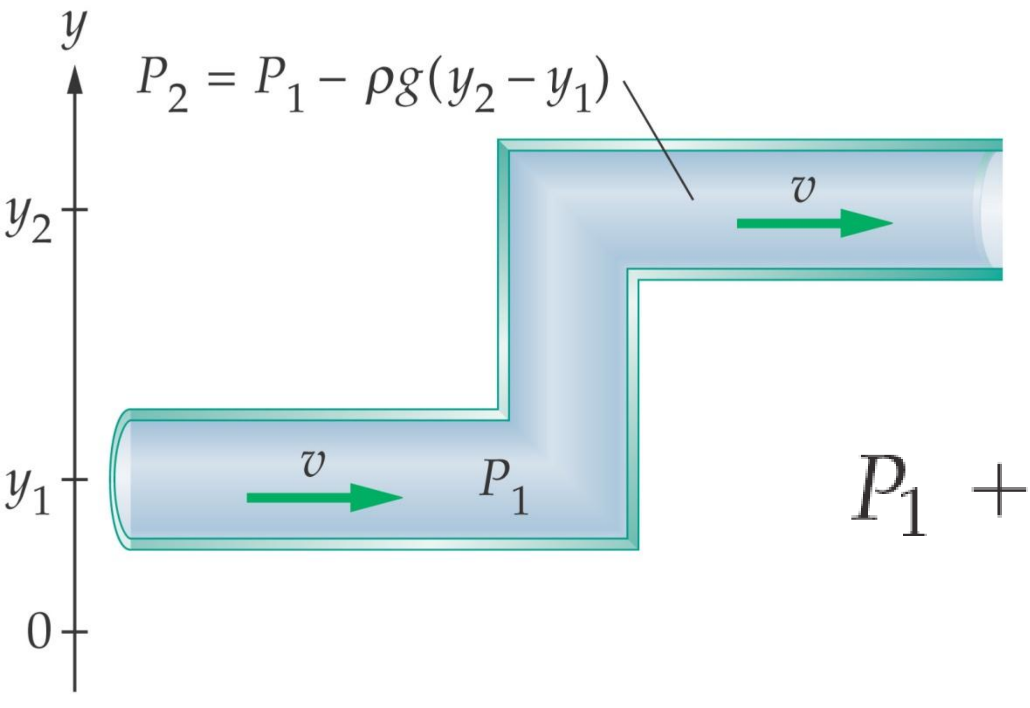
$$K = \frac{1}{2}(\Delta m)v^2 = \frac{1}{2}(\rho \Delta V)v^2$$

Equating the work done to the increase in kinetic energy gives:

$$P_1 + \frac{1}{2}\rho {v_1}^2 = P_2 + \frac{1}{2}\rho {v_2}^2$$

15-7 Bernoulli's Equation

If a fluid flows in a pipe of constant diameter, but changes its height, there is also work done on it against the force of gravity.



Equating the work done with the change in potential energy gives:

$$P_1 + \rho g y_1 = P_2 + \rho g y_2$$

15-7 Bernoulli's Equation

The general case, where both height and speed may change, is described by Bernoulli's equation:

Bernoulli's Equation

$$P_1 + \frac{1}{2}\rho v_1{}^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2{}^2 + \rho g y_2$$

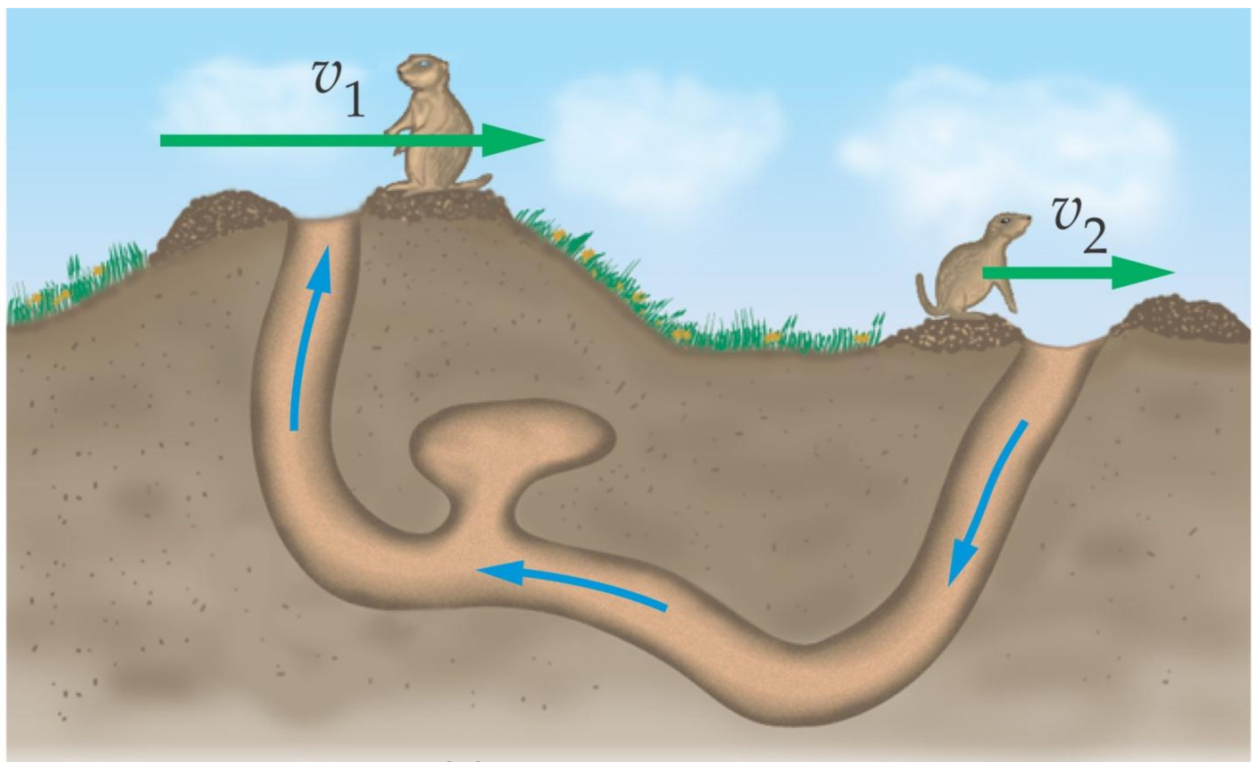
This equation is essentially a statement of conservation of energy in a fluid.

15-8 Applications of Bernoulli's Equation

The Bernoulli effect is simple to demonstrate – all you need is a sheet of paper. Hold it by its end, so that it would be horizontal if it were stiff, and blow across the top. The paper will rise, due to the higher speed, and therefore lower pressure, above the sheet.

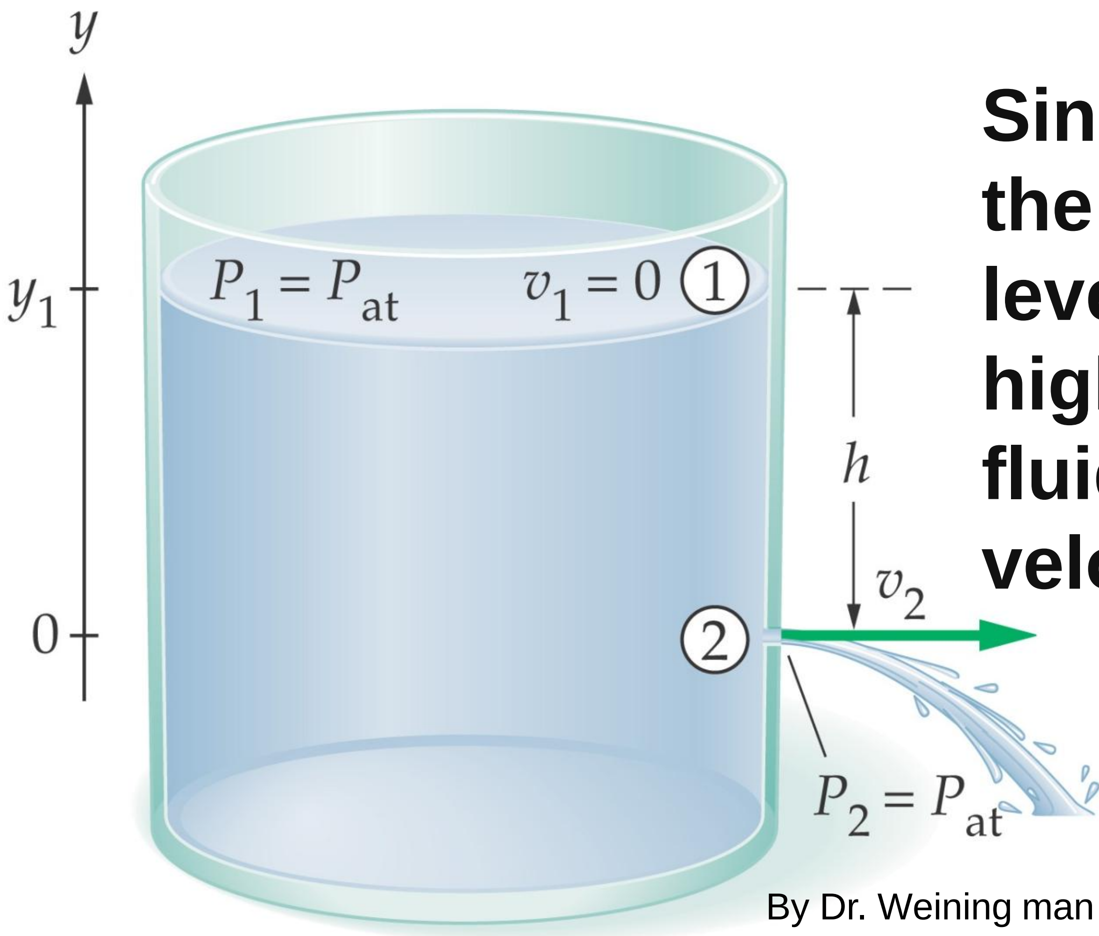
15-8 Applications of Bernoulli's Equation

This lower pressure at high speeds is what rips roofs off houses in hurricanes and tornadoes, and causes the roof of a convertible to expand upward. It even helps prairie dogs with air circulation!



15-8 Applications of Bernoulli's Equation

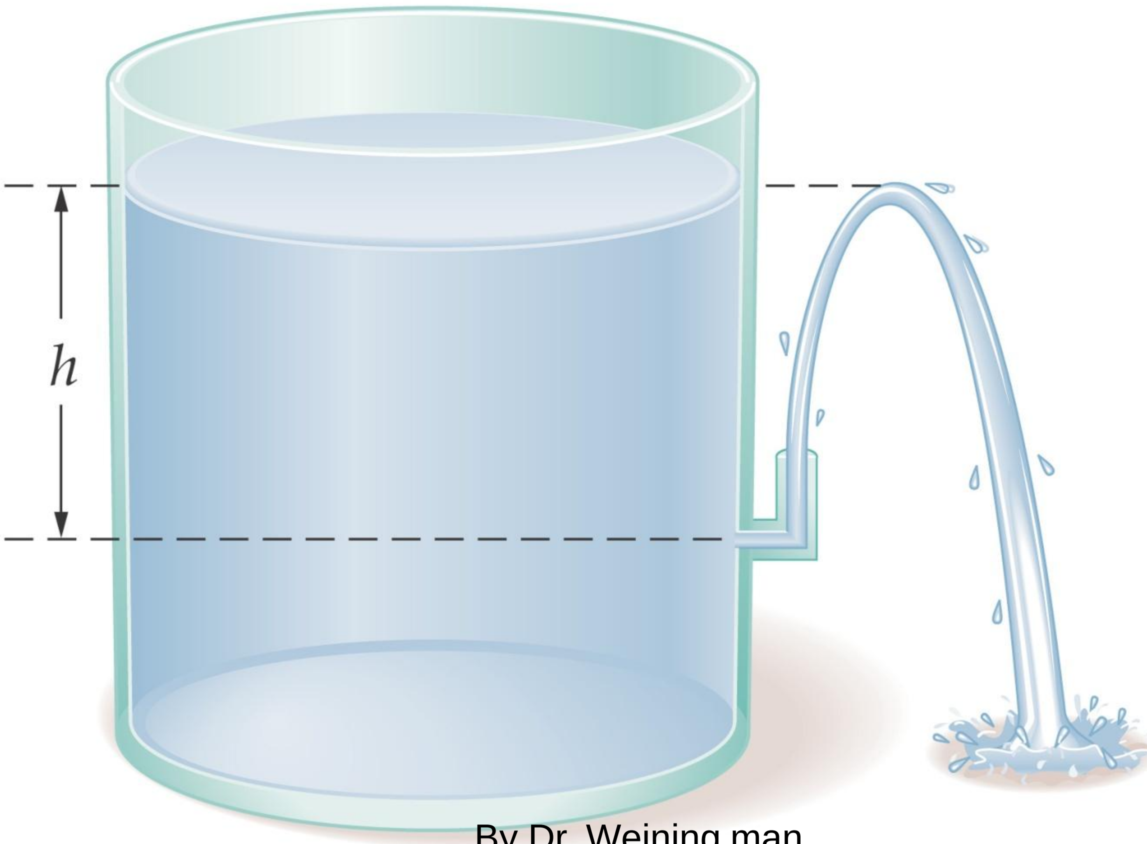
If a hole is punched in the side of an open container, the outside of the hole and the top of the fluid are both at atmospheric pressure.



Since the fluid inside the container at the level of the hole is at higher pressure, the fluid has a horizontal velocity as it exits.

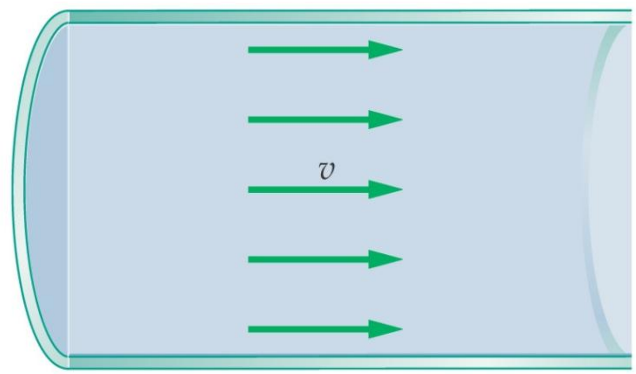
15-8 Applications of Bernoulli's Equation

If the fluid is directed upwards instead, it will reach the height of the surface level of the fluid in the container.



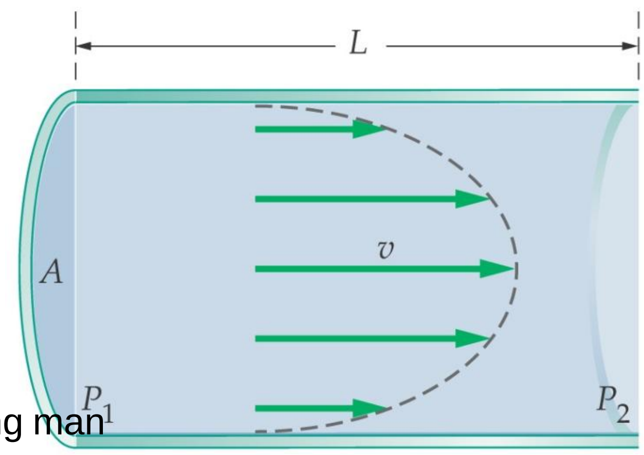
15-9 Viscosity and Surface Tension

Viscosity is a form of friction felt by fluids as they flow along surfaces. We have been dealing with nonviscous fluids, but real fluids have some viscosity.



(a)

A viscous fluid will have zero velocity next to the walls and maximum velocity in the center.



(b)

15-9 Viscosity and Surface Tension

It takes a force to maintain a viscous flow, just as it takes a force to maintain motion in the presence of friction.

A fluid is characterized by its coefficient of viscosity, *η*. It is defined so that the pressure difference in the fluid is given by:

$$P_1 - P_2 = 8\pi\eta\frac{vL}{A}$$

15-9 Viscosity and Surface Tension

Using this to calculate the volume flow rate yields:

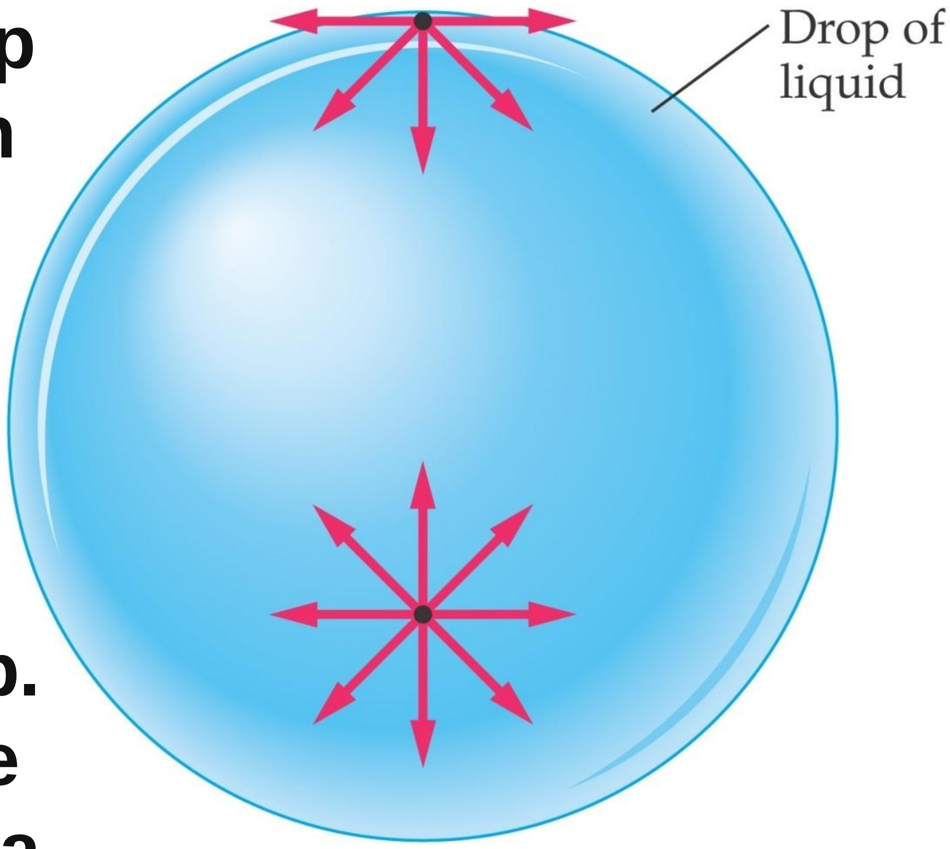
$$\text{volume flow rate} = \frac{\Delta V}{\Delta t} = vA = \frac{(P_1 - P_2)A^2}{8\pi\eta L}$$

$$= \frac{(P_1 - P_2)\pi r^4}{8\eta L}$$

Note the dependence on the fourth power of the radius of the tube!

15-9 Viscosity and Surface Tension

A molecule in the center of a liquid drop experiences forces in all directions from other molecules. A molecule on the surface, however, experiences a net force toward the drop. This pulls the surface inward so that its area is a minimum.

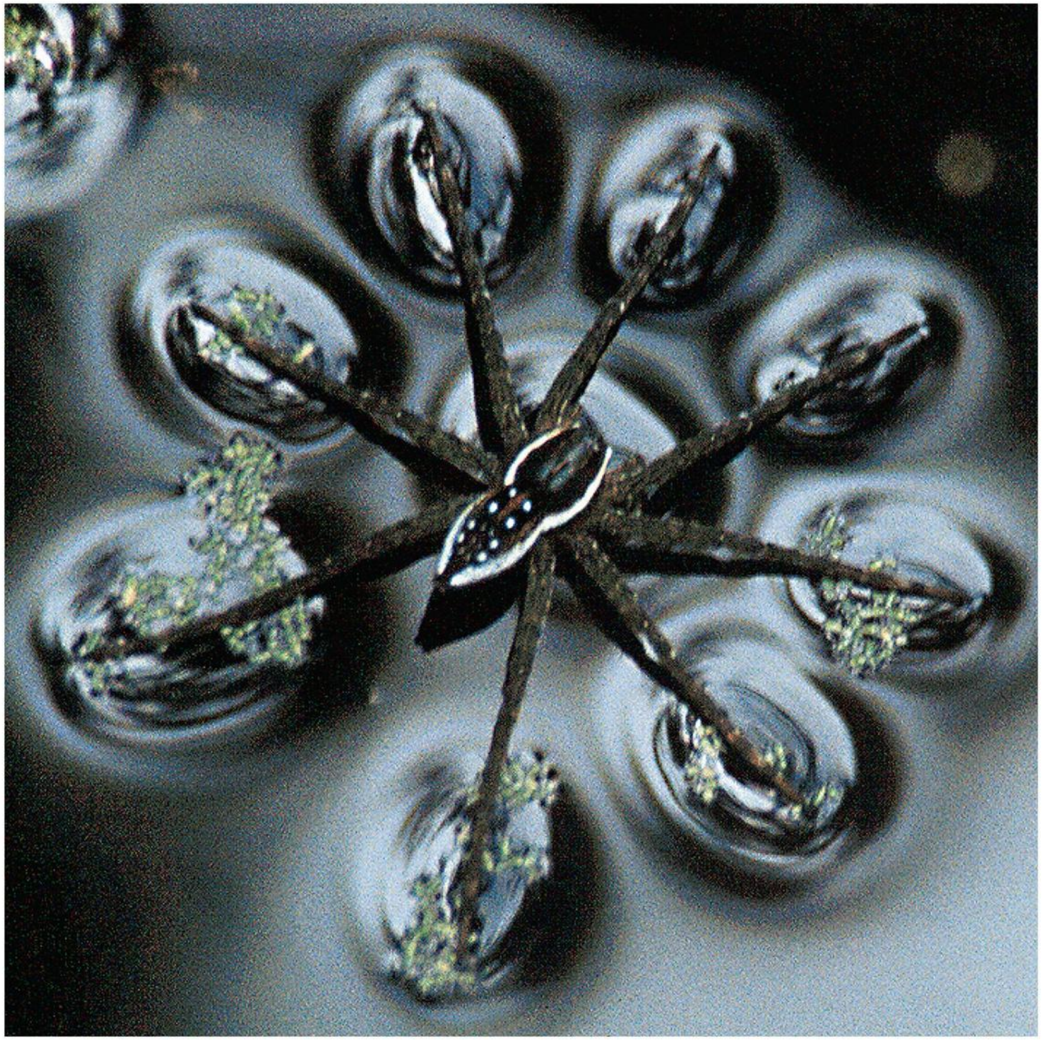


15-9 Viscosity and Surface Tension

Since there are forces tending to keep the surface area at a minimum, it tends to act somewhat like a spring – the surface acts as though it were elastic.

15-9 Viscosity and Surface Tension

This means that small, dense objects such as insects and needles can stay on top of water even though they are too dense to float.



Summary of Chapter 15

- **Density:** $\rho = M/V$
- **Pressure:** $P = F/A$
- **Atmospheric pressure:**

$$P_{\text{at}} = 1.01 \times 10^5 \,\text{N/m}^2 \approx 14.7 \,\text{lb/in}^2$$

- **Gauge pressure:**

$$P_{\text{g}} = P - P_{\text{at}}$$

- **Pressure with depth:**

$$P_2 = P_1 + \rho g h$$

Summary of Chapter 15

- **Archimedes' principle:**

An object completely immersed in a fluid experiences an upward buoyant force equal in magnitude to the weight of fluid displaced by the object.

$$F_b = \rho_{fluid} V_{sub} g$$

$$mg = \rho_{object} V_{object} g$$

- **Volume of submerged part of object:**

$$V_{\text{sub}} = V_{\text{s}}(\rho_{\text{s}}/\rho_{\text{f}})$$

Summary of Chapter 15

Flow rate:
The volume of fluid passing through per unit time = opening area * flow speed =A v

Flow rate * time = total passed volume.

- **Equation of continuity:**

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

- **Bernoulli's equation:**

$$P_1 + \frac{1}{2}\rho {v_1}^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho {v_2}^2 + \rho g y_2$$

Summary of Chapter 15

Optional

- **A pressure difference is required to keep a viscous fluid moving:**

$$\frac{\Delta V}{\Delta t} = \frac{(P_1 - P_2)\pi r^4}{8\eta L}$$