# Chapter 9

# The Behavior of Fluids

# Some Definitions

- **Fluid**: A substance that can flow, that doesn't maintain a fixed shape. Liquids and gas are fluids
- **Density**: Mass per unit volume: $\rho = m/V$
  - Lead is very dense. Styrofoam is not very dense.
  - We often write the mass of a fluid as $m = \rho V$
- **Pressure**: Force per unit area: $P = F/A$
  - Pressure takes into account the amount of force and the area over which it is applied
  - $1\ \text{N/m}^2 = 1\ \text{Pa}$
  - $1\ \text{atm} = 1.013\times10^5\ \text{Pa} = 760$ torr (mm/Hg)
    $= 14.7\ \text{lb/in}^2$ (psi)

Problem: A water bed is 2.00 m square and 30.0 cm deep

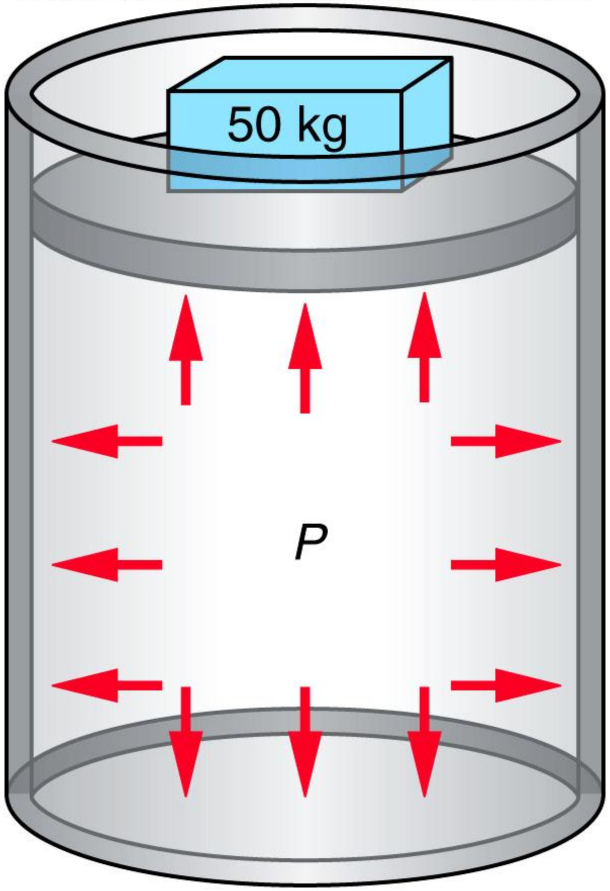
(a) What is the weight of the water it holds?

(b) What pressure does the bed exert on the floor, assuming the whole bottom surface touches the floor?

# Pressure in a Static Fluid

- Fluid pushes outward uniformly in all directions when compressed.
- Any increase in pressure is transmitted uniformly throughout the fluid.
- Pressure exerted on a piston extends uniformly throughout the fluid, causing it to push outward with equal pressure on the walls and the bottom of the cylinder.





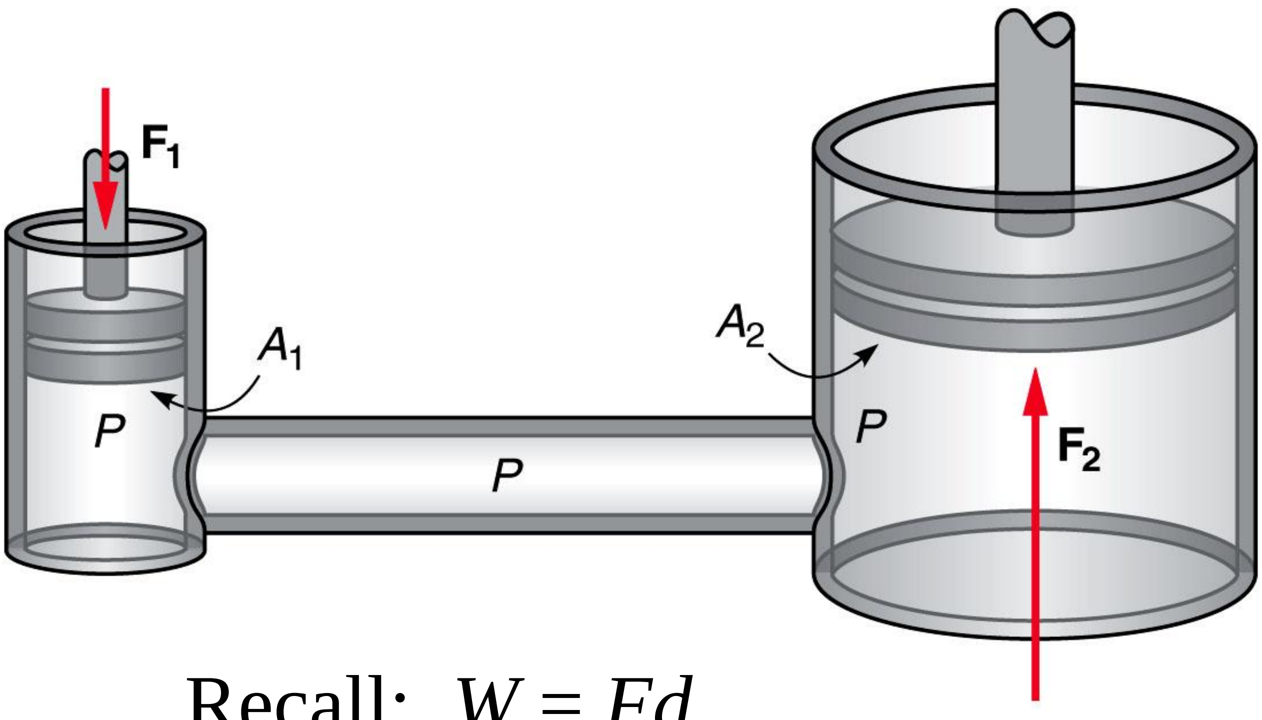
# Pascal's Principle

Static fluid pressure is the basis of ***Pascal's Principle***:

•Any change in the pressure of a fluid is transmitted uniformly in all directions throughout the fluid because $P_1 = P_2$ which means,

$$F_2/A_2 = F_1/A_1 \qquad (\text{or } F_2/F_1 = A_2/A_1)$$

- A small force applied over a small area can produce a large force over a large area. The small force must move a large distance.



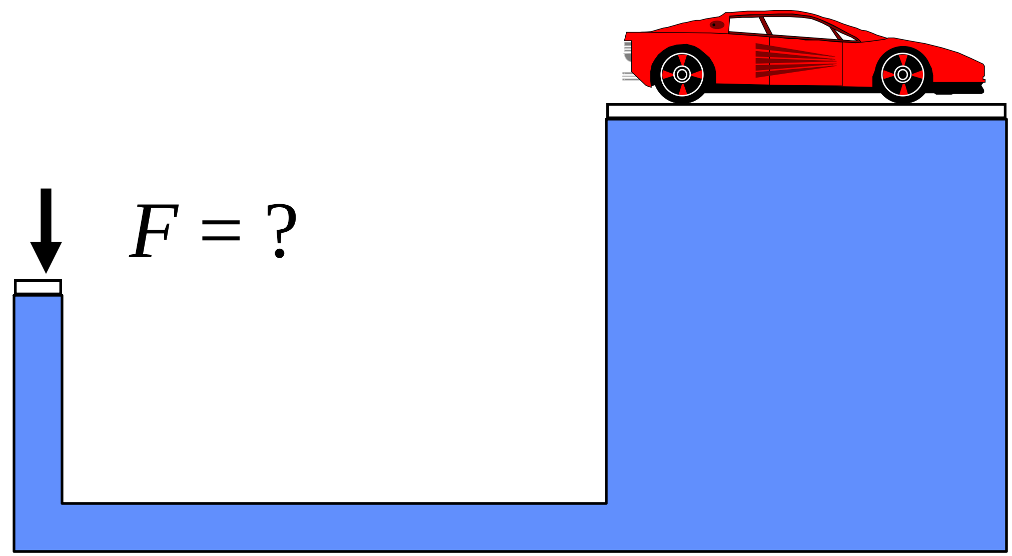

Recall: $W = Fd$

Problem: In the hydraulic press used in a trash compactor, the radii of the circular input piston and the circular output plunger are $6.4\times10^{-3}$ m and $5.1\times10^{-2}$ m, respectively. What force is applied to the trash when the input force is 330 N?

# Interactive Question

A container filled with oil is fitted with pistons on both ends. The left piston has an area of 10 $mm^2$ and the right piston lifting the car has an area of 10,000 $mm^2$. What force must be exerted on the left piston to apply a force of 10,000 N to the piston lifting the car?

A) 10 N
B) 100 N
C) 10,000 N
D) $10^6$ N
E) $10^8$ N



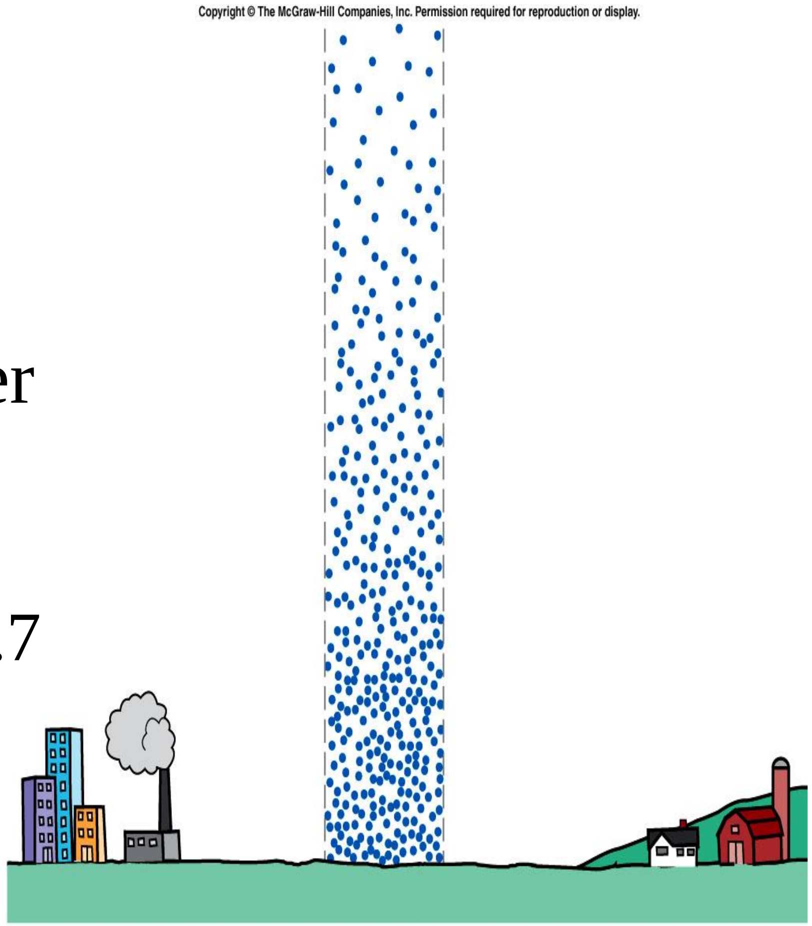
# Interactive Question

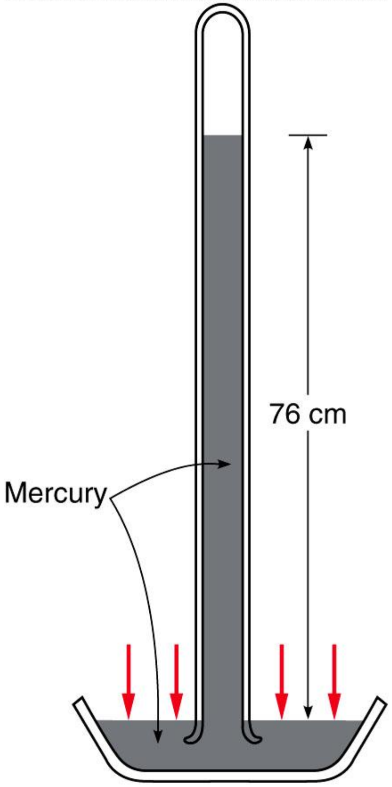
A hydraulic jack has a mechanical advantage allowing a puny human to lift a car. Which of the following statements is true?

A) The input force is equal to the output force
B) The area of the input piston is equal to the area of the output piston
C) The distances the input and output pistons move are equal
D) The work done by the output piston is equal to the work done on the input piston

# Atmospheric Pressure and the Behavior of Gases

- On the surface of the earth, we are at the bottom of a sea of air which is less dense at higher altitudes and changes density slightly due to certain weather conditions.
- This property is the ***atmospheric pressure***: the pressure of the layer of air that surrounds the earth.
  - At sea level, the atmospheric pressure is about 100 kPa, or 14.7 pounds per square inch, but it decreases with altitude.






- A barometer can measures the atmospheric pressure.
- Air pressure acting on a liquid in the open dish supports a column of liquid, of height proportional to the atmospheric pressure.
- Some things work by creating a partial vacuum and letting atmospheric pressure push the liquid up. The maximum height the liquid can rise using this method is 10.3 m = 32 ft.

- In about 1657 Otto von Guericke, who invented the vacuum pump, performed a famous experiment to demonstrate the effects of air pressure.
- He pumped the air out of the sphere formed from two bronze hemispheres and two eight-horse teams were unable to pull the hemispheres apart.



# Boyle's Law

At a constant temperature, the pressure of a gas is inversely proportional to its volume, or

$$PV = \text{constant}$$

which can also be written as,

$$P_1V_1 = P_2V_2$$

# Interactive Question

Diving in a swimming pool, you let out a stream of bubbles. As the bubbles rise towards the surface do they increase in diameter, decrease in diameter, or stay the same size?

A) increase

B) decrease

C) stay the same

Problem: A balloon has a volume of 15 $m^3$ on the surface of the Earth where the pressure is 1 atm. If the balloon rises up to a point where the pressure is 0.22 atm, what is the volume of the balloon?

# Archimedes' Principle: Buoyancy

- The average density of an object compared to a fluid determines whether the object will sink or float in that liquid.
  - If the object is less dense than the fluid then it will float and if it is more dense than the fluid it will sink.
- The upward force that pushes objects back toward the surface in liquids is called the buoyant force.

Archimedes' Principle: The buoyant force acting on an object that is either fully or partially submerged in a fluid is equal to the weight of the fluid displaced by the object.

The buoyant force exists because the pressure increases as you go deeper in the fluid, (just like for the atmosphere). So there is more pressure pushing up at the bottom than pushing down at the top.


Using the subscript f = fluid, the buoyant force is given by

$$B = W_f$$
$$= m_f g$$

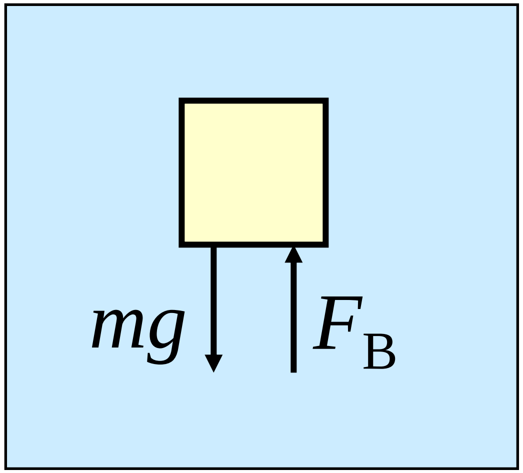
$$B = \rho_f V_f g$$

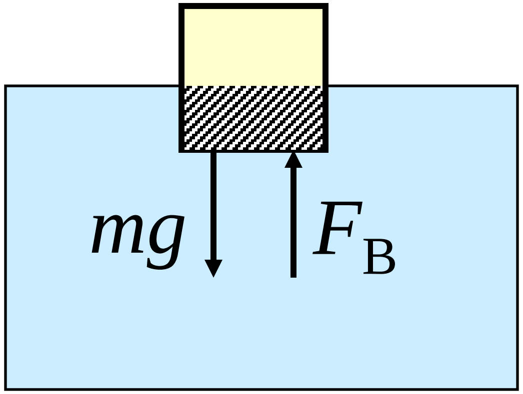
where $V_f$ is the volume of the fluid displaced by the object.

# Submerged and Floating Objects

$$B = \rho_f V_f g$$

For an object that is submerged in a fluid, $B = \rho_f V_f g = \rho_f V_{object} g$




For an object that is floating in a fluid, $B = \rho_f V_f g$

Problem:

(a) What is the buoyant force on a balloon filled with 1.0 $m^3$ helium at sea level?

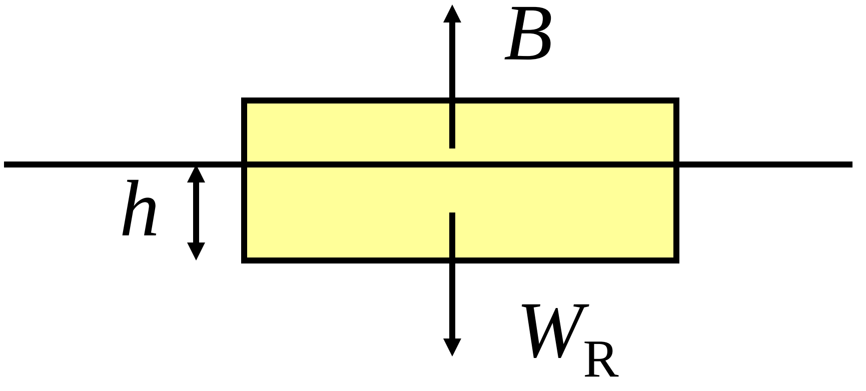
(b) What is the gravitational force (weight) on the same balloon?

# Interactive Question

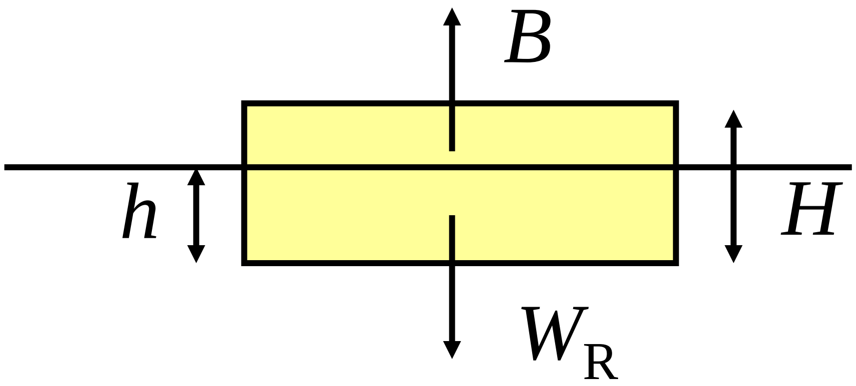
According to Archimedes' principle, the buoyant force

A) is always equal to the weight of the object
B) is always greater than the weight of the object
C) is always less than the weight of the object
D) is equal to the weight of the displaced fluid
E) is less than the weight of the displaced fluid if the object sinks

Problem: A raft is made of wood having a density of 600 kg/m$^3$. Its surface area is 5.7 m$^2$, and its volume is 0.60 m$^3$. How deep does the raft sit below water level?



Let's notice something about this example.



# Interactive Question

Icebergs, which are made of fresh water, float with 10% of their mass above the ocean, which is made of salt water. From this fact we can conclude that

A) salt water is 10% as dense as fresh water

B) salt water is 90% as dense as fresh water

C) fresh water is 10% as dense as salt water

D) fresh water is 90% as dense as salt water

E) None of the above

# Interactive Question

A 10 kg piece of aluminum sits at the bottom of a lake, right next to a 10 kg piece of lead. Which has the greater buoyant force on it? Aluminum is less dense than lead. Hint: Which piece of metal is larger?

A) The aluminum
B) The lead
C) Both have the same buoyant force
D) It is impossible to determine without knowing their volumes.

# Interactive Question

50 $cm^3$ of wood is floating on water, and 50 $cm^3$ of iron is totally submerged. Which has the greater buoyant force on it?

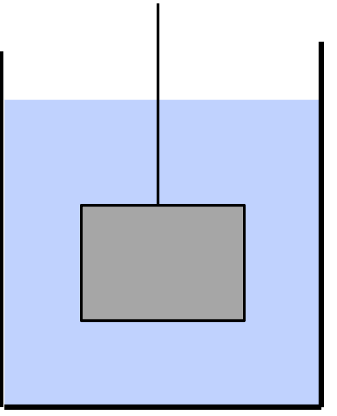
A) The wood.
B) The iron.
C) Both have the same buoyant force.
D) It is impossible to tell from the information given.

# Interactive Question

An object floats with half its volume beneath the surface of the water. The weight of the displaced water is 2000 N. What is the weight of the object?

A) 1000 N
B) 2000 N
C) 4000 N
D) Impossible to determine without more information.

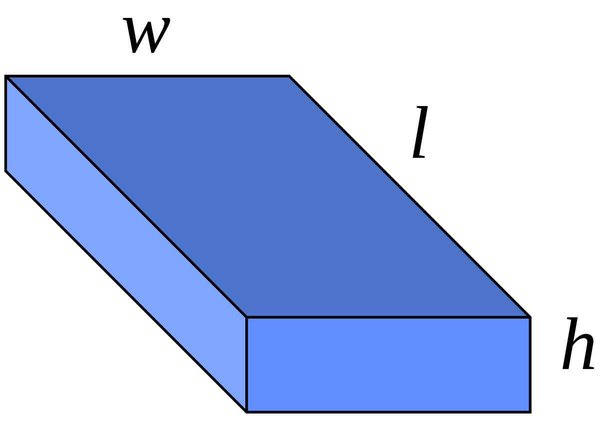
Problem: A block of aluminum with a density of 2700 $kg/m^3$ is hanging in a beaker of water by a string, but not touching the bottom. If the aluminum has a mass of 0.450 kg, what is the tension in the string?



# How does a steel boat float?

- The average density of the steel boat, the air, the cargo, etc. must be less than the average density of water.
- or, equivalently, the weight of the boat, the air, the cargo, etc. must be equal to the weight of the water displaced when part of the boat is still above the water.

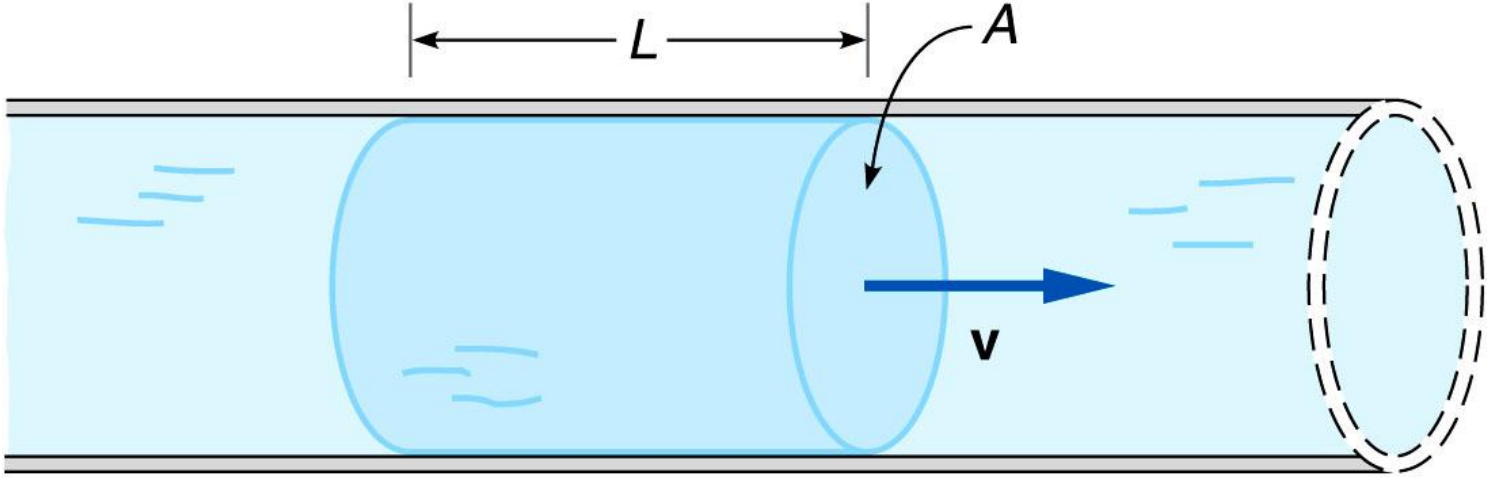
Problem: A small steel boat is shaped like a rectangular box with dimensions of 6.5 m long, by 2.0 m wide, by 0.6 m high and has a weight of 7000 N. How much cargo can you put in this boat before it sinks?



# Fluids in Motion

- The volume of a portion of water of length *L* flowing past some point in a pipe is the product of the length times the cross-sectional area *A*, or *LA*.
- The volume rate at which water moves through the pipe is this volume divided by time: $LA/t$.
- Since $L/t = v$, the flow rate $= vA$.

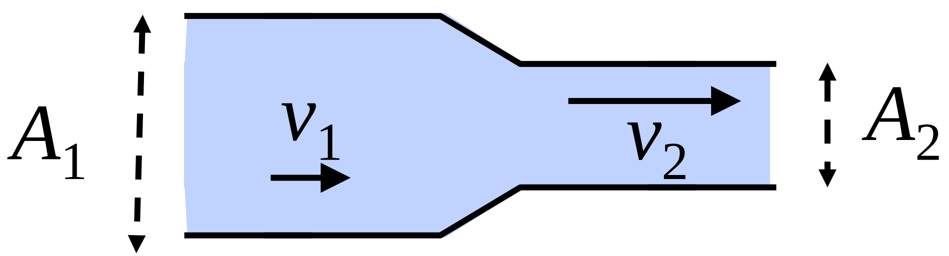





Rate of flow = *vA*

If the flow is *continuous*, and the fluid is *incompressible*, then the rate of flow must be the same at any point along the pipe.

For a pipe that changes cross sectional area, the same amount of fluid must pass through a smaller area in the same amount of time, so the fluid must speed up in regions where the pipe is thin.,

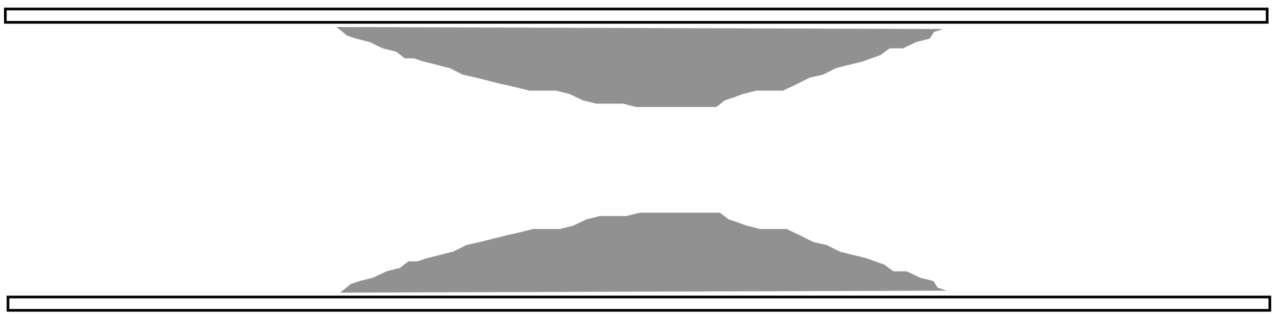



$$A_1 v_1 = A_2 v_2$$

The equation of continuity

# Interactive Question

Blood flows through a coronary artery that is partially blocked by deposits along the artery wall. Through which part of the artery is the volume flow rate largest?



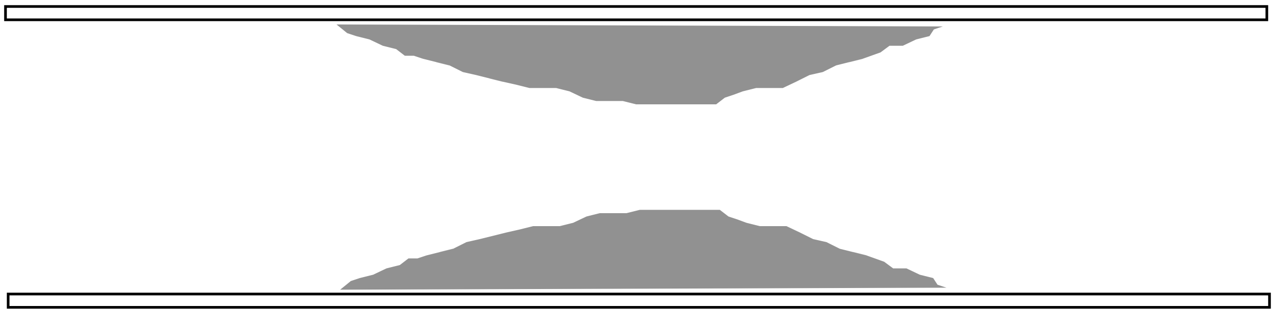
A) The narrow part

B) The wide part

C) The flow rate is the same in both parts

# Interactive Question

Blood flows through a coronary artery that is partially blocked by deposits along the artery wall. Through which part of the artery is the flow speed largest?



A) The narrow part

B) The wide part

C) The speed is the same in both parts

# Interactive Question

Water flows through pipe A into pipe B. Pipe B has three times the cross-sectional area that pipe A has. Compared to the speed of the water in pipe A, the speed in pipe B is:

A) 1/3 as fast

B) 1/2 as fast

C) the same

D) 3 times faster

E) 9 times faster

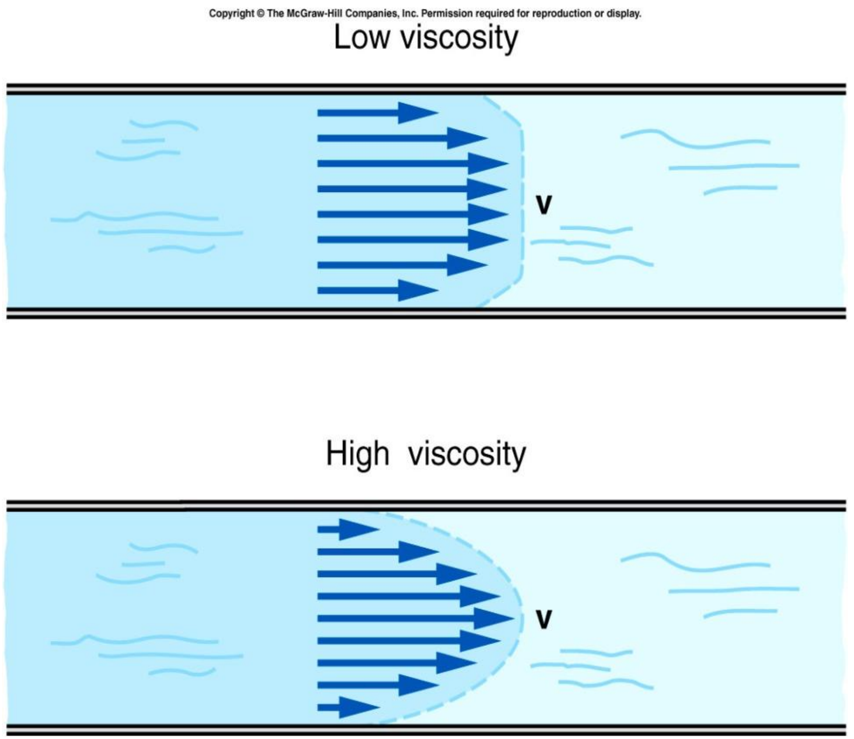
# Interactive Question

Water enters a pipe of radius $r$ with a certain velocity. The water encounters a location in the pipe where its velocity is increased to 4 times its initial velocity. What is the radius of the pipe? (Remember that $A = \pi r^2$)

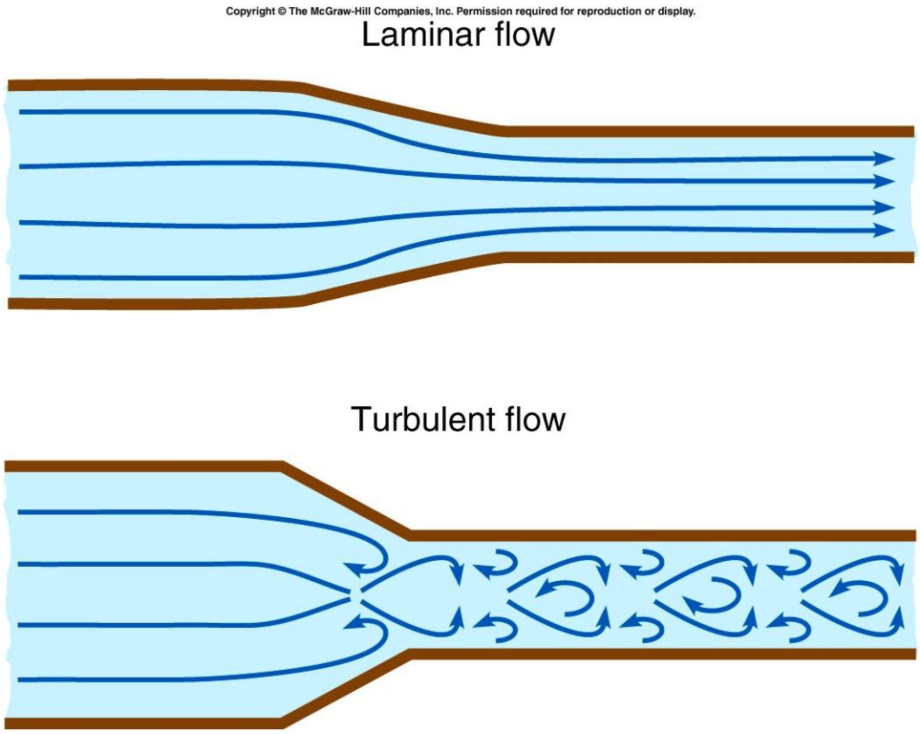
A) $r/16$
B) $r/4$
C) $r/2$
D) $2r$
E) $4r$

# Real fluid flow can be very complex.

## Viscosity (friction)



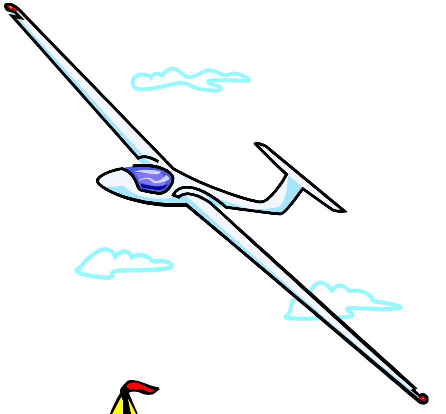

## Turbulence




We will mostly deal with steady, streamlined or laminar flow of incompressible, nonviscous fluids.

# Bernoulli's Equation

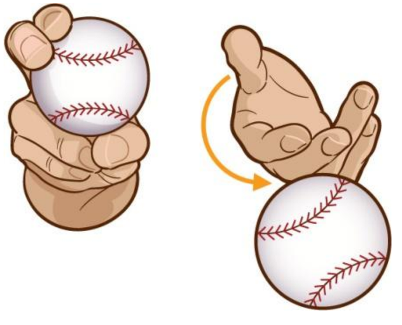
Swiftly moving fluids exert less pressure than slowly moving fluids.  A force can then be created pointing toward the region with less pressure.



$$P + (1/2)\rho v^2 = \text{constant}$$

Which can also be written as:

$$P_1 + (1/2)\rho v_1^2 = P_2 + (1/2)\rho v_2^2$$



It's a consequence of energy conservation

# Interactive Question

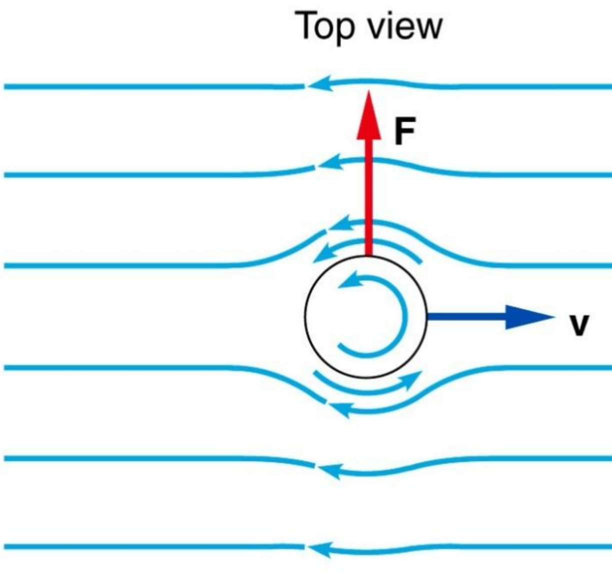
A large gravel truck is loosely covered with a tarpaulin. The edges of the tarp are tied down to the truck. When the truck is at rest the tarp is flat. When it cruises at highway speeds

A) the tarp bows down.

B) the tarp remains flat.

C) the tarp bows up.




Top view
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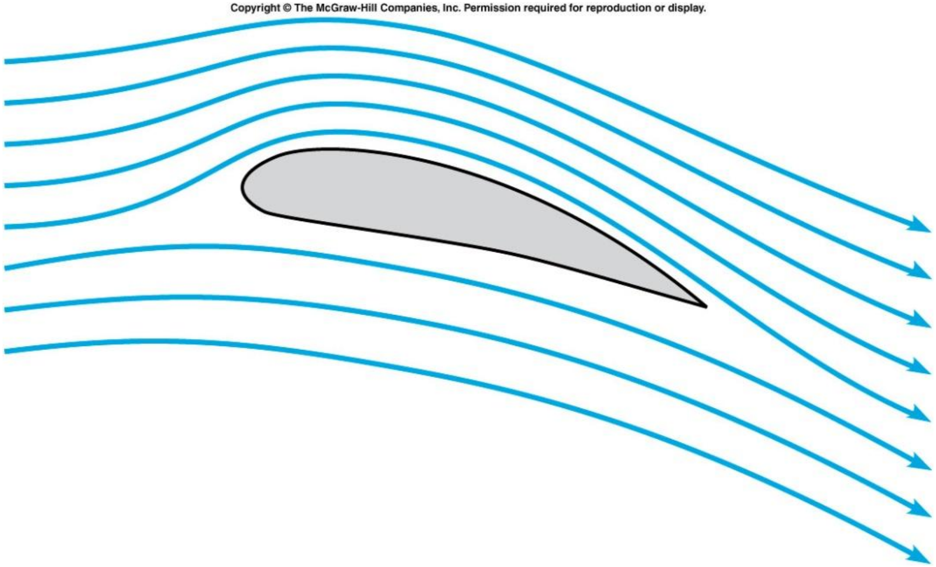
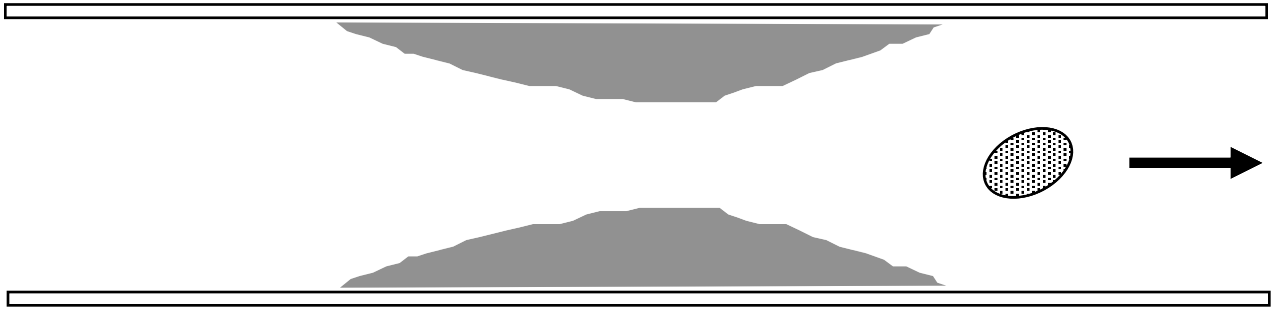




# Interactive Question

A blood platelet drifts along with the flow of blood through an artery that is partially blocked by deposits. As the platelet moves from the narrow region to the wider region, it experiences?



A) an increase in pressure.
B) no change in pressure.
C) a decrease in pressure.

Problem: If air moves over the top of an airplane wing at 250 m/s and under the bottom of the airplane wing at 220 m/s, what is the difference in pressure between the top and bottom of the wing at sea level?

Problem: A water pipe has water flowing at 1.30 m/s in a region where the radius of the pipe is 2.00 cm at a fluid pressure of 0.200 atm. What is the fluid pressure at a point where the pipe narrows to a radius of 1.00 cm?