FLUIDS

Physics

Unit 5

Physics Unit 5

- This Slideshow was developed to accompany the textbook
  - *OpenStax Physics*
    - *Available for free at https://openstaxcollege.org/textbooks/college-physics*
  - *By OpenStax College and Rice University*
  - *2013 edition*
- Some examples and diagrams are taken from the textbook.

Slides created by
Richard Wright, Andrews Academy
rwright@andrews.edu

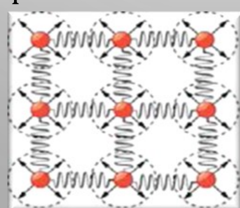
05-01 FLUIDS AND DENSITY

In this lesson you will…

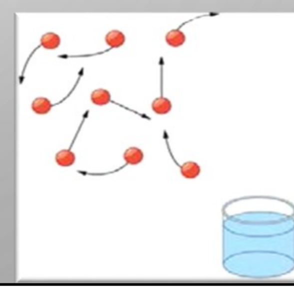
- State the common phases of matter.
- Explain the physical characteristics of solids, liquids, and gases.
- Describe the arrangement of atoms in solids, liquids, and gases.
- Define density.
- Calculate the mass of a reservoir from its density.
- Compare and contrast the densities of various substances.

05-01 FLUIDS AND DENSITY

- Phases of Matter
- Solid
  - Atoms in close contact so they can't move much
  - Set volume and shape
  - Can't compress

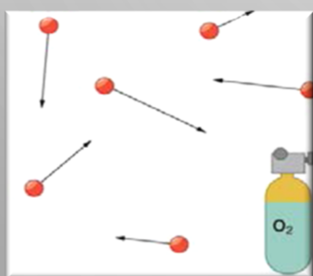


- Liquid
  - Atoms move past each other
  - Set volume
  - Takes shape of container
  - Hard to compress



05-01 FLUIDS AND DENSITY

- Gas
  - Atoms far apart
  - Neither set volume or shape
  - Compressible



- Fluids
  - Flow
  - Both liquids and gases

05-01 FLUIDS AND DENSITY

- Density
  - $\rho = \frac{m}{V}$
  - Where
    - ρ = density
    - m = mass
    - V = Volume
- Things with small density float on things with more density
- Solids most dense
- Gases least dense
  - See Table 11.1

05-01 FLUIDS AND DENSITY

- Can use density to determine unknown material
- An ornate silver crown is thought to be fake. How could we determine if is silver without damaging the crown?
- Find its mass using a balance. (It is 1.25 kg)
- Find its volume by submerging in water and finding volume of displaces water. (It is 1.60×10^{-4} m^3)
- Find the density
  - $\rho = 7.81 \times 10^3$ kg/m^3
- Table 11.1 says it is steel
  - Silver's density is 10.5×10^3 kg/m^3

$$\rho = \frac{m}{V}$$

$$\rho = \frac{1.25\ kg}{1.60 \times 10^{-4}\ m^3} = 7.81 \times 10^3\ kg/m^3$$

05-01 FLUIDS AND DENSITY

- Do the Density Lab

- **Objective**
  - Find the density in a coin and use it to help identify the metal.
  - Use a Vernier caliper.
- **Materials**
  - Coins of standard metals
    - Japan 1 Yen (1955-1989)
    - Denmark 2 øre (1948-1972)
    - Italy 50 Lire (1955-1989)
    - France 1 Franc (1959-2001)
  - Vernier caliper

05-01 HOMEWORK

- Don't be dense, you can solve these problems

- Read 11.3, 11.4

05-02 PRESSURE AND DEPTH

In this lesson you will…

- Define pressure.
- Explain the relationship between pressure and force.
- Calculate force given pressure and area.
- Define pressure in terms of weight.
- Explain the variation of pressure with depth in a fluid.
- Calculate density given pressure and altitude.

05-02 PRESSURE AND DEPTH

- The molecules in a fluid are free to wander around
- In their wanderings they sometimes collide with the sides of their container (i.e. balloon)
- The more the molecules collide with the walls, the more force is felt

05-02 PRESSURE AND DEPTH

$$P = \frac{F}{A}$$

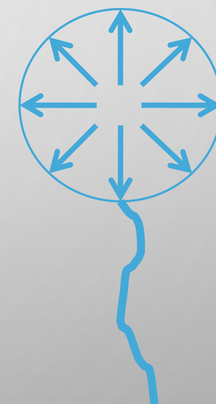
- P = Pressure
- F = Force perpendicular to surface
- A = Area of surface

- Unit: N/m^2 = Pa (pascal)
  - 1 Pa is very small so we usually use kPa or atm

05-02 PRESSURE AND DEPTH

- In a fluid the pressure is exerted perpendicularly to all surfaces

- A static fluid cannot produce a force parallel to a surface since it is not moving parallel to surface



A parallel force would cause the fluid to flow because of Newton's 3rd law

05-02 PRESSURE AND DEPTH

- You are drinking a juice box. In the process you suck all the juice and air out of the box. The top of the box is 7.5 cm by 5 cm. If the air pressure is 1.013×10^5 Pa, how much force is acting on the top of the box?
  - 380 N = 85 lbs
- Would the force of the side of the box be more or less than the top?
  - More because more area

$$A = 0.075\ m \times 0.05\ m = 0.00375\ m^2$$

$$P = \frac{F}{A} \rightarrow 1.013 \times 10^5\ Pa = \frac{F}{0.00375\ m^2} \rightarrow F = (1.013 \times 10^5\ Pa)(0.00375\ m^2)$$
$$= 379.875\ N$$

05-02 PRESSURE AND DEPTH

- The force that squashes the juice box is from the weight of all the air above it

- Atmospheric Pressure at Sea Level
  - 1.013×10^5 Pa = 1 atmosphere (1 atm)

05-02 PRESSURE AND DEPTH

- Do the Pressure vs. Depth Lab
- When will the water flow out the farthest: when the water is nearly full, half-full, or nearly empty?
- Hold the bottle over the bucket so that the water will flow out the hole into the bucket and loosen the bottle cap. Observe the flow of water. PUT THE CAP BACK ON!
- Describe how the distance the water flowed out changed as the depth of the water changed.
- The pressure of a fluid ____________________ as depth increases. So pressure and depth are ______________________ proportional. This can be written as ________________
- Next Page

Increases; directly; P = kh

05-02 Pressure and Depth

- Consider taking an elevator down from the top floor of a tall building. Consider diving down under water. Which one makes your ears hurt more?
- The pressure of a fluid ______________________ as density increases. So pressure and density are ______________________ proportional. This can be written as _______________
- Pressure is also directly proportional to the acceleration due to gravity, so $P = kg$. Put set 5, 9, and 10 together to write an equation relating pressure, depth, density, and gravity. Put all the variables that were directly related to pressure on the top of a fraction and all the variables that were inversely proportional on the bottom. (Let $k = 1$)
- Why does the water not flow out of the bottle with the cap on tightly?

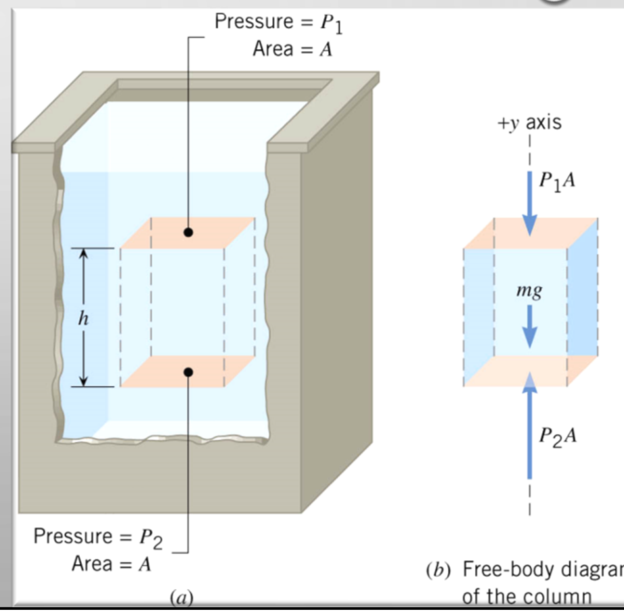
Increases; directly; $P = k\rho$

$$P = \rho g h$$

There is no pressure in the bottle to push the water out.

05-02 PRESSURE AND DEPTH

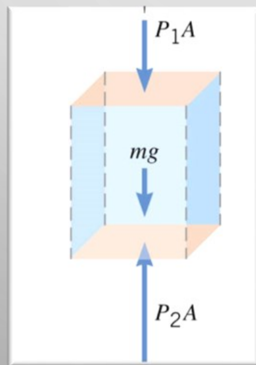
- The column of static fluid experiences several vertical forces
- Since the fluid is not moving, it is in equilibrium and $\sum F = 0$



There are horizontal forces also, but they will cancel each other.

05-02 PRESSURE AND DEPTH

- $\sum F = P_2A - P_1A - mg = 0$
- $P_2A = P_1A + mg$
- $\rho = \frac{m}{V} \rightarrow \; m = \rho V$
- $P_2A = P_1A + \rho V g$



- $V = Ah$
- $P_2A = P_1A + \rho gAh$
- $P_2 = P_1 + \rho gh$
- Or $P = \rho gh$ where P is the pressure due to the fluid at a depth h below the surface

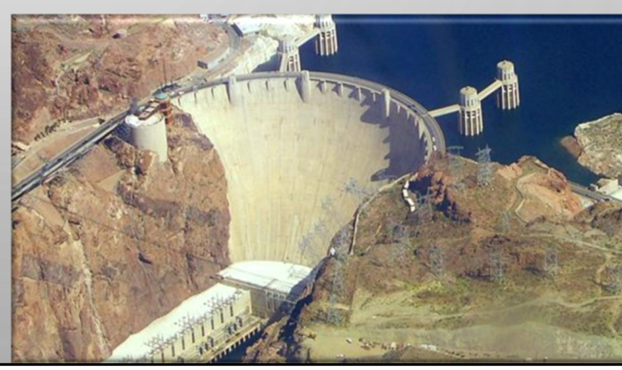
05-02 PRESSURE AND DEPTH

- If the pressure is known at a depth, the pressure lower down can be found by adding $\rho g h$
- This assumes ρ is constant with depth
- This is a good estimate for liquids, but not for gasses unless h is small

05-02 PRESSURE AND DEPTH

- Would Hoover Dam need to be just as strong if the entire lake behind the dam was reduced to an inch of water behind the dam, but the same depth as the lake?

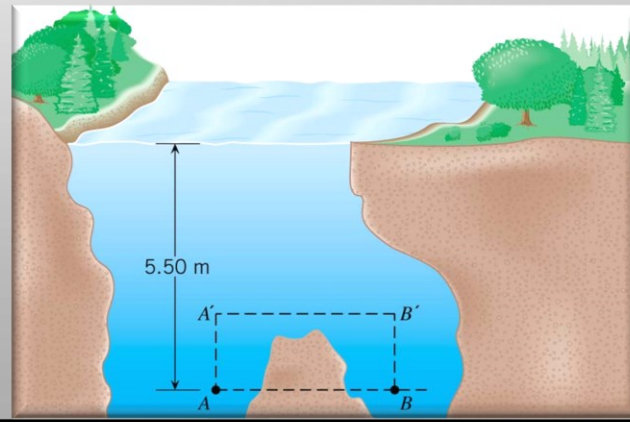
- Yes, the pressure depends only on the depth



Add a picture of Hoover Dam

05-02 PRESSURE AND DEPTH

- What is the total pressure at points A and B?
- $1.55 \times 10^5\ Pa$



$$P_1 = 1.013 \times 10^5\ Pa$$
$$h = 5.50\ m$$
$$\rho = 1000\ kg/m^3$$

$$P_A = P_1 + \rho g h \rightarrow 1.013 \times 10^5\ Pa + \left(1000\frac{kg}{m^3}\right)\left(9.80\frac{m}{s^2}\right)(5.50\ m)$$
$$= 1.55 \times 10^5\ Pa$$

The pressures are the same because the depth is the same. It doesn't matter that B has rock above it.

05-02 HOMEWORK

- Yes, there is a lot of pressure riding on this assignment

- Read 11.5, 11.6

05-03 PASCAL'S PRINCIPLE AND MEASURING PRESSURE

In this lesson you will…

- Define pressure.
- State Pascal's principle.
- Understand applications of Pascal's principle.
- Derive relationships between forces in a hydraulic system.
- Define gauge pressure and absolute pressure.

05-03 PASCAL'S PRINCIPLE AND MEASURING PRESSURE

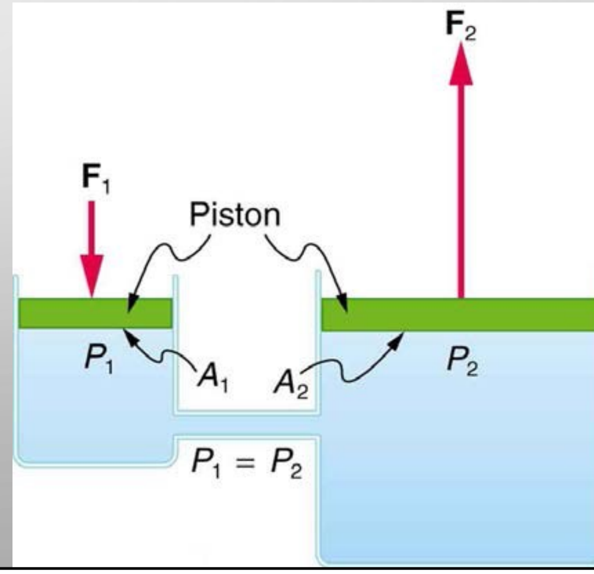
- Do the Pascal's Principle Lab.

- Did anything surprising happen?

05-03 PASCAL'S PRINCIPLE AND MEASURING PRESSURE

- Pascal's Principle
  - A change in pressure applied to an enclosed fluid is transmitted undiminished to all portions of the fluid and the walls of its container.
  - Basis of hydraulics
  - Since $P = \frac{F}{A}$, if we change the area, the force is changed

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

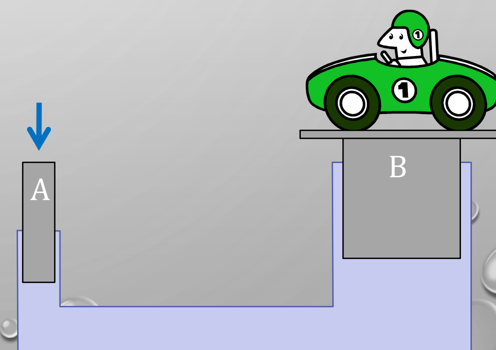


The fluid has no where to go. It flows in the container, but cannot go anywhere so the whole pressure increases.

05-03 PASCAL'S PRINCIPLE AND MEASURING PRESSURE

- How much force must be exerted at A to support the 850-kg car at B? The piston at A has a diameter of 17 mm and the piston at B a diameter of 300 mm.

- F = 26.7 N



$$P = \frac{F}{A}$$

$$F_{car} = 850\ kg\left(9.8\frac{m}{s^2}\right) = 8330\ N$$

$$A_{car} = \pi(0.150\ m)^2 = 0.0705858\ m^2$$

$$F_A = ?$$

$$A_A = \pi(0.0085m)^2 = 0.00022698\ m^2$$

$$\frac{F}{A} = \frac{F}{A}$$

$$\frac{8330\ N}{0.0705858\ m^2} = \frac{F}{0.00022698\ m^2}$$

$$F = 26.7\ N$$

05-03 PASCAL'S PRINCIPLE AND MEASURING PRESSURE

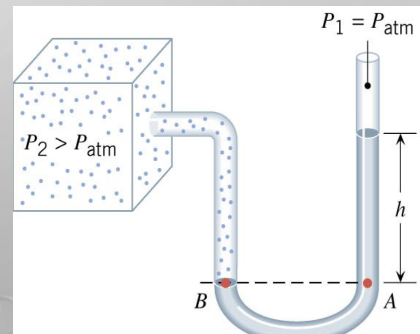
- Gauge Pressure
  - Used by pressure gauges
  - Measures pressure relative to atmospheric pressure

- Absolute Pressure
  - Sum of gauge pressure and atmospheric pressure
  - $P_{abs} = P_{gauge} + P_{atm}$

05-03 PASCAL'S PRINCIPLE AND MEASURING PRESSURE

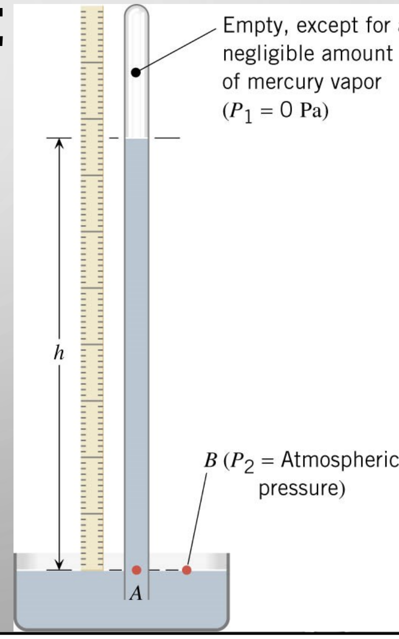
- Open-Tube Manometer
  - U-shaped tube with fluid in it
  - One end is connected to the container of which we want to measure the pressure
  - The other end is open to the air
  - $P_2 = \rho g h + P_{atm}$

- $P_2 = P_{abs}$
- $P_2 - P_{atm} = P_{gauge}$



05-03 Pascal's Principle and Measuring Pressure

- Barometer
  - Used to measure air pressure
  - A tube with the top sealed and filled with mercury
  - The bottom is open and sitting in a pool of mercury
  - Pressure at top = 0
  - Pressure at bottom = P_{atm}
  - $P = \rho g h$



$P_2 = \rho g h$
$P_2 = 13600\ kg/m^3\ (9.80 m/s^2) h$
$P_2 = 1.33 \times 10^5\ Pa/m\ h$

1 atm is 760 mm if we make $P_2 = 1.013 \times 10^5$ Pa

Changes in weather are often due to change in air pressure. Low pressure = bad weather; high pressure = sunny weather

05-03 HOMEWORK

- Let me pressure you into solving these problems
- Read 11.7

05-04 ARCHIMEDES' PRINCIPLE

In this lesson you will…

- Define buoyant force.
- State Archimedes' principle.
- Understand why objects float or sink.
- Understand the relationship between density and Archimedes' principle.

05-04 ARCHIMEDES' PRINCIPLE

- Think of trying to push a beach ball under water
- The water pushes it up
- All fluids push things up because the pressure is higher at greater depths
- The upward force is **buoyant force**

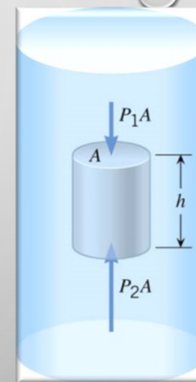
05-04 ARCHIMEDES' PRINCIPLE

- Do the Buoyancy Lab.
- When you are finished DRY the washer before putting them away!!
- Make a conclusion about the buoyant force and the weight of water displaced.

The buoyant force = weight of water displaced.

05-04 ARCHIMEDES' PRINCIPLE

- $F_B = P_2A - P_1A$
- $F_B = (P_2 - P_1)A$
- $P_2 = P_1 + \rho gh \rightarrow P_2 - P_1 = \rho gh$
- $F_B = (\rho gh)A$
- $\rho = \frac{m}{V} \rightarrow m = \rho V$
- $V = Ah$
- $m = \rho hA$



- $F_B = mg = W_{liquid}$

05-04 ARCHIMEDES' PRINCIPLE

- Archimedes' Principle
  - Buoyant force = weight of the displaced fluid
  - $F_B = W_{fl}$

- If buoyant force ≥ gravity, then it floats
- If buoyant force < gravity, then it sinks

05-04 ARCHIMEDES' PRINCIPLE

- As you might have guessed
  - An object will float if its average density < density of the fluid
  - In other words, it will float if it displaces more fluid than its own weight

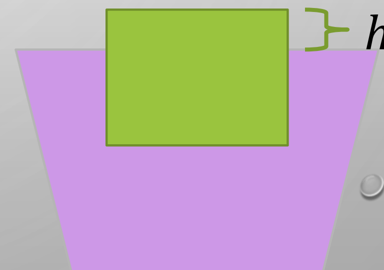
For not solid objects, think of a boat

05-04 ARCHIMEDES' PRINCIPLE

- Specific Gravity
  - $specific\ gravity = \frac{\bar{\rho}}{\rho_{fl}}$ = fraction submerged
  - If specific gravity < 1 it floats
  - If specific gravity > 1 it sinks

05-04 Archimedes' Principle

- An ice cube is floating in a glass of fresh water. The cube is 3 cm on each side. If the cube is floating so a flat face is facing up, what is the distance between the top of the cube and the water?



- 0.25 cm

$$\frac{\bar{\rho}}{\rho_{fl}} = fraction\ submerged$$

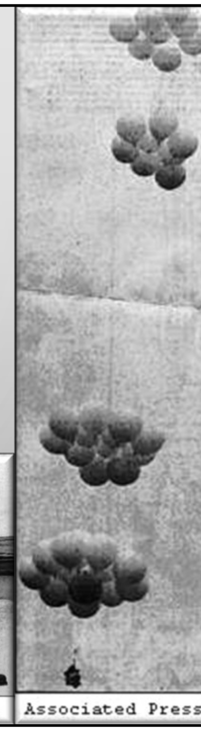
$$\frac{917\,\frac{kg}{m^3}}{1000\,\frac{kg}{m^3}} = 0.917$$

$$0.917(3\ cm) = 2.751\ cm\ submerged$$

$$3\ cm - 2.751\ cm = 0.249\ cm\ above$$

05-04 ARCHIMEDES' PRINCIPLE

- A man tied a bunch of helium balloons to a lawn chair and flew to a great altitude. If a single balloon is estimated as a sphere with a radius of 20 cm and is filled with helium, what is the net force on one balloon?
  - 0.3648 N
- How many balloons would be required to lift a 80 kg man and chair?
  - 2150 balloons



$$\sum F = F_B - W_{He}$$
$$V_{balloon} = \frac{4}{3}\pi(0.2\ m)^3 = 0.03351\ m^3$$
$$F_B = \rho_{air} V_{balloon} g = \left(1.29\frac{kg}{m^3}\right)(0.03351\ m^3)\left(9.8\frac{m}{s^2}\right) = 0.4236\ N$$
$$W_{He} = \rho_{He} V_{balloon} g = \left(0.179\frac{kg}{m^3}\right)(0.03351\ m^3)\left(9.8\frac{m}{s^2}\right) = 0.05878\ N$$
$$\sum F = 0.4236\ N - 0.05878\ N = 0.3648\ N$$

$$\sum F = F_B x - W_{He} x - W_{man} = 0$$
$$(0.3648\ N)x - (80\ kg)\left(9.8\frac{m}{s^2}\right) = 0$$
$$(0.3648\ N)x = 784\ N$$
$$x = 2150\ balloons$$

05-04 HOMEWORK

- Be buoyed up by the thought of the joy derived from solving these problems
- Read 12.1, 12.2

05-05 FLOW RATE AND BERNOULLI'S EQUATION

In this lesson you will…

- Calculate flow rate.
- Describe incompressible fluids.
- Explain the consequences of the equation of continuity.
- Explain the terms in Bernoulli's equation.
- Explain how Bernoulli's equation is related to conservation of energy.
- Calculate with Bernoulli's principle.
- List some applications of Bernoulli's principle.

05-05 FLOW RATE AND BERNOULLI'S EQUATION

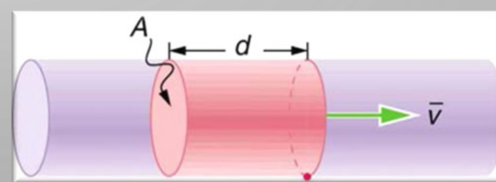
- Do the Air Streams Lab

- All the motion observed in this lab was caused by differences in pressure.
- In all the experiments, which way is the object move: towards or away from the moving air?
- An object will move from higher to lower pressure. Where was the pressure the lowest: moving or still air?
- Where was the pressure the highest?

Towards
Moving air
Still air

05-05 FLOW RATE AND BERNOULLI'S EQUATION

- Flow Rate
  - $Q = \frac{V}{t}$
    - Q = Flow rate
    - V = Volume of fluid
    - t = time
- $Q = \frac{V}{t} = \frac{Ad}{t} = A\overline{v}$
  - A = cross-section area
  - $\overline{v}$ = average velocity of fluid

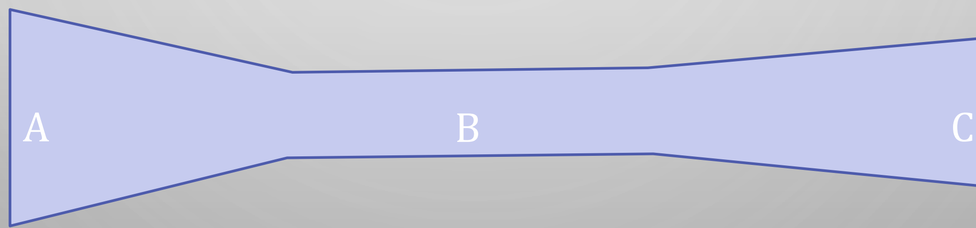


05-05 Flow Rate and Bernoulli's Equation

- Since flow rate is constant for a given moving fluid
- Equation of continuity
  - $\rho_1 A_1 \bar{v}_1 = \rho_2 A_2 \bar{v}_2$
- If incompressible
  - $A_1 \bar{v}_1 = A_2 \bar{v}_2$
- If incompressible and several branches
  - $n_1 A_1 \bar{v}_1 = n_2 A_2 \bar{v}_2$

05-05 Flow Rate and Bernoulli's Equation

- Where does the water flow the fastest?



B, then C, then A

My old woodstove had 8in round pipe, then entered 10in square chimney. Since the area got bigger, the smoke slowed down. That let the creosote in the smoke build up on the chimney walls more and cause chimney fires.

05-05 FLOW RATE AND BERNOULLI'S EQUATION

- A garden hose has a diameter of 2 cm and water enters it at 0.5 m/s. You block 90% of the end of the hose with your thumb. How fast does the water exit the hose?

- v = 5 m/s

Incompressible so

$$A_1\overline{v}_1 = A_2\overline{v}_2$$
$$(\pi(0.01\ m)^2)\left(0.5\frac{m}{s}\right) = 0.1(\pi(0.01\ m)^2)v$$
$$v = 5\frac{m}{s}$$

05-05 FLOW RATE AND BERNOULLI'S EQUATION

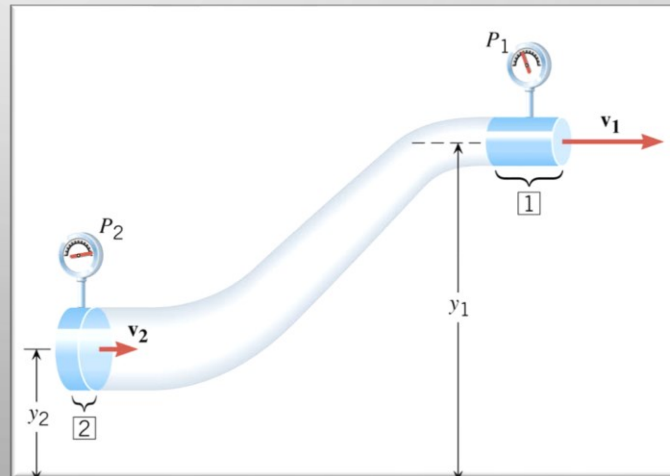
- When a fluid goes through narrower channel, it speeds up
- It increases kinetic energy
- $W_{net} = \frac{1}{2}mv^2 - \frac{1}{2}mv_0^2$
- Net work comes from pressure pushing the fluid

05-05 FLOW RATE AND BERNOULLI'S EQUATION

- Derivation
- $W_{net} = E_f - E_0$
- $E = KE + PE$

$$= \frac{1}{2}mv^2 + mgh$$

- $W_{net} = F \cdot x$
- $P = \frac{F}{A} \rightarrow F = PA \rightarrow Fx = PV$
- $W_{net} = (P_2 - P_1)V$



05-05 FLOW RATE AND BERNOULLI'S EQUATION

$W_{net} = (P_2 - P_1)V = \left(\frac{1}{2}mv_1^2 + mgh_1\right) - \left(\frac{1}{2}mv_2^2 + mgh_2\right)$

- Divide by V and rearrange
  - $\rho = \frac{m}{V}$

- Bernoulli's Equation

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

- This is a form of conservation of energy $E_0 + W_{nc} = E_f$ where the net work comes from the pressure in the fluid.

05-05 FLOW RATE AND BERNOULLI'S EQUATION

- Think about driving down a road with something in your car's trunk. The object is too large to completely shut the trunk lid. While the car is stopped, the lid quietly rests as far down as it can go. As you drive down the road, why does the trunk open?

- The air in the trunk is still. The air above the trunk is moving.
- The air in the trunk is at a higher pressure than above the trunk. So the trunk is pushed open.

05-05 FLOW RATE AND BERNOULLI'S EQUATION

- The blood speed in a normal segment of a horizontal artery is 0.15 m/s. An abnormal segment of the artery is narrowed down by an arteriosclerotic plaque to one-half the normal cross-sectional area. What is the difference in blood pressures between the normal and constricted segments of the artery?

- 35.8 Pa

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

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

$$A_1 v_1 = A_2 v_2$$

$$A_1 0.15\frac{m}{s} = \frac{1}{2}A_1 v_2 \rightarrow v_2 = 0.30\frac{m}{s}$$

$$P_1 - P_2 = \frac{1}{2}\left(1060\frac{kg}{m^3}\right)\left(0.30\frac{m}{s}\right)^2 - \frac{1}{2}\left(1060\frac{kg}{m^3}\right)\left(0.15\frac{m}{s}\right)^2$$

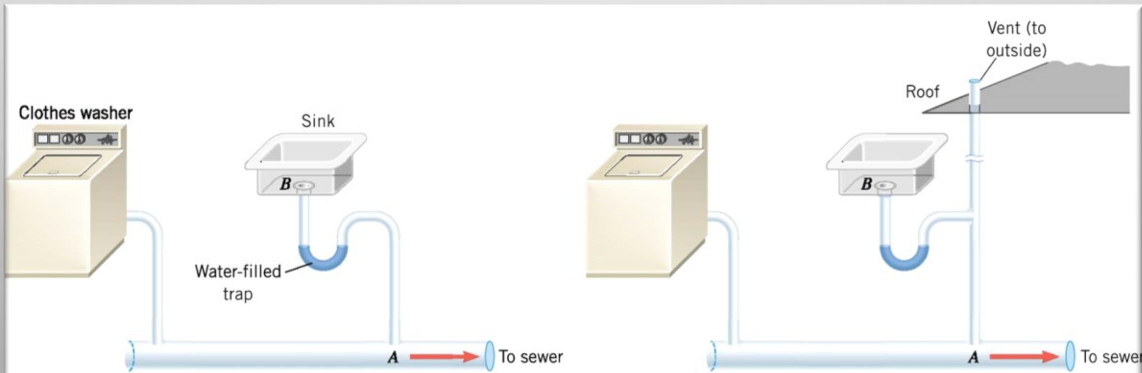
$$P_1 - P_2 = 35.8\ Pa$$

05-05 FLOW RATE AND BERNOULLI'S EQUATION

- Why do all houses need a plumbing vent?

- Waste water flows through a sewer line.
- Something like a sink is connected to the line, but there is a water trap to keep the sewer gasses from entering the house.
- The flowing water in the sewer means the air directly above the flowing water has a lower pressure than the air above the sink.
- This pushes the water in the trap down the pipe and sewer gasses enter the house

05-05 FLOW RATE AND BERNOULLI'S EQUATION

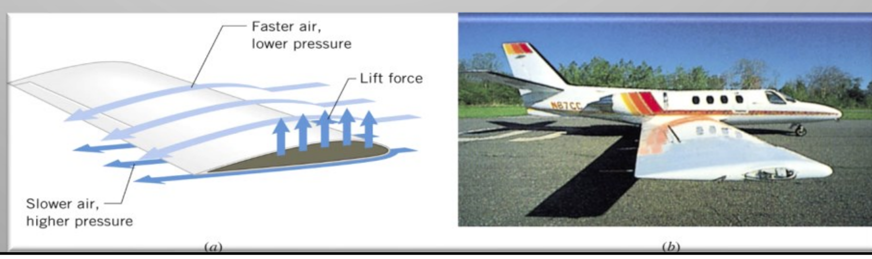


(a) Without vent (b) With vent

05-05 FLOW RATE AND BERNOULLI'S EQUATION

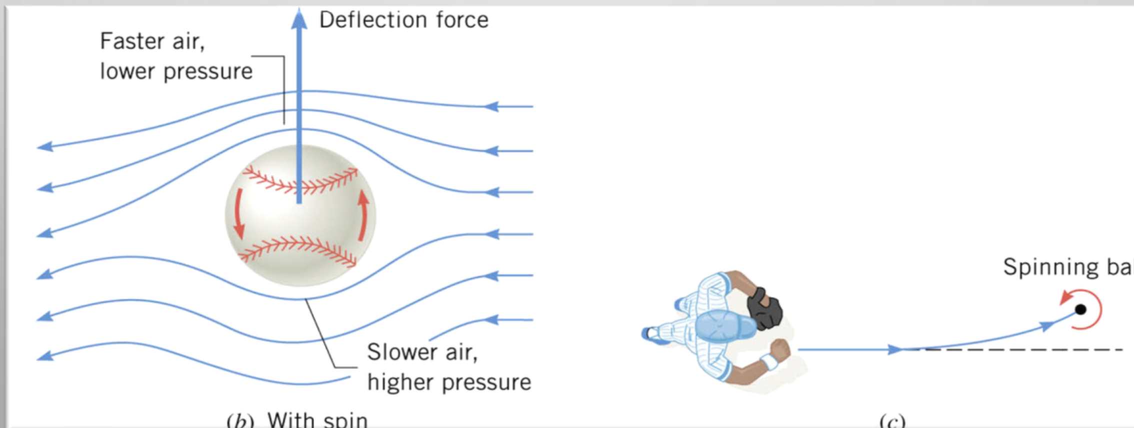
- How do airplane wings work (even paper airplanes)?

- The top of the wing is curved and the bottom is not. The air flows faster over the top of the wing, than the bottom. This pushes the wing up.



05-05 FLOW RATE AND BERNOULLI'S EQUATION

- How does a curve ball in baseball work?



Bottom: spin against air flow → slow relative velocity → high pressure
Top: spin with air flow → fast relative velocity → low pressure

05-05 HOMEWORK

- The faster you work, the less pressure you'll feel?

- Read 12.3

05-06 THE MOST GENERAL APPLICATIONS OF BERNOULLI'S EQUATION

In this lesson you will…

- Calculate with Bernoulli's principle.
- Calculate power in fluid flow.

05-06 THE MOST GENERAL APPLICATIONS OF BERNOULLI'S EQUATION

- Previous examples of Bernoulli's Equation had simplified conditions
- Bernoulli's Equation work in real world

05-06 THE MOST GENERAL APPLICATIONS OF BERNOULLI'S EQUATION

- Water circulates throughout a house in a hot-water heating system. If the water is pumped at a speed of 0.50 m/s through a 4.0-cm-diameter pipe in the basement under a pressure of 3.0 atm, what will be the flow speed and pressure in a 2.6-cm-diameter pipe on the second floor 5.0 m above? Assume the pipes do not divide into branches.
- $v_2 = 1.2\frac{m}{s}$
- $P_2 = 2.5\ atm$

Equation of Continuity

$$v_1A_1 = v_2A_2$$

$$\left(0.50\frac{m}{s}\right)(\pi(0.02\ m)^2) = v_2(\pi(0.013\ m)^2)$$

$$v_2 = 1.183\frac{m}{s}$$

Bernoulli's Equation

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

$$\left(3(1.01\times 10^5\ Pa)\right) + \frac{1}{2}\left(1000\frac{kg}{m^3}\right)\left(0.50\frac{m}{s}\right)^2 + 0$$

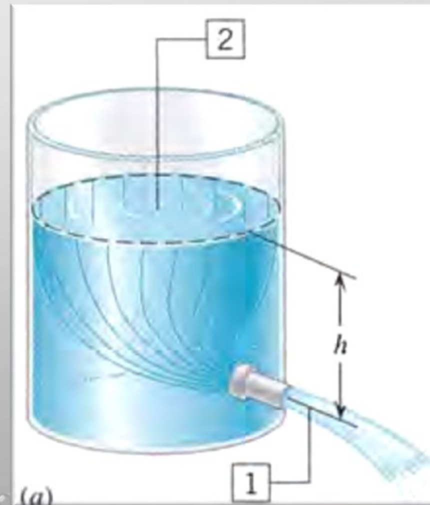
$$= P_2 + \frac{1}{2}\left(1000\frac{kg}{m^3}\right)\left(1.183\frac{m}{s}\right)^2 + \left(1000\frac{kg}{m^3}\right)\left(9.8\frac{m}{s^2}\right)(5.0\ m)$$

$$303125\ Pa = P_2 + 49700\ Pa$$

$$P_2 = 253425\ Pa = 2.5\ atm$$

05-06 THE MOST GENERAL APPLICATIONS OF BERNOULLI'S EQUATION

- The tank is open to the atmosphere at the top. Find an expression for the speed of the liquid leaving the pipe at the bottom.
- $v_1 = \sqrt{2gh}$



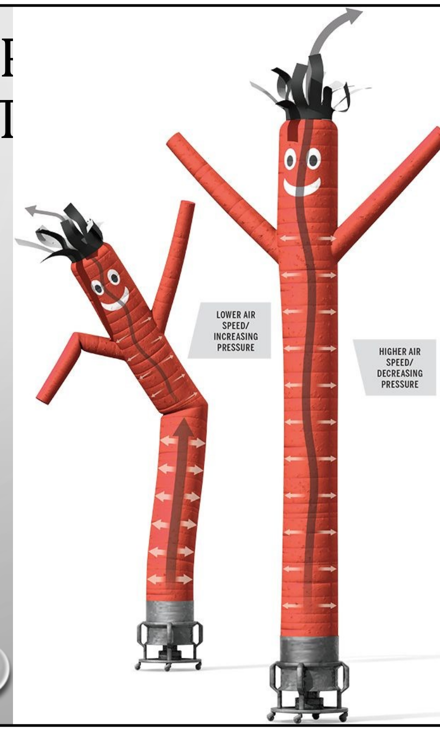
$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$
$$1\ atm + \frac{1}{2}\rho v_1^2 + 0 = 1\ atm + 0 + \rho g h$$
$$\frac{1}{2}\rho v_1^2 = \rho g h$$
$$\frac{1}{2}v_1^2 = gh$$
$$v_1 = \sqrt{2gh}$$

05-06 THE MOST GENERAL APPLICATIONS OF BERNOULLI'S EQUATION

- Since Bernoulli's Equation is conservation of energy, the water would rise up to the same height as the water in the tank.

05-06 THE MOST GENERAL API BERNOULLI'S EQUAT

- AirDancer used to draw attention at used car lots.
- The behavior is explained by Bernoulli's principle.
- Initially, the moving air, which behaves as an incompressible flow in the open-ended AirDancer, creates enough pressure to inflate the tube.
- As the tube stands more upright, the turbulent air inside flows more freely and its speed increases until the decreasing pressure can no longer support the mass of the nylon fabric.
- The collapsing material creates a kink in the tube, a constriction that causes the air speed to temporarily slow and the pressure to rise again.
- The elevated pressure drives the bend upward, sending a shimmy through the AirDancer and restarting the cycle.



05-06 THE MOST GENERAL APPLICATIONS OF BERNOULLI'S EQUATION

- Power in Fluid Flow
- Power is rate of work or energy
- Bernoulli's Equation terms are in energy per volume
- Multiply Bernoulli's Equation by volume and divide by time
  - Or multiply by flow rate Q
- $Power = \left(P + \frac{1}{2}\rho v^2 + \rho g h\right) Q$

05-06 HOMEWORK

- Apply yourself to these applications
- Read 12.4, 12.5

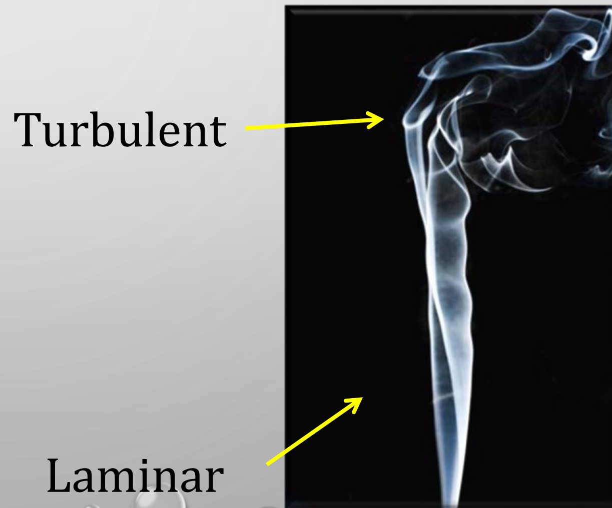
05-07 VISCOSITY, POISEUILLE’S LAW, AND TURBULENCE

In this lesson you will…

- Define laminar flow and turbulent flow.
- Explain what viscosity is.
- Calculate flow and resistance with Poiseuille’s law.
- Explain how pressure drops due to resistance.
- Calculate Reynolds number.
- Use the Reynolds number for a system to determine whether it is laminar or turbulent.

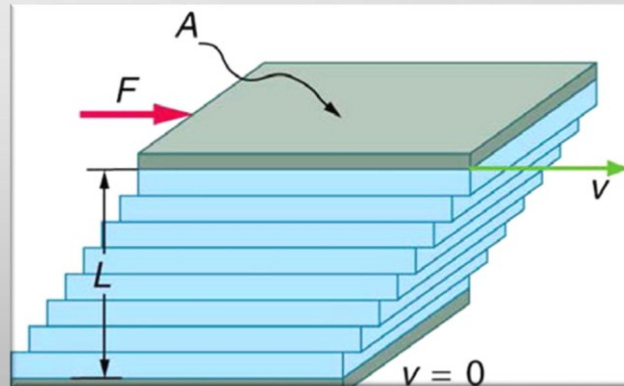
05-07 VISCOSITY, POISEUILLE'S LAW, AND TURBULENCE

- Viscosity
  - Fluid friction
- Laminar Flow
  - Smooth flow in layers that don't mix
- Turbulent Flow
  - Has eddies and swirls that mix layers of fluid
  - Turbulent flow is slower than laminar flow



05-07 VISCOSITY, POISEUILLE'S LAW, AND TURBULENCE

- How viscosity is measured
  - Two plates with fluid between
  - Top plate moved
  - Friction causes the fluid to move



- $\eta = \frac{FL}{vA}$

η is coefficient of viscosity
F is force applied to top plate
L is distance between plates
v is speed that top plate is moved
A is area of plate

05-07 VISCOSITY, POISEUILLE'S LAW, AND TURBULENCE

- Laminar flow in tubes
  - Difference in pressure causes fluids to flow

$$Q = \frac{P_2 - P_1}{R}$$

  - Where
  - Q is flow rate
  - P_1 and P_2 are pressures
  - R is resistance
- Poiseuille's law for resistance

$$R = \frac{8\eta l}{\pi r^4}$$

  - Where
  - η is viscosity
  - l is length of tube
  - r is radius of tube

Resistance is most effected by radius

05-07 VISCOSITY, POISEUILLE'S LAW, AND TURBULENCE

- Since flow rate depends on pressure
  - Higher pressure difference, higher Q
- Higher resistance, higher pressure difference to maintain constant Q
  - In blood vessels this is a problem with plaque on artery walls

05-07 VISCOSITY, POISEUILLE'S LAW, AND TURBULENCE

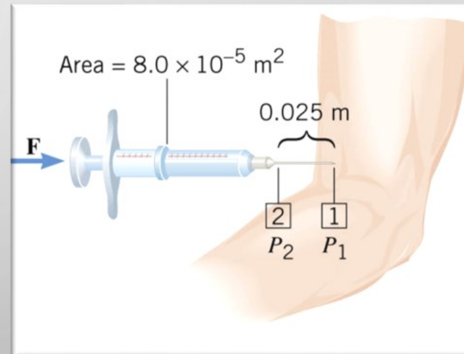
- How to tell if laminar or turbulent flow
  - Low speed with smooth, streamlined object → laminar
  - High speed or rough object → turbulent
- Reynolds number
  - Below 2000 → laminar
  - Above 3000 → turbulent
  - Between 2000 and 3000 depends on conditions

$$N_R = \frac{2\rho v r}{\eta}$$

$N_R = Reynolds\ number$
$\rho = fluid\ density$
$v = speed\ of\ fluid$
$r = radius\ of\ tube$
$\eta = viscosity$

05-07 VISCOSITY, POISEUILLE'S LAW, AND TURBULENCE

- A hypodermic syringe is filled with a solution whose viscosity is 1.5×10^{-3} Pa · s. The plunger area of the syringe is 8.0×10^{-5} m^2, and the length of the needle is 0.025 m. The internal radius of the needle is 4.0×10^{-4} m. The gauge pressure in a vein is 1900 Pa (14 mmHg). What force must be applied to the plunger, so that 1.0×10^{-6} m^3 of solution can be injected in 3.0 s?
- $F = 0.25$ N



- Is the flow laminar if the density is 1000 kg/m³?
- $N_R = 353$; Yes

$$\eta = 1.5 \times 10^{-3}\ Pa \cdot s, l = 0.025\ m, r = 4.0 \times 10^{-4}\ m, P_1 = 1900\ Pa, V = 1.0 \times 10^{-6}\ m^3, t = 3.0\ s$$

$$Q = \frac{V}{t} = \frac{1.0 \times 10^{-6}\ m^3}{3.0\ s} = 3.3 \times 10^{-7}\ m^3/s$$

$$R = \frac{8\eta l}{\pi r^4} = \frac{8(1.5 \times 10^{-3}\ Pa \cdot s)(0.025\ m)}{\pi(4.0 \times 10^{-4}\ m)^4} = 3.730 \times 10^9\ Pa \cdot s/m^3$$

$$Q = \frac{P_2 - P_1}{R}$$

$$3.3 \times 10^{-7} \frac{m^3}{s} = \frac{P_2 - 1900\ Pa}{3.730 \times 10^9 \frac{Pa \cdot s}{m^3}}$$

$$P_2 - 1900\ Pa = 1243\ Pa$$

$$P_2 = 3143\ Pa$$

$$P = \frac{F}{A}$$

$$3143\ Pa = \frac{F}{8.0 \times 10^{-5}\ m^2}$$

$$F = 0.25\ N$$

Laminar?

$$Q = Av \rightarrow 3.33 \times 10^{-7} \frac{m^3}{s} = \pi(4 \times 10^{-4}\ m)^2 v \rightarrow v = 0.662\ m/s$$

$$N_R = \frac{2\rho v r}{\eta} = \frac{2\left(1000\,\frac{\mathrm{kg}}{\mathrm{m}^3}\right)\left(0.662\,\frac{\mathrm{m}}{\mathrm{s}}\right)(4.0 \times 10^{-4}\ m)}{1.5 \times 10^{-3}\ Pa \cdot s} = 353$$

05-07 HOMEWORK

- Let the answers flow