PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 22000

General Physics

Lecture 19 - Fluids

Fall 2016 Semester

Prof. Matthew Jones

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SUPPLEMENTAL INSTRUCTION

Free Study Sessions!

Rachel Hoagburg

Come to SI for more help in **PHYS 220**

Tuesday and Thursday	7:30-8:30PM Shreve C113

Office Hour
Tuesday 1:30-2:30 4th floor of Krach

For other SI-linked courses and schedules, visit purdue.edu/si or purdue.edu/boilerguide

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What's New This Time?

- Previously, we had ignored the effect of gravity on the gas particles that were described by the ideal gas model.
- In Chapter 10, our interest expands to include phenomena in which the force exerted by Earth plays an important role.
  – We will confine the discussion to static fluids—fluids that are not moving.

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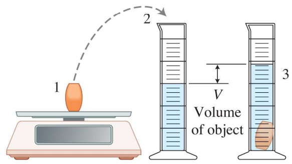
Density

- To find the density of an object or a substance, determine its mass and volume and then calculate the ratio of the mass and volume:

$$\rho = m/V$$

- To find the volume of a solid object of irregular shape, submerge it in a graduated cylinder filled with water.

1. Measure mass of object.
2. Place the object in water in a graduated cylinder.
3. Measure the volume change of the water. Volume change of water = volume of object.
4. Density = $\rho = m/V$



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Density

Table 10.1 Densities of various solids, liquids, and gases.

Solids		Liquids		Gases	
Substance	Density (kg/m^3)	Substance	Density (kg/m^3)	Substance	Density (kg/m^3)
Aluminum	2700	Acetone	791	Dry air 0° C	1.29
Copper	8920	Ethyl alcohol	789	10° C	1.25
Gold	19,300	Methyl alcohol	791	20 °C	1.21
Iron	7860	Gasoline	726	30 °C	1.16
Lead	11,300	Mercury	13,600	Helium	0.178
Platinum	21,450	Milk	1028–1035	Hydrogen	0.090
Silver	10,500	Seawater	1025	Oxygen[2]	1.43
Bone	1700–2000	Water 0 °C	999.8		
Brick	1400–2200	3.98 °C	1000.00		
Cement	2700–3000	20 °C	998.2		
Clay	1800–2600	Blood plasma	1030		
Glass	2400–2800	Blood whole[1]	1050		
Ice	917				
Balsa wood	120				
Oak	600–900				
Pine	500				
Planet Earth	5515				
Moon	3340				
Sun	1410				
Universe (average)	10^{-26}				
Pulsar	10^{11}–10^{18}				

[1]Densities of liquids are at 0 °C unless otherwise noted.
[2]Densities of gases are at 0 °C and 1 atm unless otherwise noted.

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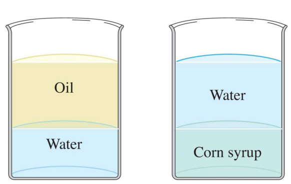
Density and Floating

- Helium-filled balloons accelerate upward in air, whereas air-filled balloons accelerate (slowly) downward.
  - The air-filled balloon must be denser than air.
- This situation is analogous to how a less dense liquid will float on a more dense liquid.



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Solid Water Floats in Liquid Water

- The solid form of a particular substance is almost always denser than the liquid form of the same substance, with one very significant exception: liquid water and solid ice.
  - Because ice floats on liquid water, we can assume that the density of ice is less than that of water.
  - Ice has a lower density because in forming the crystal structure of ice, water molecules spread apart.

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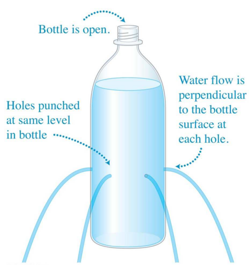
Pressure Exerted by a Fluid

- Take a water bottle and poke four holes at the same height along its perimeter.
  - Parabolic-shaped streams of water shoot out of the holes.
  - The water inside must push out perpendicular to the wall of the bottle, just as gas pushes out perpendicular to the wall of a balloon.
  - Because the four streams are identically shaped, the pressure at all points at the same depth in the fluid is the same.



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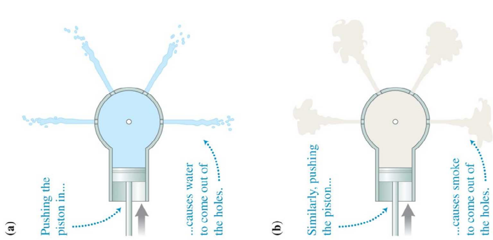
Pascal's First Law

Pascal's first law An increase in the pressure of a static, enclosed fluid at one place in the fluid causes a uniform increase in pressure throughout the fluid.



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Pascal's first law at a microscopic level

- Particles inside a container move randomly in all directions.
- When we push harder on one of the surfaces of the container, the fluid becomes compressed.
- The molecules near that surface collide more frequently with their neighbors, which in turn collide more frequently with *their* neighbors.
- The extra pressure exerted at one surface quickly spreads, such that soon there is increased pressure throughout the fluid.

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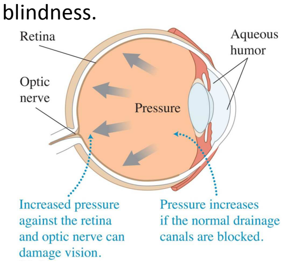
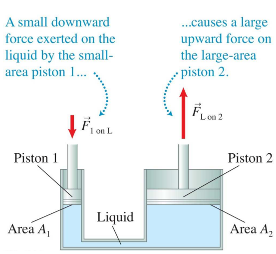
Glaucoma

- A person with glaucoma has closed drainage canals. The buildup of fluid causes increased pressure throughout the eye, including at the retina and optic nerve, which can lead to blindness.



Hydraulic Lift



- Pressure changes uniformly throughout the liquid, so the pressure under piston 2 is the same as the pressure under piston 1 if they are at the same elevation.

$$F_{L\ on\ 2} = PA_2 = \left(\frac{F_{1\ on\ L}}{A_1}\right)A_2 = \left(\frac{A_2}{A_1}\right)F_{1\ on\ L}$$

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Example

- A hydraulic lift has a small piston with surface area 0.0020 m^2 and a larger piston with surface area 0.20 m^2. Piston 2 and the car placed on piston 2 have a combined mass of 1800 kg. What is the minimal force that piston 1 needs to exert on the fluid to slowly lift the car?

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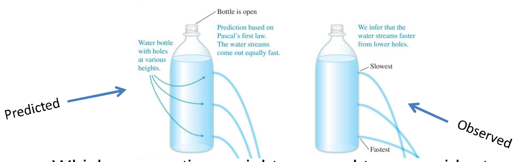
Pressure Variation with Depth

- Is the pressure the same throughout a vertical column of fluid?
  - If the pressure is the same, we should observe water coming out at the same parabolic arcs.
  - However, what we actually observe is this:



  - Which assumptions might we need to reconsider to reconcile this observation with Pascal's first law?

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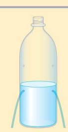
Observational Experiments

OBSERVATIONAL EXPERIMENT TABLE

10.2 How does the location of the holes affect the streams leaving the holes?

Observational experiment	Analysis
Experiment 1. Place two tacks on each side of a plastic bottle, one hole above the other, and fill the bottle with water above the top tack. Remove the tacks. Water comes out on the left and right and the stream from the lower holes shoots farther. 	There must be greater pressure inside than outside. The pressure must be greater at the bottom holes than at the top holes.
Experiment 2. Repeat Experiment 1 but this time fill the bottle with water to the same distance above the bottom tack as it was filled above the top tack in Experiment 1. Remove the tacks. The stream comes out the bottom holes with the same arc as it came out of the top holes in Experiment 1. 	The total water depth seems not to matter, just the height of the water above the hole.

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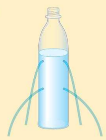
Observational Experiments

OBSERVATIONAL EXPERIMENT TABLE

10.2 How does the location of the holes affect the streams leaving the holes? *(Continued)*

Observational experiment	Analysis
Experiment 3. Repeat Experiment 1 using a thinner bottle with the water level initially the same distance above the top tack as it was in Experiment 1. Remove the tacks. The water streams are identical to those in Experiment 1. 	Because the water comes out in exactly the same arc in a bigger bottle and in a smaller bottle when the water level above the top tack is at the same height, we can conclude that the mass of the water in the bottle does not affect the pressure.

Patterns

The stream shape at a particular level:
- Depends on the height of the water above the hole.
- Is the same in different directions at the same level.
- Does not depend on the amount of liquid (volume or mass) above the hole (just the height of the water above the hole).
- Does not depend on the amount (mass or volume) or depth of the water below the hole.

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Pressure Variation with Depth

- From the observed patterns, we reason that the pressure of the liquid at the hole depends only on the height of the liquid above the hole, and not on the mass of the liquid above. We also see that the pressure at a given depth is the same in all directions.
- Pascal's first law fails to explain this pressure variation at different depths below the surface.

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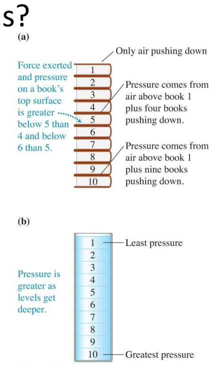
Why Does Pressure Vary at Different Depths?

- The top surface of the bottom book in the stack must balance the force exerted by the nine books above it plus the pressure force exerted by the air on the top book.
- The pressure increases on the top surface of each book in the stack as we go lower in the stack.



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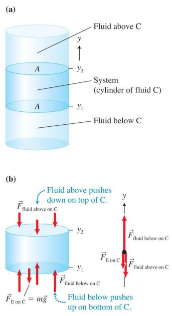
Pressure Change with Depth



Pascal's second law—variation of pressure with depth The pressure P_1 in a static fluid at position y_1 can be determined in terms of the pressure P_2 at position y_2 as follows:

$$P_1 = P_2 + \rho_{\text{fluid}}(y_2 - y_1)g, \quad (10.3)$$

where ρ_{fluid} is the fluid density, assumed constant throughout the fluid, and $g = 9.8\ \text{N/kg}$. The positive y-direction is up.

Free body diagram:

$$F_1 = P_1 A = F_2 + m_{fluid}\, g(y_2 - y_1)$$
$$= P_2 A + \rho_{fluid}\, g(y_2 - y_1)A$$

$$\boldsymbol{P_1 = P_2 + \rho_{fluid}(y_2 - y_1)g}$$

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Tip

- When using Pascal's second law, picture the situation. Be sure to include a vertical *y*-axis that points upward and has a defined origin, or zero point. Then choose the two points of interest and identify their vertical *y*-positions relative to the axis. This lets you relate the pressures at those two points.

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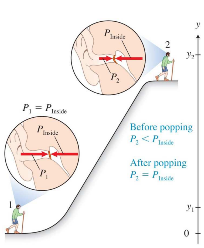
Example

- If your ears did not pop, then what would be the net force exerted by the inside and outside air on your eardrum at the top of a 1000-m-high mountain? You start your hike from sea level. The area of your eardrum is $0.50\ \text{cm}^2$. The density of air at sea level at normal conditions is $1.3\ \text{kg/m}^3$.
- The situation at the start of the hike, $y_1 = 0$, and at the end of the hike, $y_2 = 1000$ m, is sketched here.



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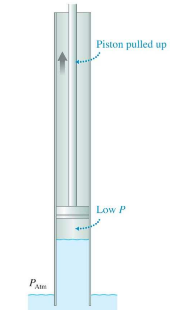
Measuring Atmospheric Pressure

- Its been known since Galileo's time that a pump consisting of a piston in a long cylinder that pulls up water can lift water only 10.3 m.



Atmospheric pressure P_{Atm} pushes water up the cylinder.

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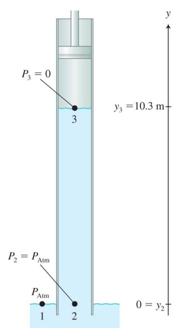
Measuring Atmospheric Pressure

- Consider the pressure at three places:
  - The pressure at point 1 is atmospheric pressure.
  - The pressure at point 2, according to Pascal's second law, is also atmospheric pressure.
  - We assume that the pressure at point 3 is zero because the water is at a maximum height.
- Using $P_2 = P_1 + \rho_{fluid}(y_2 - y_1)g$ gives exactly the value of atmospheric pressure



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Testing Torricelli's Hypothesis

TESTING EXPERIMENT TABLE

10.3 Testing Torricelli's hypothesis using mercury.

Testing experiment	Prediction based on Torricelli's hypothesis that atmospheric pressure limits the height of the liquid in a suction pump	Outcome
■ Torricelli filled a long glass tube closed at one end with mercury. 	Mercury should start leaking from the tube into the dish. When it leaks, it leaves an empty evacuated space at the top of the tube. It will leak until the height of the mercury column left in the tube produces the same pressure as the atmosphere at the bottom of the column at position 1. The height of the mercury in the tube should be $y_2 - y_1 = \frac{P_1 - P_2}{\rho_{mercury} g} = \frac{(1.01 \times 10^5 \text{ N/m}^2 - 0)}{(13.6 \times 10^3 \text{ kg/m}^3)(9.8 \text{ N/kg})} = 0.76 \text{ m}$	Torricelli observed some mercury leaking from the tube and then the process stopped. He measured the height of the remaining mercury to be 0.76 m = 760 mm, in agreement with the prediction.

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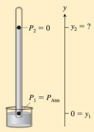
Torricelli's Hypothesis

TESTING EXPERIMENT TABLE

10.3 **Testing Torricelli's hypothesis using mercury.** *(Continued)*

Testing experiment	Prediction based on Torricelli's hypothesis that atmospheric pressure limits the height of the liquid in a suction pump	Outcome
■ He put his finger over the open end and placed it upside down in a dish filled with mercury. He then removed his finger.  Predict what he observed based on the hypothesis that atmospheric pressure limits the height of the liquid in a suction pump.		

Conclusion

The outcome of the experiment was consistent with the prediction based on Torricelli's hypothesis that atmospheric pressure limits the height of the liquid being lifted in a suction pump. Thus the hypothesis is supported by evidence.

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Atmospheric Pressure using Mercury

TIP We now understand why pressure is often measured and reported in mm Hg and why atmospheric pressure is 760 mm Hg. The atmospheric pressure (101,000 N/m^2) can push mercury of density (13,600 kg/m^3) 760 mm up a column.

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Example

- The bottom of a 4.0-m-tall diving bell is at an unknown depth underwater. The pressure of the air inside the bell is 2.0 atm (it was 1 atm before the bell entered the water). The average density of ocean water is slightly greater than the density of fresh water, $\rho_{\text{ocean water}} = 1027\ kg/m^3$. How high is the water inside the bell and how deep is the bottom of the bell under the water?

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