PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 22000

General Physics

Lecture 20 - Fluids

Fall 2016 Semester

Prof. Matthew Jones

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Second Midterm Exam

Wednesday, November 16th, 8:00-9:30 pm
Location: Elliot Hall of Music - ELLT 116.

Covering material in chapters 6-10

Multiple choice, probably about 25 questions, 15 will be conceptual, 10 will require simple computations.
A formula sheet will be provided.
You can bring one page of your own notes.

I put a couple exams from previous years on the web page.

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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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Pascal's Second Law

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:

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

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.

Relation between pressure and force:

$$F = PA$$

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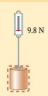
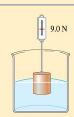
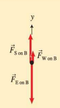
Buoyant Force

OBSERVATIONAL EXPERIMENT TABLE

10.4 Effect of depth of submersion on a steel block suspended in water.

VIDEO 10.4

Observational experiment	Analysis
Experiment 1. Hang a 1.0-kg block from a spring scale. The force that the scale exerts on the block balances the downward force that Earth exerts on the block ($mg = (1.0\ \text{kg})(9.8\ \text{N/kg}) = 9.8\ \text{N}$). 	Force diagram for the block B: 
Experiment 2. Lower the block into a container of water, so it is partially submerged. The water level rises. The reading of the scale decreases. 	We explain the decreased reading on the scale by the water pushing upward a little on the block. 

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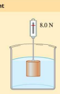
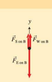
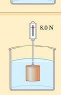
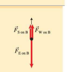
Buoyant Force

OBSERVATIONAL EXPERIMENT TABLE

10.4 Effect of depth of submersion on a steel block suspended in water. *(Continued)*

VIDEO 10.4

Observational experiment	Analysis
Experiment 3. Lower the same block into the container of water only to the point where the block is completely submerged. As the water level rises, the reading of the scale decreases. 	The upward force exerted by the water increases. 
Experiment 4. Lower the block into the container of water so that the block is completely submerged near the bottom. The water level and the reading of the scale do not change. 	The upward force exerted by the water does not change once it is completely submerged. 

Patterns

We notice two effects:

1. The level of the water in the container rises as more of the block is submerged in the water.
2. The scale reading decreases as more of the block is submerged. The water exerts an upward force on the block. The magnitude of this force depends on how much of the block is submerged. After it is totally submerged, the force does not change, even though the depth of submersion changes.

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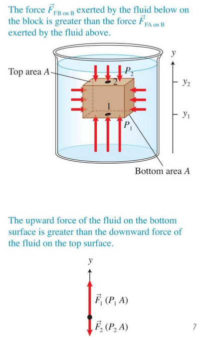
The magnitude of the force of fluid on a submerged object

- The force exerted by the fluid pushing up on the bottom is greater than the force exerted by the fluid pushing down on the top of the block.



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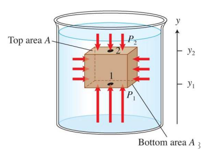
The magnitude of the force of fluid on a submerged object

- To calculate the magnitude of the upward buoyant force exerted by the fluid on the block, we use Pascal's second law to determine the upward pressure of the fluid on the bottom surface of the block, compared to the downward pressure of the fluid on the top surface of the block:

$P_1 = P_2 + \rho_{fluid}(y_2 - y_1)g$
$P_1A = P_2A + \rho_{fluid}(y_2 - y_1)Ag$
$F_1 = F_2 + \rho_{fluid}Vg$



Archimedes' Principle: Buoyant force

Archimedes' principle—the buoyant force A stationary fluid exerts an upward buoyant force on an object that is totally or partially submerged in the fluid. The magnitude of the force is the product of the fluid density ρ_{fluid}, the volume V_{fluid} of the fluid that is displaced by the object, and the gravitational constant g:

$$F_{\text{F on O}} = \rho_{\text{fluid}} V_{\text{fluid}}\, g \quad (10.4)$$

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Archimedes' Principle: Buoyant force

TIP (1) If an object is completely submerged in the fluid (as in the case of the block), the volume used in Eq. (10.4) is just the volume of the object. However, if the object floats, the volume in the equation then equals the volume of space taken up by the object below the fluid's surface. (2) The derivation of Eq. (10.4) was for a solid cube, but the result applies to objects of any shape, though calculus is needed to establish that.

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Example

Suppose your mass is 70.0 kg and your density is 970 kg/m^3. If you could stand on a scale in a vacuum chamber on Earth's surface, the reading of the scale would be mg = (70.0 kg)(9.80 N/kg) = 686 N. What will the scale read when you are completely submerged in air of density 1.29 kg/m^3?

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Example

Pretend for a moment that you are Archimedes, who needs to determine whether a crown made for the king is pure gold or some less valuable metal. From Table 10.1, you know that the density of gold is 19,300 kg/m^3. You find that the force that a string attached to a spring scale exerts on the crown is 25.0 N when the crown hangs in air and 22.6 N when the crown hangs completely submerged in water. Is the crown made of gold?

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Buoyancy

- If the object's density is less than that of the fluid $\rho_{object} < \rho_{fluid}$, then $\rho_{object} V_{object} g < \rho_{fluid} V_{object} g$; the object floats *partially* submerged since the buoyant force can balance the gravitational force with less than the entire object below the surface of the fluid.
- If the densities are the same $\rho_{object} = \rho_{fluid}$, then $\rho_{object} V_{object} g = \rho_{fluid} V_{object} g$; the sum of the forces exerted on the object is zero and it remains wherever it is placed totally submerged at any depth in the fluid.
- If the object is denser than the fluid $\rho_{object} > \rho_{fluid}$, then $\rho_{object} V_{object} g > \rho_{fluid} V_{object} g$; the magnitude of the gravitational force is always greater than the magnitude of the buoyant force. The object sinks at increasing speed until it reaches the bottom of the container.

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Application: submarines

- A submarine's density increases when water fills its compartments.
  - With enough water in the compartments, the submarine's density is greater than that of the water outside, and it sinks.
- When the water is pumped out, the submarine's density decreases.
  - With enough air in the compartments, its density is less than that of the outside water, and the submarine rises toward the surface.

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Example

An empty life raft of cross-sectional area 2.0 m x 3.0 m has its top edge 0.36 m above the waterline. How many 75-kg passengers can the raft hold before water starts to flow over its edges? The raft is in seawater of density 1025 kg/m^3.

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Stability of ships

- A challenge to building watercraft is to maintain stable equilibrium for the ship, allowing it to right itself if it tilts to one side due to wind or rough seas.
- The center-of-gravity of the ship is always at the same location, determined by its distribution of mass.
- The center-of-buoyancy moves, depending on which parts of the hull are below the water line.
- These two forces produce a torque about an imaginary point called the “metacenter”…

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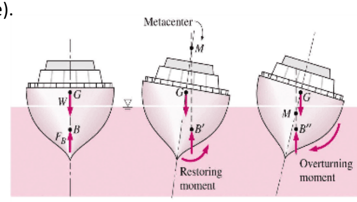
Stability of Ships

The buoyant force always points through the metacenter, so it accounts for no torque on the ship.

The force of gravity produces a torque about the metacenter that can either right the ship (stable) or cause it to tip more (unstable).



(a) Stable (b) Stable (c) Unstable

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Hot Air Balloons

Using hot air, balloonists can adjust the average density of the balloon (e.g., the balloon's material, people, equipment) to match the density of air so that the balloon can float at any location in the atmosphere (up to certain limits).

- A burner under the opening of the balloon regulates the temperature of the air inside the balloon and hence its volume and density.
- This allows control over the buoyant force that the outside cold air exerts on the balloon.

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Effects of Altitude on Humans

- “Partial pressure” is the contribution to the total pressure due to one species of gas particle.
- The pressure of atmospheric air decreases as one moves higher and higher in altitude.

Table 10.5 **The pressure of air and the pressure due to the oxygen in the air (called partial pressure) at different elevations.**

Location	Elevation (m)	P_{air} (atm)	P_{oxygen} (atm)
Sea level	0	1.0	0.21
Mount Washington	1917	0.93	0.18
Pikes Peak	4300	0.59	0.12
Mount McKinley	6190	0.47	0.10
Mount Everest	8848	0.34	0.07
Jet travel	12,000	0.23	0.05

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Effects of Altitude on Humans

- Between 4600 m and 6000 m, heart and breathing rates increase dramatically, and cognitive and sensory function and muscle control decline.
- Between 6000 m and 8000 m, climbers undergo critical hypoxia, characterized by rapid loss of muscular control and loss of consciousness.

4809 meters

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SCUBA Diving

- Scuba divers breathe compressed air.
  - While moving slowly downward, a diver adjusts the pressure outlet from the compressed-air tank to accumulate gas from the cylinder into her lungs, increasing the internal pressure to balance the increasing external pressure.
  - If a diver returns too quickly to the surface, the great gas pressure in the lungs can force bubbles of gas into the bloodstream.
  - This gradual process is called decompression.

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