Course announcement

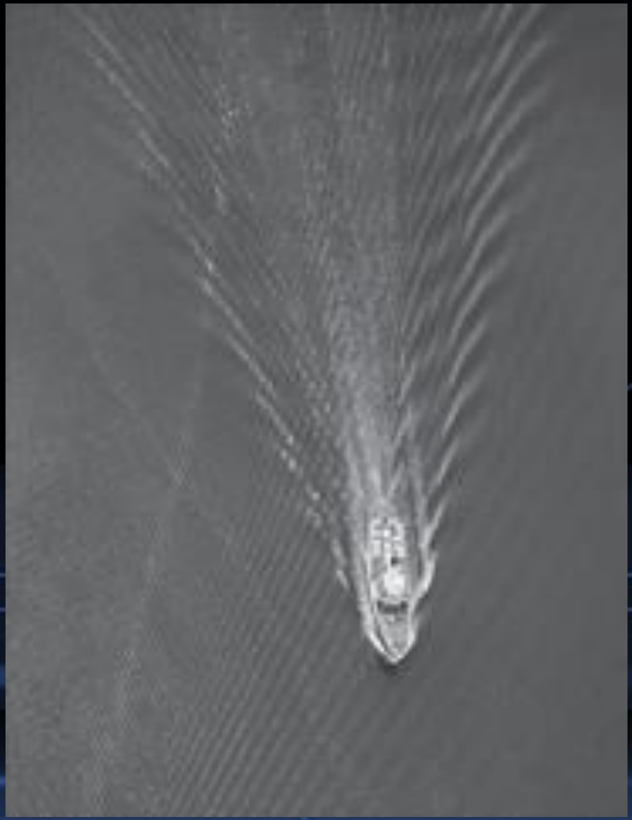
- Homework set 4 will be posted on eLearn today. It will be due on 12/2 Friday at 5PM.
- Final check of your grade of the first midterm (Posted on eLearn).
- The second midterm will on 12/6 (Tuesday). Range: from chapter 9 to chapter 15 of Wolfson (skip chapter 12). Exam will be started 8:00AM. Please bring student ID and calculator. You can bring one A4 information sheet for the exam.

Midterm Exam 1 Final Score

- Midterm Exam Final Score
- Midterm 1_finale score_final check

Shock waves

- **Shock waves** occur when a wave source moves through the medium at a speed *u* greater than the wave speed *v*:

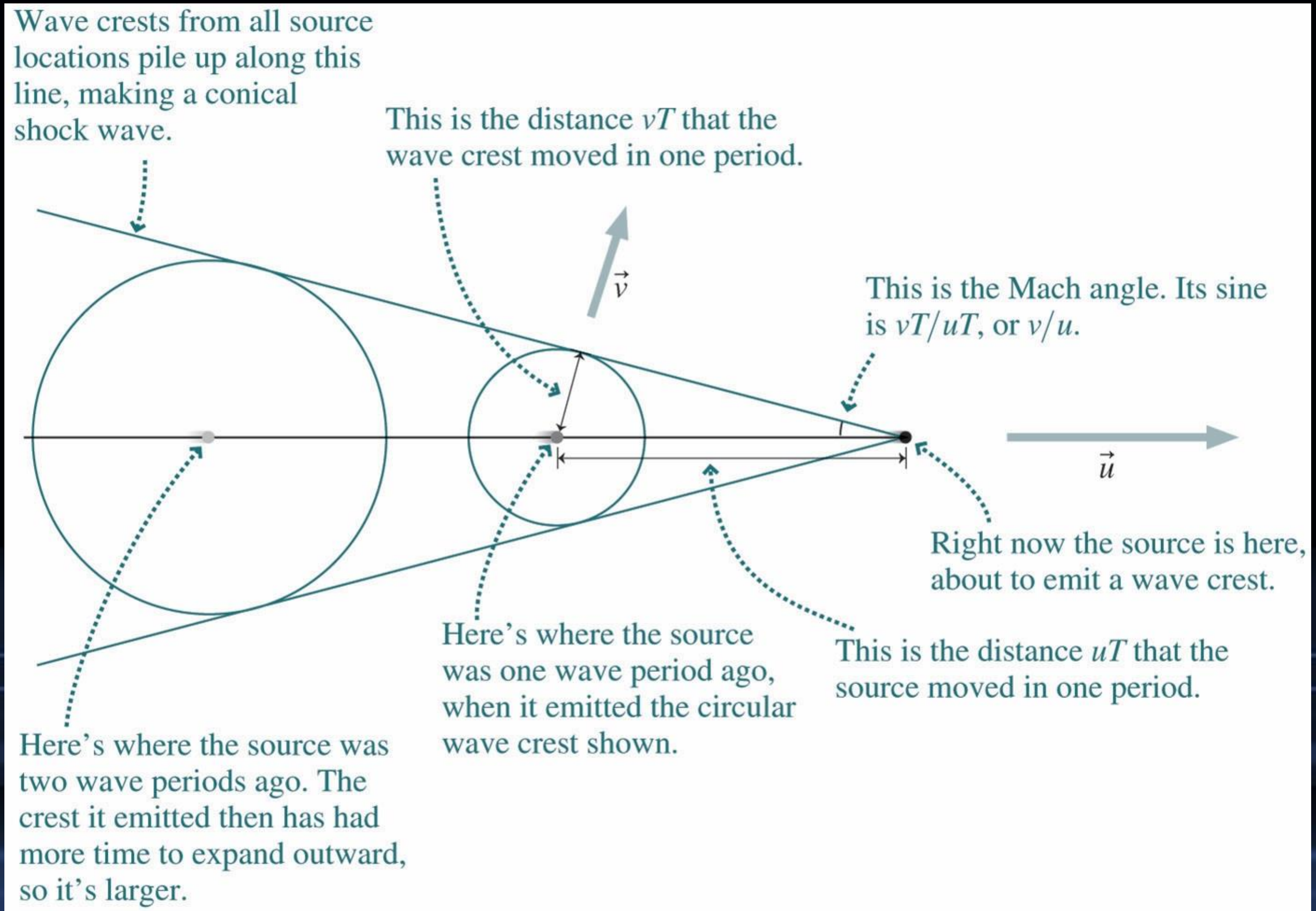


https://qph.cf2.quoracdn.net/main-qimg-ab7a30704e51218f1853a0fe5e9598e0

Shock waves

The ratio u/v is called the **Mach number**.

The **Mach angle** θ is defined by $\sin\theta = v/u$



11	11/22(Tue.)	**Oscillation and Waves:** propagation of waves
11	11/25(Fri.)	**Fluid Motion:** Density, Pressure, and Hydrostatic Equilibrium (Homework4)
12	11/29(Tue.)	**Fluid Motion:** Fluid Dynamics and Application
12	12/2(Fri.)	**Review II**
13	12/6(Tue.)	Mid Term 2

GENERAL PHYSICS B1
FLUID MOTION

Density, Pressure, and Hydrostatic Equilibrium

2022/11/25

What is a fluid

- **Fluid** is matter that flows under the influence of external forces:
  - Fluids include gases and liquids:
    - Gases: molecules are far apart and the density changes readily.
    - Liquids: molecules are close together and density remains essentially constant.

https://www.nasa.gov/sites/default/files/thumbnails/image/edu_fluid_large.jpg

https://acegif.com/tornado-gifs/

https://www.nasa.gov/feature/goddard/2022/nasa-s-webb-takes-star-filled-portrait-of-pillars-of-creation

Quantities to describe fluid: density and pressure

- Fluids cannot maintain a fixed structure but flow to assume the configuration of any container they're confined to.
- When we discuss rigid bodies, physical quantities that we find useful are mass and force.
- With fluids, we are more interested in the extended substance and in properties that can vary from point to point in that substance. It is more useful to speak of density and pressure

Density

- To find the density ρ of a fluid at any point, we isolate a small volume element ΔV around that point and measure the mass Δm of the fluid contained within that element. The density is then: $\rho = \frac{\Delta m}{\Delta V}$
- In practice, we assume that a fluid sample is large relative to atomic dimensions and thus is "smooth" with uniform density. Thus, the density in terms of the mass m and volume V of the sample: $\rho = \frac{m}{V} \quad \text{(uniform density)}$
- Liquids are nearly **incompressible** (constant density) and gases are **compressible:**

List of densities in nature

Material or Object		Density (kg/m^3)
Interstellar space		10^{-20}
Best laboratory vacuum		10^{-17}
Air: 20°C and 1 atm pressure		1.21
	20°C and 50 atm	60.5
Styrofoam		1×10^2
Ice		0.917×10^3
Water: 20°C and 1 atm		0.998×10^3
	20°C and 50 atm	1.000×10^3
Seawater: 20°C and 1 atm		1.024×10^3
Whole blood		1.060×10^3

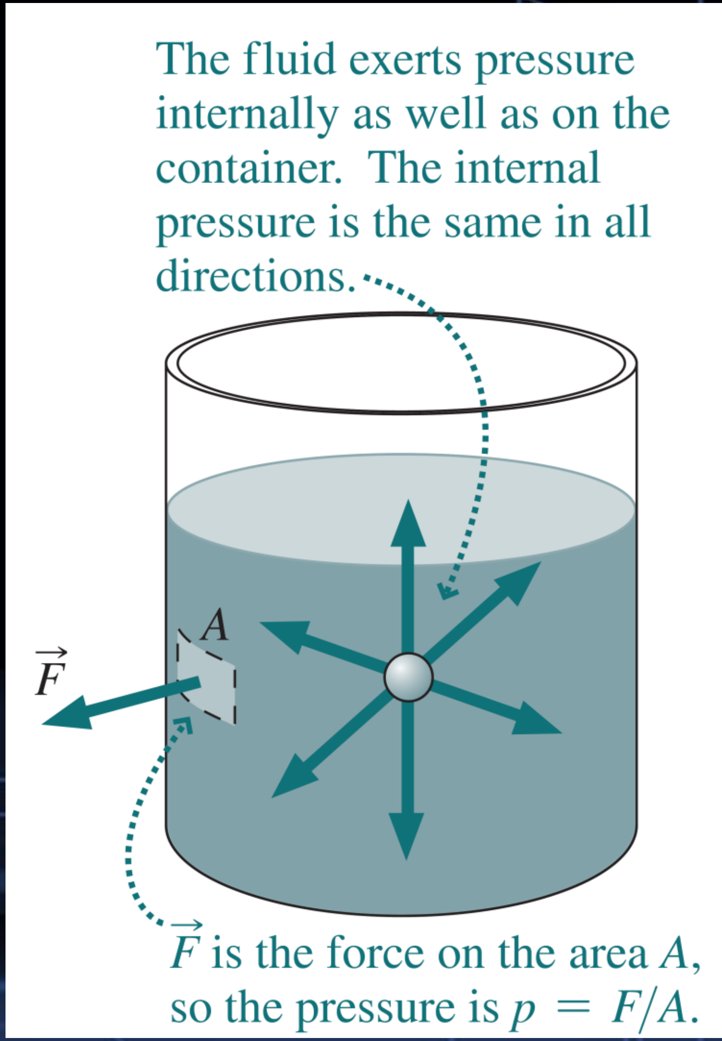
Iron		7.9×10^3
Mercury (the metal, not the planet)		13.6×10^3
Earth: average		5.5×10^3
	core	9.5×10^3
	crust	2.8×10^3
Sun: average		1.4×10^3
	core	1.6×10^5
White dwarf star (core)		10^{10}
Uranium nucleus		3×10^{17}
Neutron star (core)		10^{18}

Pressure

- **Pressure** is the force per unit area exerted by a fluid: $p = F/A$
- The SI unit for pressure is N/m^2 or pascal (Pa)

$$1 \text{ atm} = 101.3 \text{ kPa} = 14.7 \text{ psi}$$

- Pressure is exerted on the fluid's container as well as on adjacent fluid.
- Pressure is exerted equally in all directions.

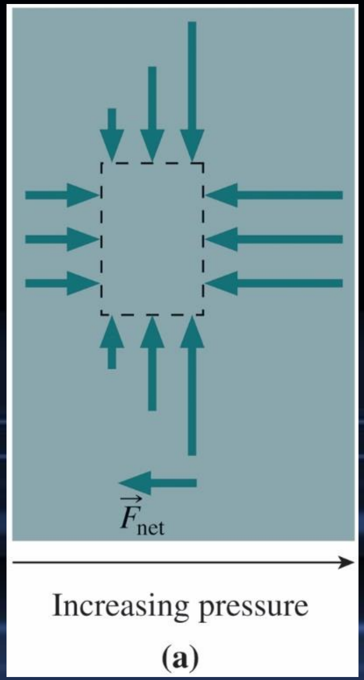


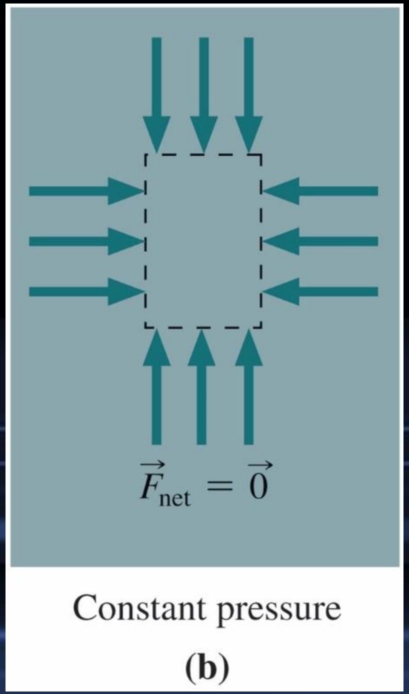
List of pressures in nature

	Pressure (Pa)
Center of the Sun	2×10^{16}
Center of Earth	4×10^{11}
Highest sustained laboratory pressure	1.5×10^{10}
Deepest ocean trench (bottom)	1.1×10^{8}
Spike heels on a dance floor	10^{6}
Automobile tire[a]	2×10^{5}
Atmosphere at sea level	1.0×10^{5}
Normal blood systolic pressure[a,b]	1.6×10^{4}
Best laboratory vacuum	10^{-12}

Net force in fluid and hydrostatic equilibrium

- There is a net force due to pressure only when pressure varies with position.
- For a fluid to remain at rest, the net force everywhere in the fluid must be zero and we called it hydrostatic equilibrium

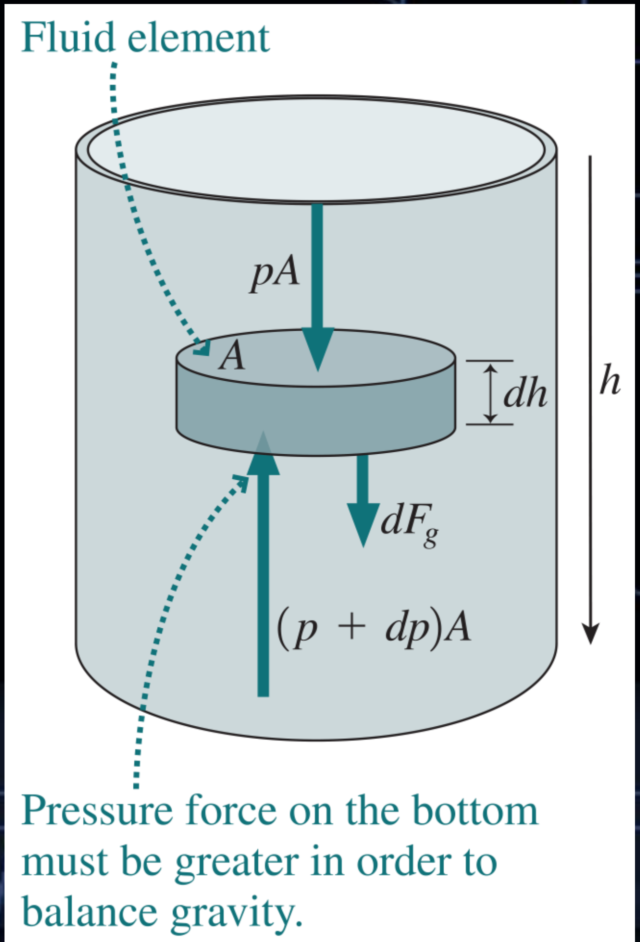




Hydrostatic equilibrium with gravity

- In the presence of gravity, the pressure in a static fluid must increase with depth:
  - This allows an upward pressure force to balance the downward gravitational force.
  - This condition is hydrostatic equilibrium.
  - Details depend on the nature of the fluid:
    - Incompressible fluids like liquids have constant density; for them, pressure as a function of depth h is as follows: $p = p_0 + \rho g h$

  where p_0 is the pressure at the surface



Hydrostatic equilibrium with gravity

- For the fluid element of area A, thickness dh, and mass dm, the net force on this is zero since it is in equilibrium.

The force downward: pA and mg=gρAdh

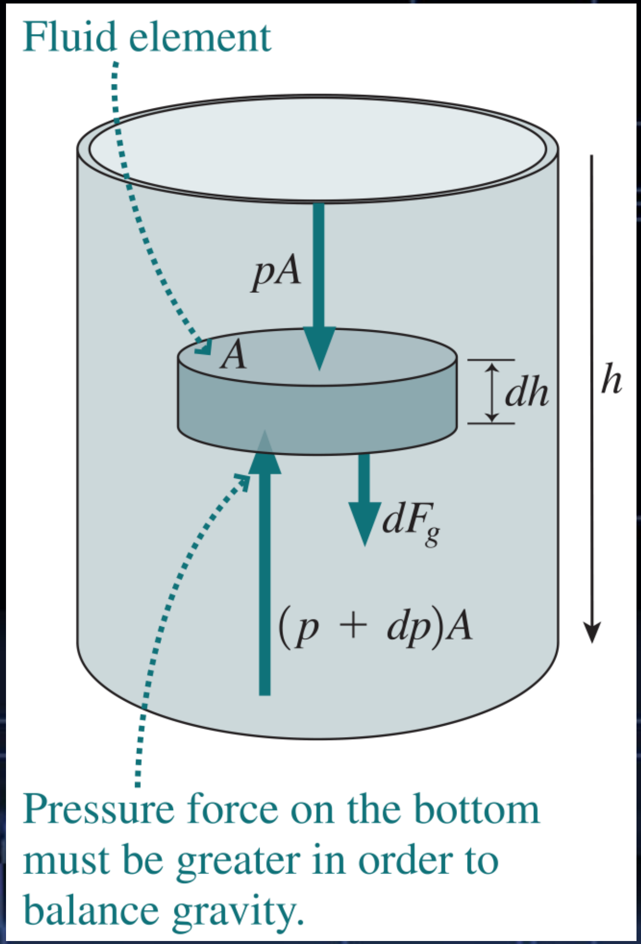
The force upward: (p+dp)A

In equilibrium: (p+dp)A = pA + gρAdh.

We have: $\frac{dp}{dh} = \rho g$

- Thus, at depth h: $p = p_0 + \rho g h$

where p_0 is the pressure at the surface



Example: Pressure Ocean Depths

- (a) At what water depth is the pressure twice atmospheric pressure?

Example: Pressure Ocean Depths

- (a) At what water depth is the pressure twice atmospheric pressure? (1 atmospheric pressure =101kPa and the density of sea water is 1030kg/m^3)

We have $p=2p_0$. Thus:

$$h = \frac{p - p_0}{\rho g} = 10m$$

Example: Pressure Ocean Depths

- (b) What is the pressure at the bottom of the 11-km-deep Marianas Trench, the deepest point in the ocean?

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$$p = p_0 + \rho g h = 110 MPa$$

This pressure is more than 1000 times larger than 1 atm (101kPa)!

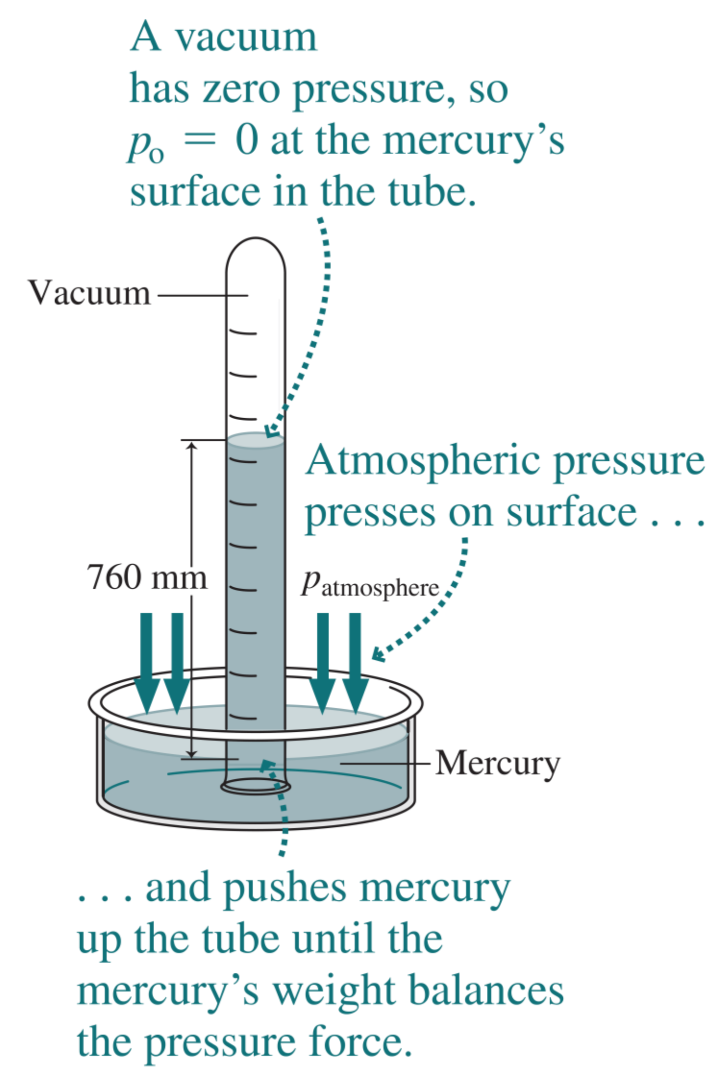
https://www.quora.com/Will-very-deep-water-fish-explode-if-rapidly-brought-to-the-surface

Measuring Pressure

- A traditional mercury **barometer** measures the **absolute pressure** (relative to a vacuum) of a fluid, typically air. We have:

$$p = \rho g h$$

- Modern barometers often use electronic sensors.

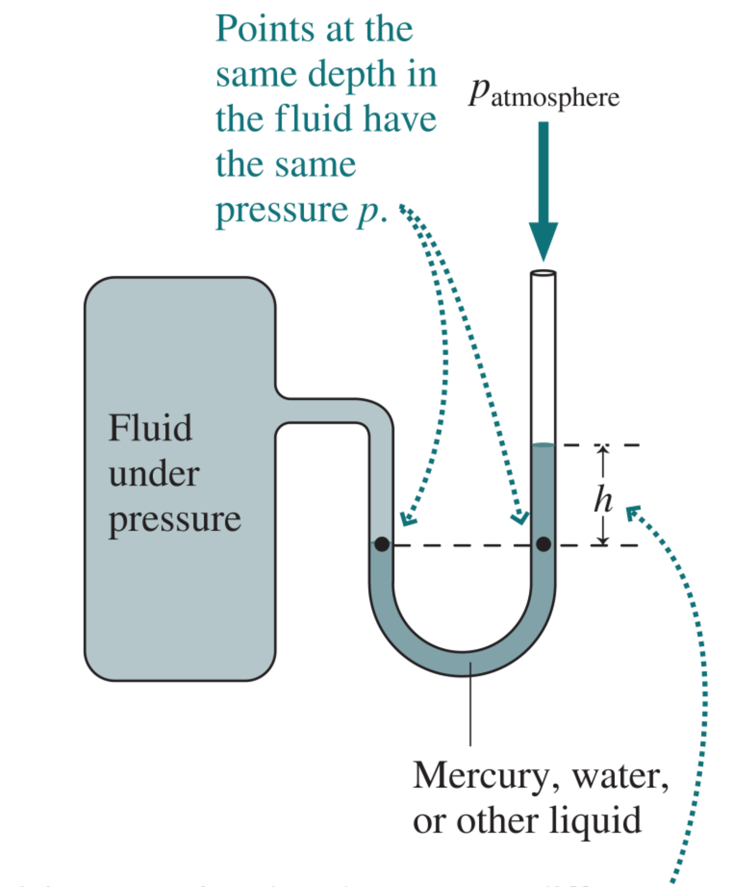


Measuring Pressure

- A **manometer** measures pressure differences.
  - **Gauge pressure** is a measure of pressure relative to the ambient atmosphere:

$$p_{gauge} = p - p_{atmosphere} = \rho g h$$

  - Tire pressure, for example, is actually gauge pressure—which measures the tire's excess pressure over atmospheric pressure.

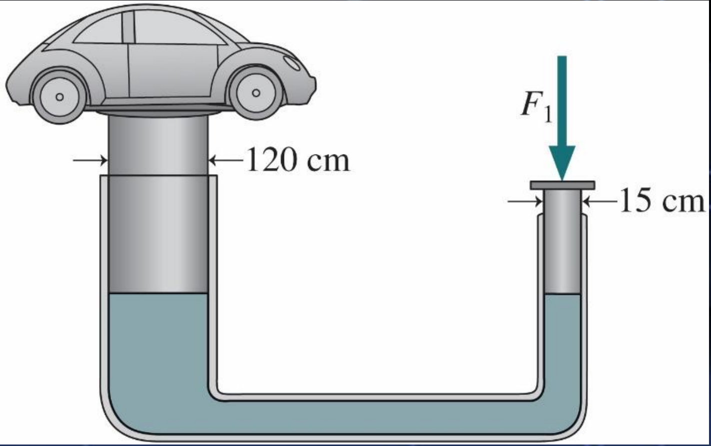


h is proportional to the pressure difference between fluid and atmosphere.

Pascal's Law

- A pressure increase anywhere is felt through out the fluid: Pascal's law.
- Pascal's law's application: hydraulic press.
- Example: lift a car with hydraulic press as shown

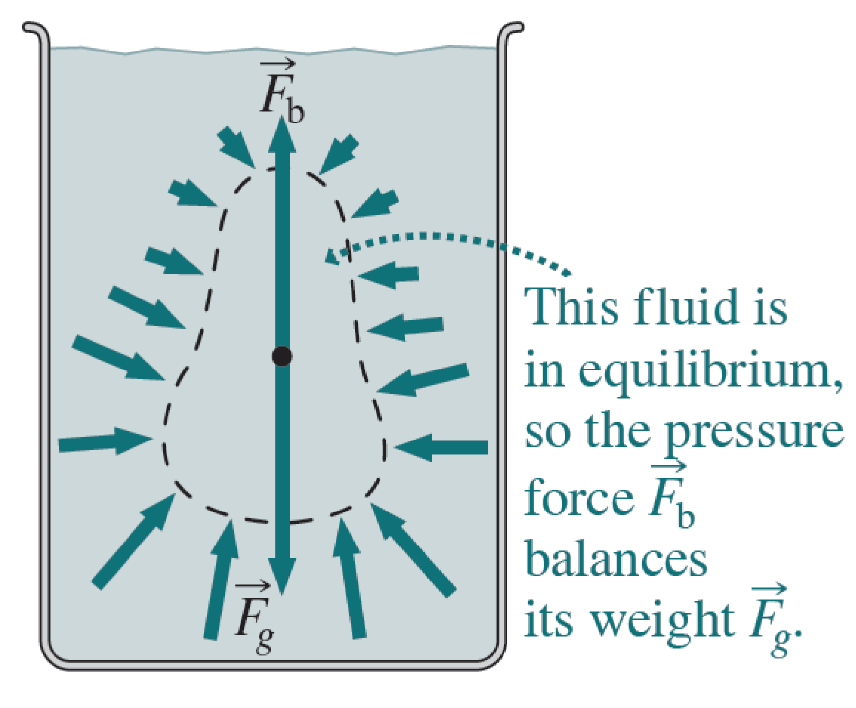
$$m_{car}g = p\pi(60)^2 = \frac{F_1}{\pi(7.5)^2}\pi(60)^2$$



- Thus: $F_1 = \frac{m_{car}g}{64}$

Archimedes' Principle and Buoyancy

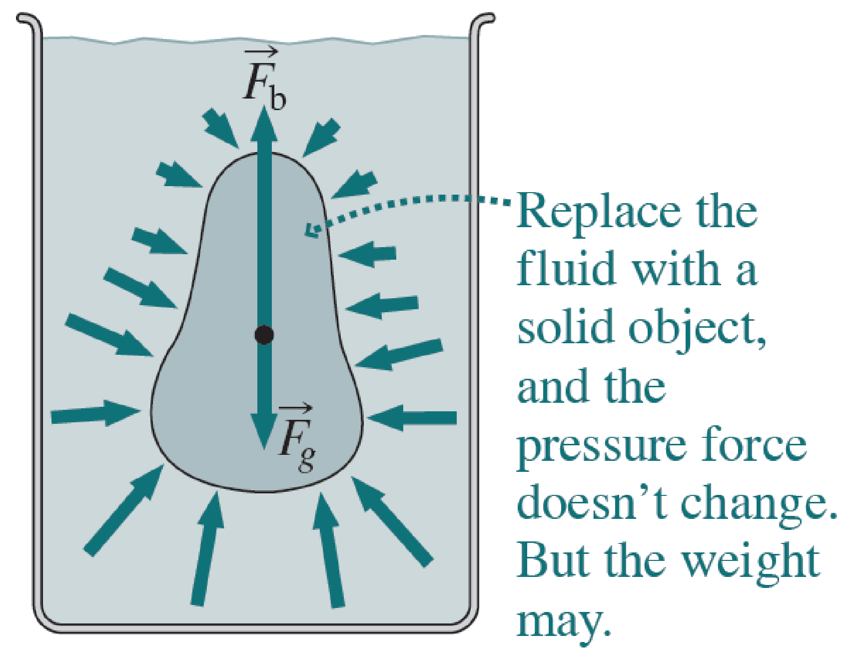
- When a fluid is in hydrostatic equilibrium, the force due to pressure differences on an arbitrary volume of fluid exactly balances the weight of the fluid.



(a)

Archimedes’ Principle and Buoyancy

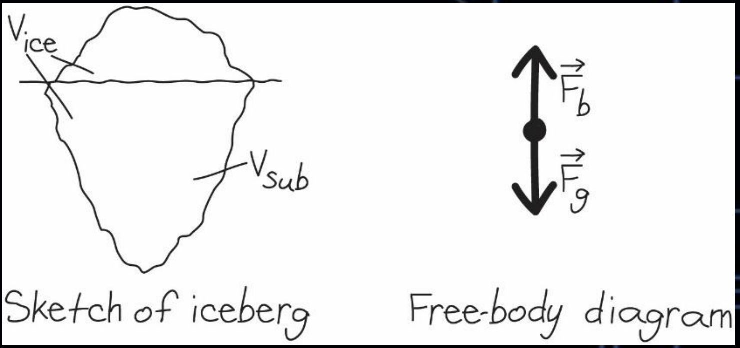
- Replacing the fluid with an object of the same shape doesn’t change the force due to the pressure differences:
  - Therefore, the object experiences an upward force equal to the weight of the original fluid.
  - This is the **buoyancy force**.
  - **Archimedes’ principle** states that the buoyancy force is equal to the weight of the displaced fluid: $F_b = \rho_f g V_f$



(b)

Floating Objects

- If a submerged object is less dense than a fluid, then the buoyancy force is greater than its weight and the object rises.
- In a liquid, the object eventually reaches the surface:
  - Then the object floats at a level such that the buoyancy force equals its weight.
  - That means the submerged portion displaces a weight of liquid equal to the weight of the object.
- In the atmosphere, a buoyant object (like a balloon) rises to a level where its density is equal to that of the atmosphere.
- This is **neutral buoyancy**.



Example

- The average density of a typical arctic iceberg is 0.86 that of sea water. What fraction of an iceberg's volume is submerged?

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The weight of iceberg is equal to buoyancy force:

Weight of iceberg: $m_{ice}g = \rho_{ice}V_{ice}g$

buoyancy force: $W_{water} = \rho_{water}gV_{sub}$

Thus:

$$\frac{V_{sub}}{V_{ice}} = \frac{\rho_{ice}}{\rho_{water}} = 0.86$$

Center of Buoyancy

- The buoyancy force acts not at the center of mass of a floating object but at the center of mass of the water that would be there if the object weren't. This point is called the center of buoyancy.
- For stable equilibrium, the center of buoyancy must lie above the center of mass.