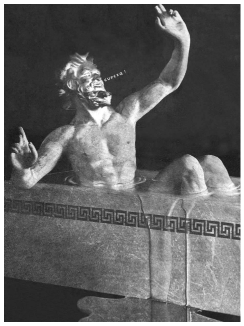
PHY131H1F Summer – Last Class!

Today:
- Fluids
- Pressure
- Pascal's Law
- Gauge Pressure
- "Suction"
- Buoyancy, Archimedes' Principle
- Course Review!



Archimedes (287-212 BC) was asked to check the amount of silver alloy in the king's crown. The answer occurred to him in the tub and he shouted "Eureka!"

Pre-class reading quiz on Chapter 15 (1 of 2)

What is the approximate density of water?

A. 10^{-5} kg/m^3
B. 0.01 kg/m^3
C. 0.1 kg/m^3
D. 1 kg/m^3
E. 1000 kg/m^3

Pre-class reading quiz on Chapter 15 (2 of 2)

What is the approximate density of air?

A. 10^{-5} kg/m^3
B. 0.01 kg/m^3
C. 0.1 kg/m^3
D. 1 kg/m^3
E. 1000 kg/m^3

Last day I asked at the end of class:

- If you stand on a waterproof bathroom scale in a wading pool, so that part of your legs are immersed in the water, will your measured weight be different than normal?
- ANSWER:
- Yes! Your weight will be less.
- That is because the water exerts an upward buoyancy force on the part of your legs that is immersed.
- Archimedes' Principle states that your weight will be less by the weight of the amount of water that your legs displace.

Definition: **Density**

The ratio of a fluid's or object's mass to its volume is called the **mass density**, or sometimes simply "the density."

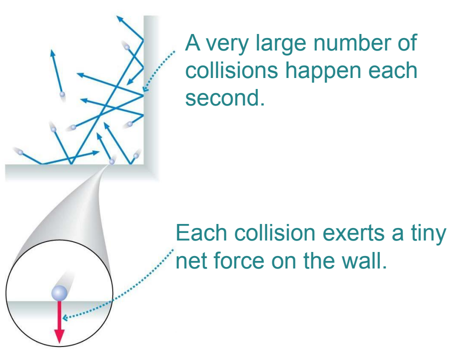
$$\rho = \frac{m}{V} \qquad \text{(mass density)}$$

The SI units of mass density are kg/m^3.

The density of water is 1.00×10^3 kg/m^3.

Your body is composed of about 60% water.

Pressure is due to the net force of the molecules in a fluid colliding with the walls.



Definition: **Pressure**

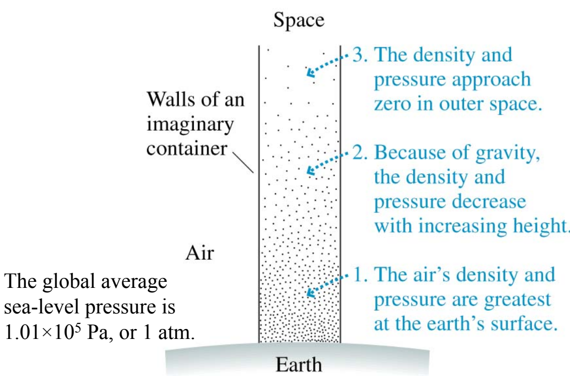
A fluid in a container presses with an outward force against the walls of that container. The **pressure** is defined as the ratio of the force to the area on which the force is exerted.

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

The SI units of pressure are N/m^2, also defined as the pascal, where 1 pascal = 1 Pa = 1 N/m^2.
Other units:

1 atm = 1.01×10^5 Pa
1 mmHg = 133 Pa
1 kPa = 10^3 Pa
1 psi = 6890 Pa

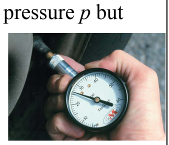
Atmospheric Pressure



Gauge Pressure

Pressure gauges, such as tire gauges and blood pressure monitors, measure not the actual or absolute pressure p but what is called **gauge pressure** p_g.

$$p_g = p - 1\text{ atm}$$



where 1 atm = 1.01×10^5 Pa.

• ie "120 over 80" means the maximum gauge pressure in your arteries is 120 mmHg or 1.6×10^4 Pa.

• The actual, or "absolute" pressure in your arteries has a maximum of $p = p_g + 1\text{atm}$
$= 1.6\times10^4 + 1.01\times10^5\text{ Pa} = 1.17\times10^5\text{ Pa}$

Is *gauge pressure* larger, smaller, or equal to true pressure?

A. Larger
B. Smaller
C. equal to

Pressure and "Suction"

What is the force of air pressure on the top of your outstretched hand?

Atmospheric Pressure:

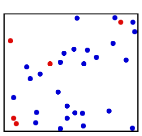
$$\left(1.013\times 10^{5}\ \frac{\text{N}}{\text{m}^2}\right)\left[\frac{0.0254\text{m}}{1\ \text{inch}}\right]^2\left[\frac{2.2\ \text{pounds}}{9.8\ \text{N}}\right] = 15\text{psi}$$

20 square inches = 300 pounds!

Why don't you feel that force pushing your hand down?

What if all the air below your hand was removed (a vacuum)?

Pressure and "Suction"



A fluid can only **push** walls or objects; a fluid **cannot pull** on a wall.

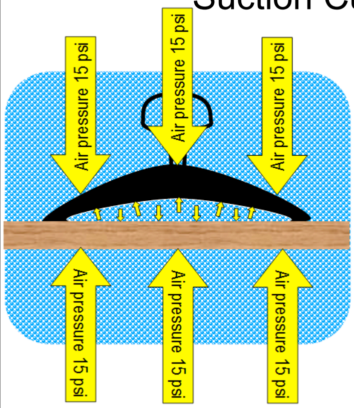
What we call "suction" is when the fluid on one side has a higher pressure than the fluid on the other side.

It is the pressure **difference** which creates a pushing force into the lower pressure area (into the vacuum).

This is how we breath:

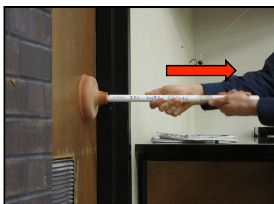
1. We expand our lung cavity, lowering the pressure inside.
2. The higher air pressure outside ***pushes*** air into our lungs.

Suction Cups



When we lower the pressure inside a suction cup, it is the pushing forces of the pressurized air all around which creates the net forces.

Suction cups would not work on the moon!



Harlow uses a toilet plunger to pull a door.
The maximum pulling force that Harlow can exert on the door in this way

A. is determined by Harlow's strength.
B. is determined by the strength of the door.
C. equals $P_{atm} A$, where A = area of the suction cup
D. equals $m g$, where m = mass of the door
E. equals $\mu_s (m g)$, where μ_s is the coefficient of static friction between the cup and the door

Fluids

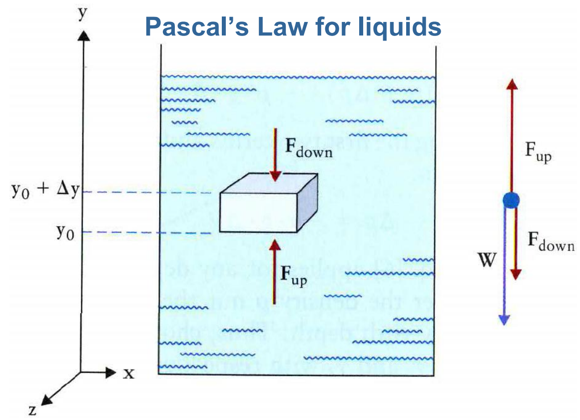
- Fluids include both Liquids and Gases: what's the difference?
- **Gas:** Pressure and Volume are related by the ideal gas law:

$$PV = nRT$$

At constant temperature, if the Pressure of a gas is increased, its Volume decreases (it is compressed)

- **Liquid:** Pressure does not change the Volume much. "Incompressible"

Pascal's Law for liquids



Pascal's Law for liquids

- Consider a small element of fluid in a beaker.
- Pressure acts inward on all surfaces of the small element.
- Gravity pulls it downward.
- To balance the force of gravity, the upward pressure on the bottom surface must be greater than the downward pressure on the top surface: "buoyancy"

$$p_2 - p_1 = -\rho g\,(y_2 - y_1)$$

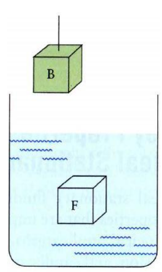
- This is the equation for the pressure of an incompressible fluid in hydrodynamic equilibrium in a gravitational field.
- Pressure increases with depth! Scuba divers know this!

Buoyancy: Archimedes Principle

- Let's do a "thought experiment" (Gedanken).
- Imagine a beaker with a fluid and a block, B, hanging near it.
- There is a fluid element F with the same shape and volume as the block B.
- The fluid element F is in mechanical equilibrium:

$$F_{up} - F_{down} - W_F = 0$$

- where F_{up} is the pressure force on the bottom surface, F_{down} is the pressure force on the top surface, and W_F is the weight of fluid F.

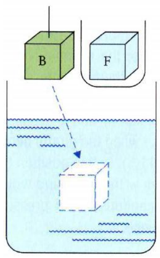


Buoyancy: Archimedes Principle

- **Step 1:** Remove F from the beaker and place it in a small container, leaving an empty bubble of the same size in the beaker.
- The bubble is not in mechanical equilibrium, since its weight is much less than that of the removed fluid, but the pressure forces are the same.:

$$F_{\text{up}} - F_{\text{down}} = W_F > 0$$

- where F_{up} is the pressure force on the bottom surface, F_{down} is the pressure force on the top surface, and W_F is the weight of the removed fluid F.

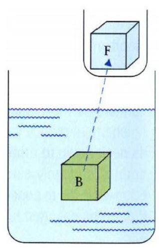


Buoyancy: Archimedes Principle

- **Step 2:** Block B, with weight W_B, is placed in the bubble.
- There is a net force on Block B:

$$F_{\text{net}} = F_{\text{up}} - F_{\text{down}} - W_B = W_F - W_B$$

- where W_F is the weight of the removed fluid F, and W_B is the weight of the block B.
- This is equal to the force of gravity, $-W_B$, plus a new force called "Buoyancy",which is due to the pressure gradient in the fluid.



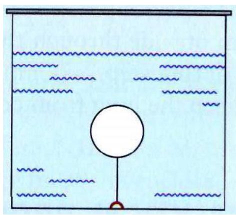
Archimedes' principle: When an object is immersed in a fluid, the fluid exerts an upward force on the object equal to the weight of the fluid displaced by the object.

The buoyant force on an object submerged in a liquid depends on

A. the object's mass.
B. the object's volume.
C. the density of the liquid.
D. both A and B.
E. both B and C.

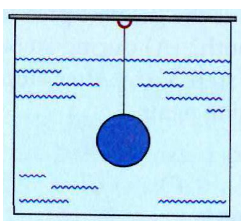
Example

- A wooden sphere with a diameter of d = 10 cm and density ρ = 0.9 g/cm^3 is held under water by a string. What is the tension in the string?
- Note that the density of water in these units is 1.00 g/cm^3.



Example

- A sphere with a radius of r = 10 cm and density ρ = 2.0 g/cm^3 is suspended in water. What is the tension in the string?
- Note that the density of water in these units is 1.00 g/cm^3.



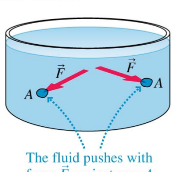
What Causes Buoyancy? : Pressure!

Recall: A fluid in a container presses with an outward force against the walls of that container. The **pressure** is defined as the ratio of the force to the area on which the force is exerted.

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

The SI units of pressure are N/m^2, also defined as the pascal, where 1 pascal = 1 Pa = 1 N/m^2.

FIGURE 15.4 The fluid presses against area A with force $\vec{F}$.



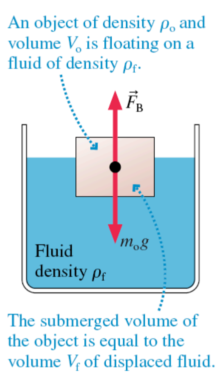
What Causes Buoyancy? : Pressure!

Recall: The pressure at depth *d* in a liquid is

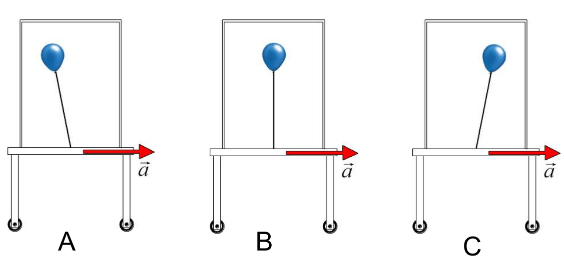
$$p = p_0 + \rho g d \qquad \text{(hydrostatic pressure at depth } d\text{)}$$

where ρ is the liquid's density, and p_0 is the pressure at the surface of the liquid. Because the fluid is at rest, the pressure is called the **hydrostatic pressure**. The fact that g appears in the equation reminds us that there is a gravitational contribution to the pressure.

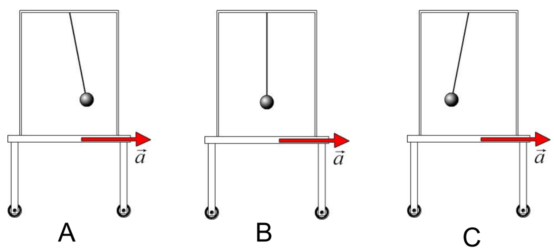
FIGURE 15.23 A floating object is in static equilibrium.



- A cart is covered by an enclosed transparent box. A helium-balloon is attached to the bottom of the box by a string. Predict: As the box is accelerating toward the right, which will be the best sketch of the situation?



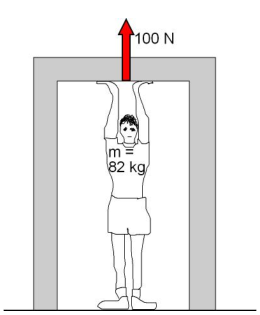
- A cart is covered by an enclosed transparent box. A ball is attached to the top of the box by a string. Predict: As the box is accelerating toward the right, which will be the best sketch of the situation?



Normal Force is Not always mg !

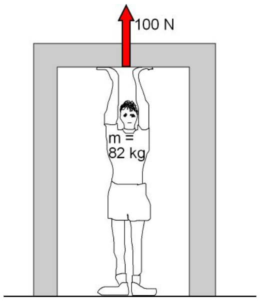
- Gravity, F_G, has an equation for it which predicts the correct magnitude (it's always mg here on Earth).
- Normal force, Tension and Static friction are all self-adjusting forces: ***there is no equation for these!!***
- Normal force is whatever is needed to keep the object from crashing through the surface.
- Tension is whatever is needed to keep the string or rope from breaking.
- Static friction is whatever is needed to keep the object from slipping along the surface.
- In all these cases, you must draw a free-body diagram and figure out by using equilibrium and Newton's 2nd law what the needed force is.

Bob stands under a low concrete arch, and presses upwards on it with a force of 100 N. Bob's mass is 82 kg. What is the **normal force** of the arch on Bob?



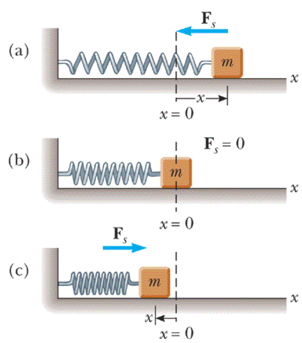
A. 100 N, upward
B. 100 N, downward
C. 900 N, upward
D. 700 N, upward
E. 900 N, downward

Bob stands under a low concrete arch, and presses upwards on it with a force of 100 N. Bob's mass is 82 kg. What is the **normal force** of the ground on Bob? (Note that 82 × 9.8 = 800.)

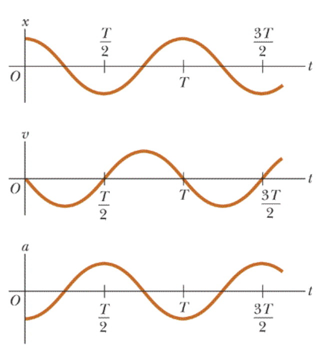


A. 800 N, upward
B. 800 N, downward
C. 900 N, upward
D. 700 N, upward
E. 900 N, downward

Simple Harmonic Motion:
Restoring Force provided by Hooke's Law

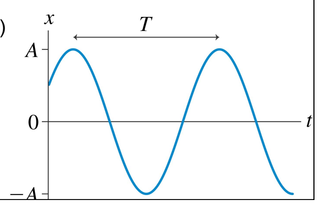


x,v,a for Simple Harmonic Motion



Simple Harmonic Motion notes…

- S.H.M. is *not* constant acceleration, or constant force – both vary with time.
- S.H.M. results when restoring force is proportional to displacement. Other types of oscillatory motion are possible, but not discussed in this course.
- Angular frequency $\omega = 2\pi/T$, where T = period.
  ($T = 2\pi/\omega$)
- "frequency" $f = 1/T$ (in Hertz)



Gravitational Field Note: Prep for PHY132

- When a mass m is near the surface of the Earth, it has a potential energy, given by

$$U_g = mgy + U_0$$

- where y is the vertical height, and U_0 is an arbitrary constant, in Joules.
- Since m is so much smaller than the mass of the Earth, we can think of m as a "test particle".
- No matter where we place m, it has a gravitational potential energy due to the Earth.
- We can think of this as a property of the space itself: the gravitational potential energy field.
- This is a scalar field: a number is associated with every (x,y,z) point in space.

Gravitational Field Note: Prep for PHY132

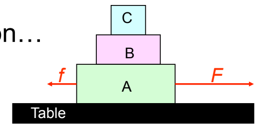
- Recall from section 11.6, eq.11.28: The Force on an object is the negative of the gradient of its potential energy.

$$\vec{F}_g = -\vec{\nabla} U_g = -\left(\frac{\partial U_g}{\partial x}\hat{x} + \frac{\partial U_g}{\partial y}\hat{y} + \frac{\partial U_g}{\partial z}\hat{z} \right)$$

$$\vec{F}_g = -\left[\frac{\partial}{\partial y}\left(mgy + U_0 \right) \right]\hat{y} = mg, \quad \text{downward}$$

- No matter where we place m, there is a gravitational force at every point in space due to the Earth, which is the negative gradient of the potential energy.
- We can think of this as a property of the space itself: the gravitational force field.
- This is a vector field. A vector is associated with every (x,y,z) point in space.

A former exam question…

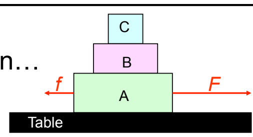


Three blocks sit on top of each other. They are being accelerated to the right. Horizontal forces acting on the lower block A are an external force *F* to the right and a frictional force *f* from the table.

Horizontal forces acting on the upper block C are:

A. The frictional force exerted on it by the middle block B and the frictional force f by the table.
B. The frictional force exerted on it by the lower block A and the frictional force exerted on it by the middle block B.
C. Just F and f
D. Zero
E. The frictional force exerted on it by the middle block B.

A former exam question…



The magnitude of the net horizontal force exerted on the upper block C is

A. $m_C \dfrac{F-f}{m_A+m_B+m_C}$
B. $F-f$
C. $m_C \dfrac{F-f}{m_A}$
D. Zero
E. $m_B \dfrac{f}{m_A+m_B+m_C}$

that's all for PHY131…

- The 3 hour final exam will cover the entire course, including all of the assigned reading plus Practicals materials and what was discussed in class
- Approximately even spread over Knight Chs. 1-15
- I recommend you are familiar with all Masteringphysics homework and Practicals work you did.
- Please email me (jharlow @ physics.utoronto.ca) with any questions. Keep in touch! It's been a really fun course for me!