The background features a gradient from red at the top to blue at the bottom, overlaid with faint, semi-transparent circular gauges and arrows. One large gauge on the left has numerical markings from 140 to 260. Several circular arrows indicate clockwise or counter-clockwise rotation, suggesting a scientific or technical theme.

BEHAVIOR OF FLUIDS: PRESSURE, DENSITY, AND VOLUME

PES 1000 – PHYSICS IN EVERYDAY LIFE

MACROSCOPIC VS. MICROSCOPIC QUANTITIES

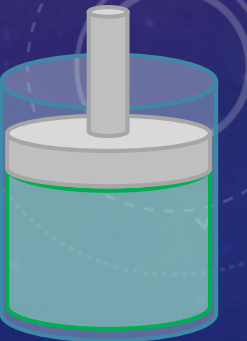
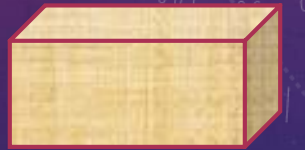
- We have been studying the motion of regular-sized (**macroscopic**) objects. We know these objects are made up of countless atoms and molecules (**microscopic**). Here are some questions you might have:
 - **How many** microscopic particles would a macroscopic object have in it?
 - The number is inconceivably large. You are made up of about 1.6×10^{27} **molecules**. A jar-full of seemingly-insubstantial air has about 3×10^{22} (30 billion trillion) molecules.
 - Does the physics we have learned apply to both microscopic and macroscopic objects?
 - Yes, although it is quite difficult to measure our standard quantities of mass, force, velocity, etc. for so many small objects.
 - How can we keep track of so many microscopic objects?
 - We can't very easily. What we do instead is to measure the bulk behavior of these particles using macroscopic variables like **density**, **volume**, **pressure**, and **temperature**.

MACROSCOPIC VARIABLES

- **Density:** A measure of the total mass of particles within a given volume
 - The SI units are kg/m^3 (also used: g/cm^3 or g/cc , $slug/ft^3$).
 - The variable often used is ρ , the Greek 'rho'.
- **Volume:** The amount of space the particles occupy
 - The SI units are m^3 (also used: cm^3 or cc).
 - The variable is usually V .
- **Pressure:** The combined force per unit area of all the particles on a surface
 - The SI unit is the *Pascal* (Pa). 1 Pascal = 1 Newton/ m^2 .
 - The variable is often P .
- **Temperature:** The average kinetic energy of all of the particles
 - The SI unit is the *Kelvin* (K). This is one of the fundamental units in physics.
 - The variable used is generally T .

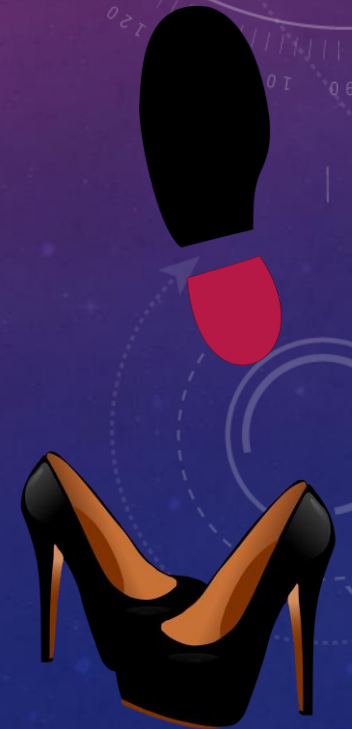
COMPRESSIBILITY

- **Density** depends on how much matter is within a unit volume ($\rho=m/V$)
 - The SI unit is kg/m^3 . Another useful unit is g/cm^3 . They differ by a factor of 1000.
- Most liquids don't compress easily, so they have a standard density.
 - Water has a density of 1 g/cm^3 (or 1000 kg/m^3)
 - Anything with lower density floats. Anything with higher density sinks.
 - Mercury, another liquid, has a density of 13.6 g/cm^3
- Most solids don't compress easily, either. Solids and liquids are called '*incompressible*'.
 - Examples: wood density is $\rho \approx 0.6 \text{ g/cm}^3$, lead density is $\rho = 11.3 \text{ g/cm}^3$
- Gases are '*compressible*'. A gas will occupy the volume of its container, which can vary, so its density depends on its environment.



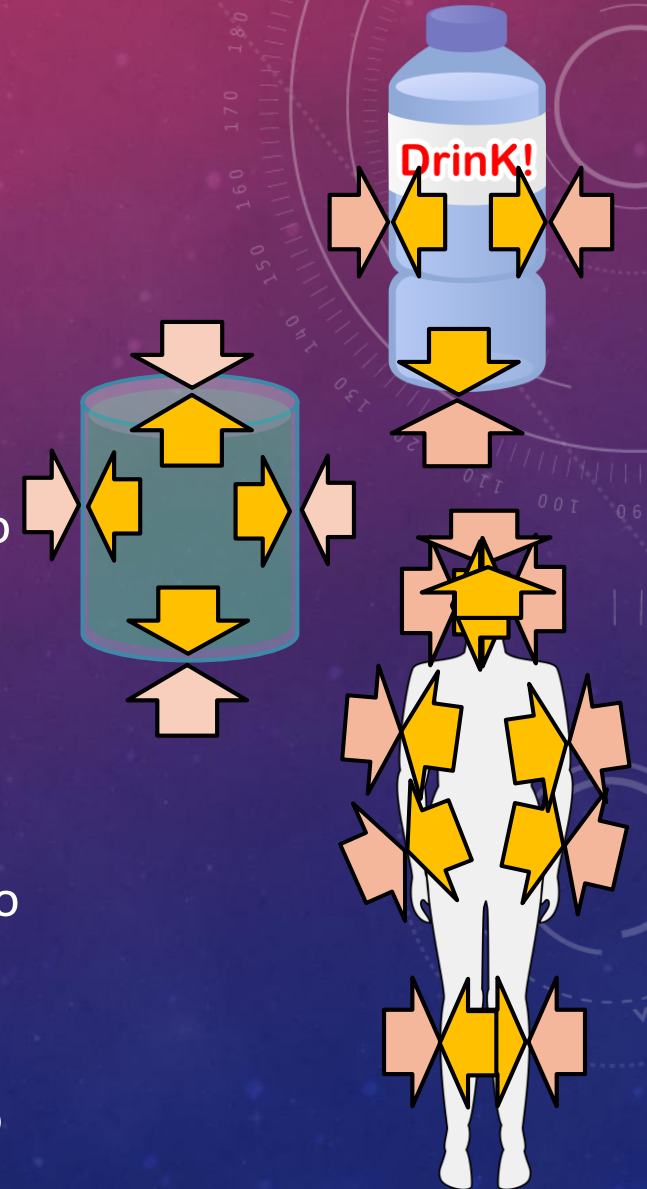
PRESSURE RELATIONSHIPS

- **Pressure** is defined as the amount of force per unit area: $P=F/A$
- The force can be obtained from this equation, too. $F=P*A$
 - The direction of force is perpendicular to the surface.
- An example using the heels of shoes:
 - A typical guy weighs about 800 N. The heel of his dress shoe has an area of about 4cm x 4cm, or 0.0016 m². If all his weight is on one heel, that's a pressure of **500,000 Pa**, or 500 kPa.
 - A typical gal weighs about 500 N. The heel of her dress shoe has an area of about 1cm x 1cm, or 0.0001 m². If all her weight is on one heel, that's a pressure of **5,000,000 Pa**, or 5000 kPa. Ten times the pressure!



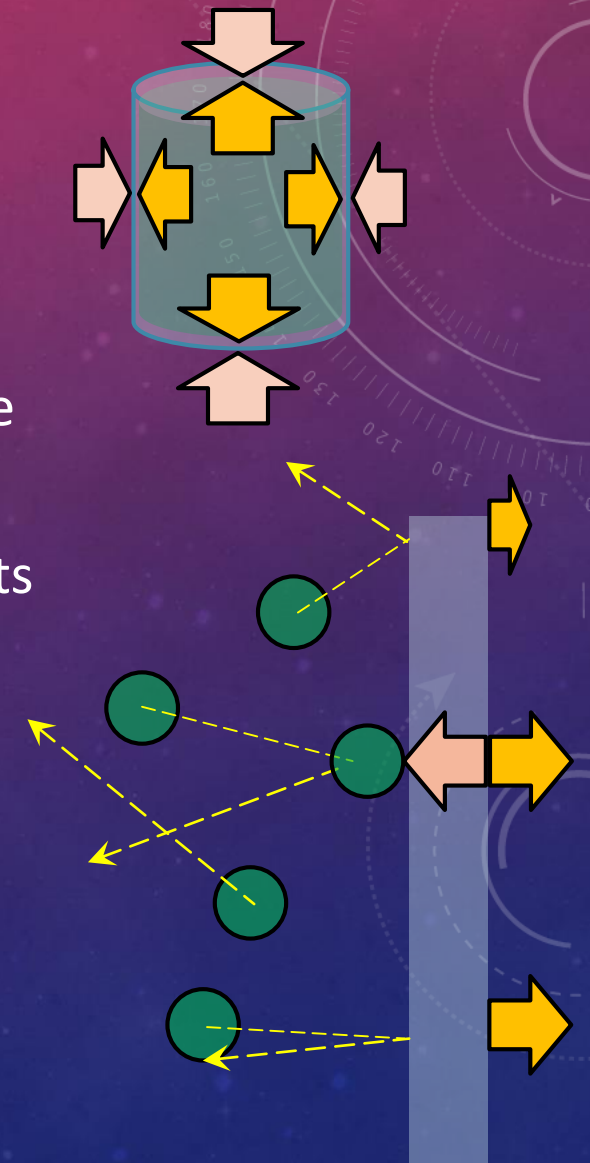
CONTAINER FORCES

- Liquid exerts **pressure** on the bottom and sides of its container (due to its weight). The container exerts equal and opposite pressure on the liquid.
- Gas exerts **pressure** on all sides of its container.
- An object submerged in a fluid (liquid or gas) experiences **equal pressure on each point** on its surface. This pressure exerts a force perpendicular to the surface at each point.
- We are immersed in a fluid **atmosphere**, which exerts **pressure on our bodies**. Our bodies maintain an internal pressure to counter the external forces.
 - If we are in the vacuum of space, the external pressure is removed, so our unbalanced internal pressure makes us swell.
 - When we bring deep sea fish (which are under many times atmospheric pressure due to the weight of the ocean above them) to the surface, the same thing happens to them.



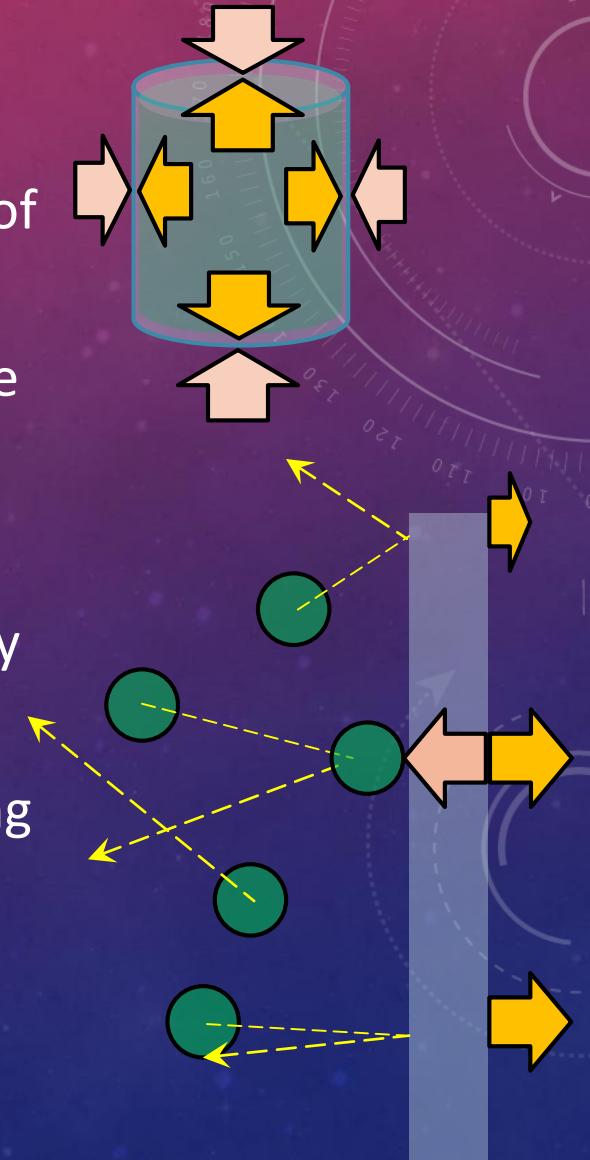
MICROSCOPIC VIEW OF PRESSURE

- The gas exerts **pressure** on its container. How does it do this?
- At a microscopic level, a gas molecule rebounds from the glass.
 - A **force** must have been exerted (by the container) to reverse the momentum of the gas particle.
 - The equal and opposite **force** of the particle on the container acts perpendicular to a tiny area, creating a tiny bit of **pressure**.
 - The net effect of all the collisions creates a **net pressure** on the container.



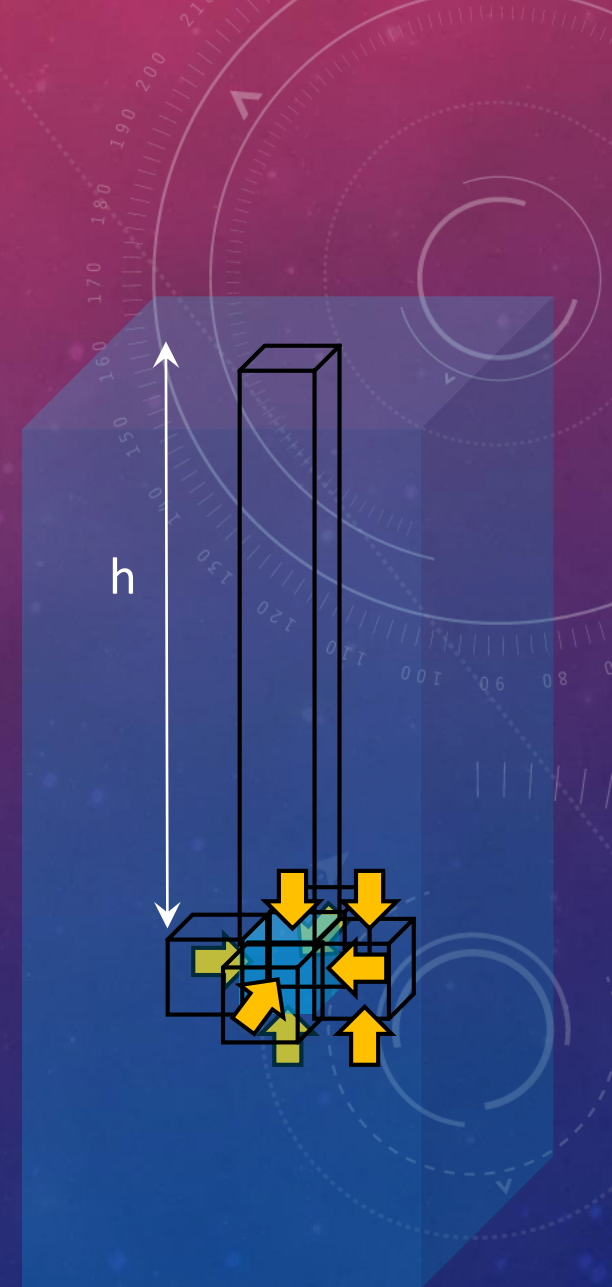
MICROSCOPIC VIEW OF PRESSURE

- When we measure pressure, we are measuring this net effect of all of the forces.
- A vacuum is empty, so there are no particles to exert pressure on the walls of the container, and therefore the pressure is zero.
 - *Absolute pressure* is measured relative to a vacuum.
 - *Gauge pressure* is measured relative to another pressure (usually atmospheric pressure).
 - When you measure tire pressure, for instance, it is measuring the excess pressure in the tire compared to atmospheric pressure.



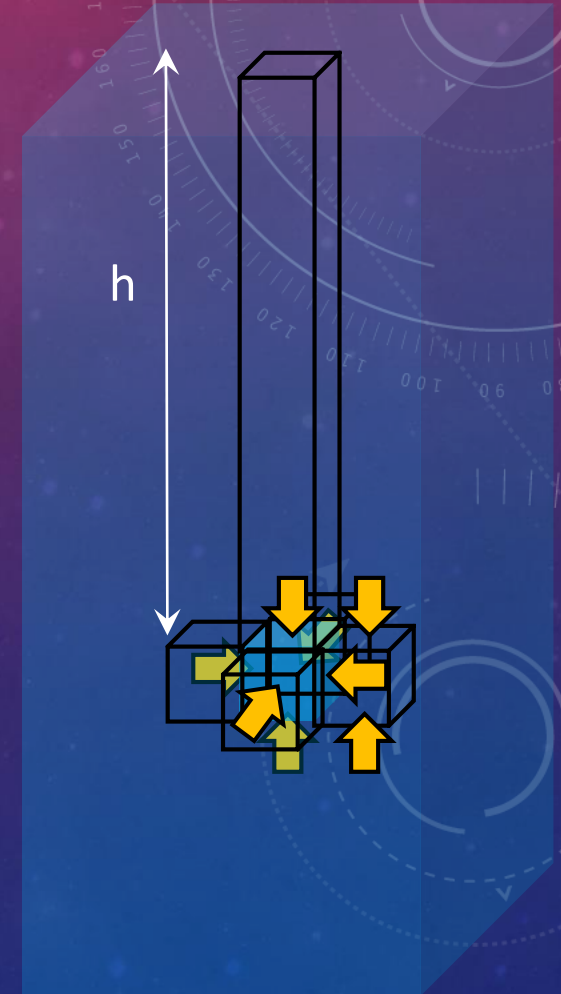
FLUID PRESSURE WITH DEPTH

- The **pressure** at a point in a fluid changes depending on **how deep** that point is.
- For example, imagine a tiny cube of water within a body of water.
 - The **weight** of the column above the cube presses down on it.
 - The water below it **presses** up because water is incompressible.
 - The cube to its side is being pressed from above and below, and would slide to the side were it not for our cube, so it **presses against our cube from the side**.
 - Our cube has other cubes all around it, all **pressing inward** on it.
 - Pressure is **omni-directional** at any point in the fluid; we don't feel it only on top of our head, but we feel it pressing in from all around.



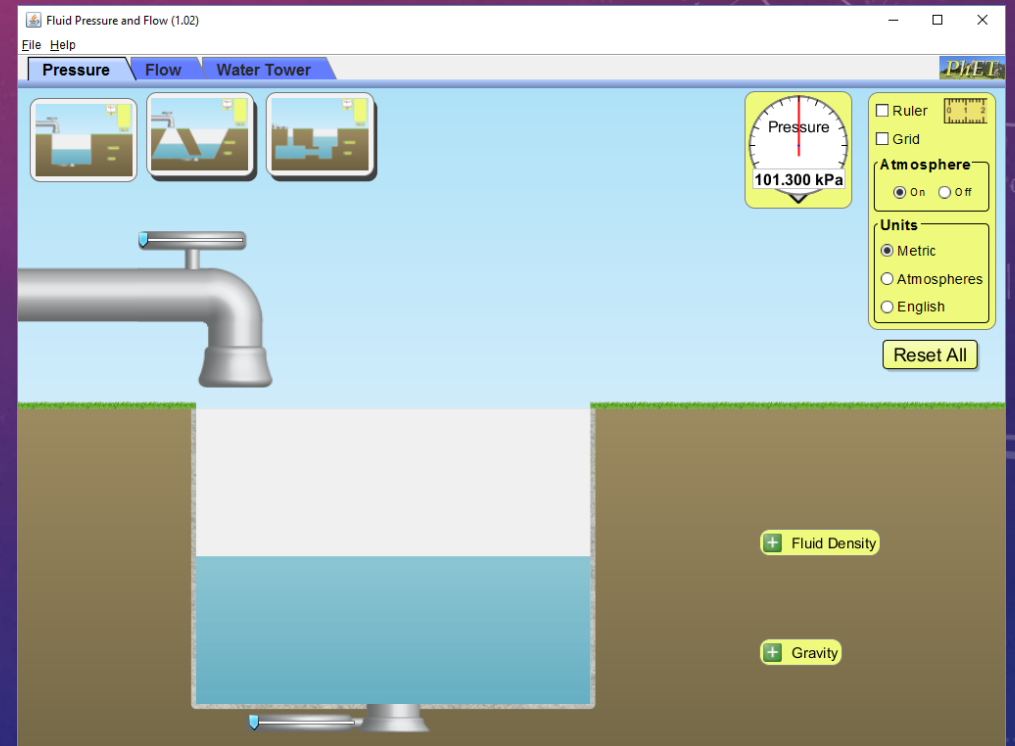
FLUID PRESSURE WITH DEPTH

- The **deeper** the cube is, the higher the column of water, the more weight the column has, and so the **greater pressure** the cube experiences.
- The weight of the column depends on the fluid **density, ρ** , and gravity, so the equation for pressure of a fluid is:
 - $P = \rho * g * h$
 - Note: this assumes that density is constant (incompressible fluids)



PRESSURE SIMULATION

- Link to simulation: <https://phet.colorado.edu/en/simulation/legacy/fluid-pressure-and-flow>
- Things to do:
 - On the 'Pressure' tab:
 - Try draining water and adding water for various container shapes. What happens to the water level?
 - What happens to the pressure when you change gravity? Fluid density?
 - On the 'Water Tower' tab:
 - With the tower drain sealed, fill the tower.
 - Open the tower drain. Water speed is related to pressure, which is related to depth. What happens to the base of the stream as the water level drops?

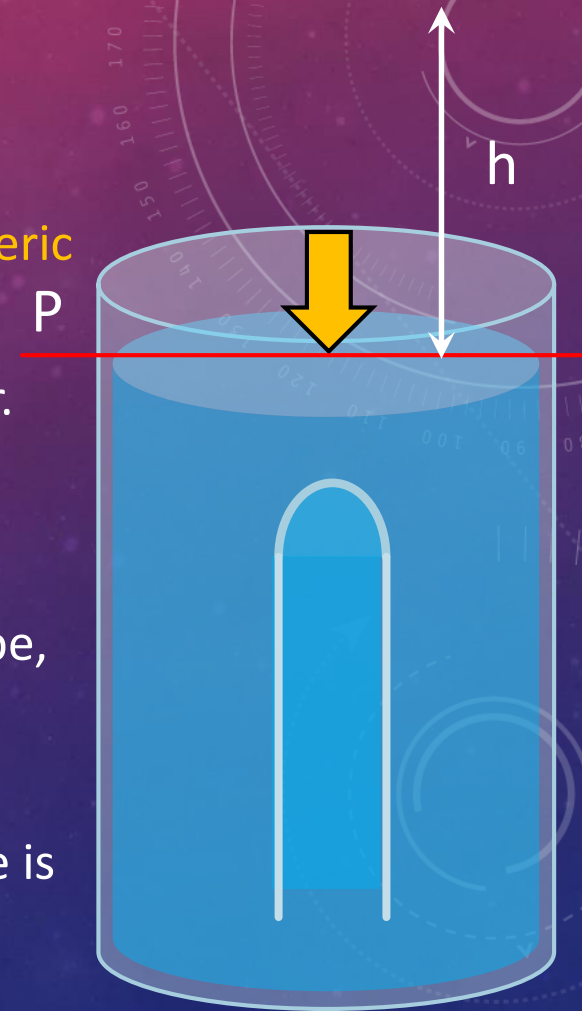


ATMOSPHERIC PRESSURE

- Calculating the **pressure** on us due to our **atmosphere** is not so straightforward
 - The gases in the atmosphere are compressible, and so the density is not constant
 - Density and pressure drop exponentially with altitude.
 - A barometer can use this **pressure difference** to estimate altitude.
 - Atmospheric pressure has physical implications (like boiling point) and physiological effects (like altitude sickness).
- Instead of calculating the pressure, we simply **measure it relative to vacuum pressure**. Here is the amount of atmospheric pressure in some useful units:
 - SI units: **101,000 Pa** (or 100 kPa)
 - US units: **14.7 psi** (pounds per square inch)
 - Standard atmospheres: **1 atm**
 - **760 mmHg** (millimeters of mercury)

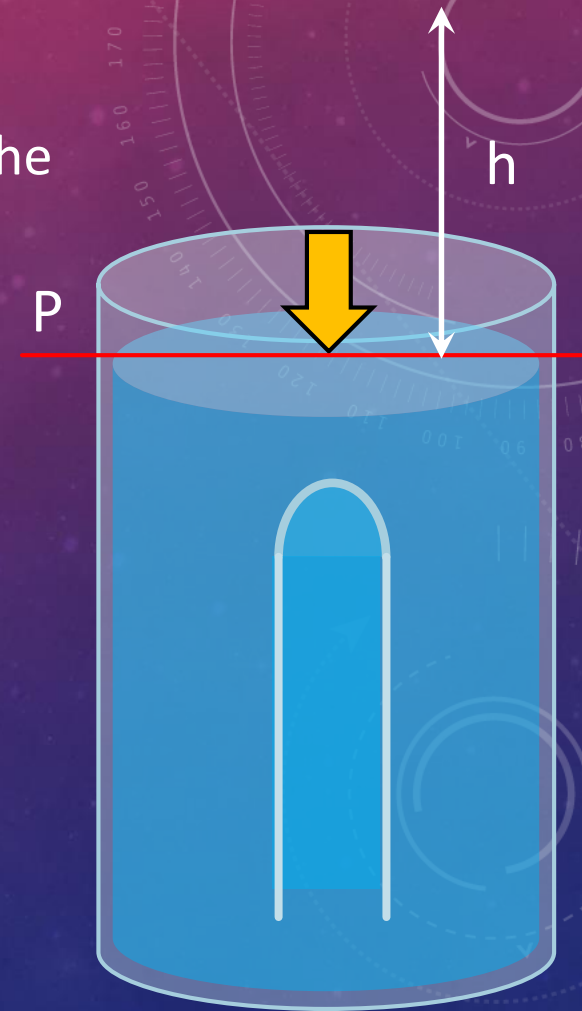
TORRICELLI BAROMETER

- Why would we use a linear measurement (mm) to describe pressure?
- Evangelista Torricelli (1608-1647) developed a barometer to **measure atmospheric pressure**.
 - Imagine a test-tube filled with water and immersed in a container of water.
 - Keeping the open end within the water, raise the closed end up out of the water.
 - At some point, the weight of the water in the tube will pull it down the tube, leaving a small region of vacuum at the closed end of the tube.
 - At this point, the **pressure** at the surface of the water outside the tube is **atmospheric pressure**, while the pressure at the same level inside the tube is due to the **weight of water** above it. Since these have to be the same pressure, the height of the water in the tube is a measure of atmospheric pressure. Minor changes in atmospheric pressure due to **weather** are reflected by **changes in water level**.



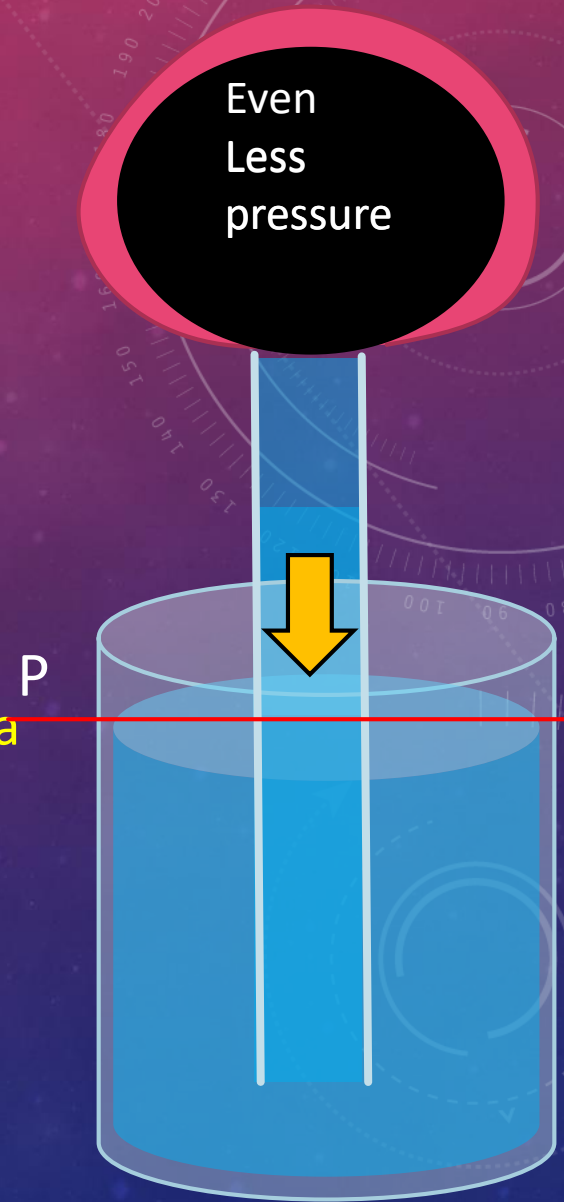
TORRICELLI BAROMETER

- Problem: The **water** column must be **32 feet tall!** (Torricelli built his on the side of a building.)
- Solution: **Use a denser fluid, like mercury.** Mercury has a density 13.6 times water's, so a column of mercury only **760 mm** (0.76 m) high has enough weight to balance against atmospheric pressure.



APPLICATION: HOW DOES A STRAW WORK?

- With the top of the straw open to the air, the **pressure** inside the open straw is the same as outside the straw.
- Placing your mouth over the top and then **lowering the pressure** within your mouth creates the condition that pressure outside the straw is greater than the pressure in the now closed upper part of the straw.
- To balance the pressure at the surface of liquid, the **atmosphere pushes a column of water** up the straw until its **weight balances the pressure difference** between your mouth and the atmosphere.
- To make the water reach your mouth, you must **lower the pressure** even more, until the pressure difference makes the atmosphere push a long-enough column of water up the straw.
- What is the maximum straw height? Even with a perfect vacuum, the longest straw is **32 feet**.



USING THE ATMOSPHERE TO CRUSH A CAN

- We are not aware of the incredible pressure from the atmosphere pressing on us all time because our bodies are adapted to it.
- If we were to remove all the air from inside a can or even a steel drum, the atmosphere pressing in against the vacuum is likely to completely crush the can.
 - Here is a video demonstration: <https://www.youtube.com/watch?v=JsoE4F2Pb20>
- The Mythbusters did this demonstration using a steel tanker car. Initially, the tanker car's structure was able to withstand the intense pressure, but watch what happened when they dented the top of the tanker: <https://www.youtube.com/watch?v=kM-k1zofs58>

CONCLUSION

- We can't keep track of the the many particles in a fluid, so we instead measure **macroscopic** properties such as **density**, **volume**, **pressure**, and **temperature**.
- Fluids may be easily *compressible*, or almost *incompressible*.
- **Pressure** within a fluid is **omni-directional** (so it is not a vector) at any point and is due to the **weight** of the fluid above that point.
- **Pressure** in an incompressible fluid increases directly with **depth**.
- We can measure the **atmospheric pressure** using a **barometer**.
- Atmospheric pressure is so large that it can crush steel containers.