AP®

Hydrostatic Pressure

Unit: Fluids & Pressure

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS2-10(MA), HS-PS2-1

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): 8.2.B, 8.2.B.1, 8.2.B.2, 8.2.B.3

Mastery Objective(s): (Students will be able to…)

- Calculate the hydrostatic pressure exerted by a column of fluid of a given depth and density.

Success Criteria:

- Pressures are calculated correctly with correct units.

Language Objectives:

- Explain how gravity causes a column of fluid to exert a pressure.

Labs, Activities & Demonstrations:

- Bottle with hole (feel suction, pressure at exit)
- Burette & funnel manometer
- Syphon hose
- Cup of water & index card
- Magdeburg hemispheres
- Shrink-wrap students

Notes:

<u>hydrostatic pressure</u>: the pressure caused by the weight of a column of fluid

The force of gravity pulling down on the particles in a fluid creates pressure. The more fluid there is above a point, the higher the pressure at that point.

The atmospheric pressure that we measure at the surface of the Earth is caused by the air above us, all the way to the highest point in the atmosphere, as shown in the picture at right.

Use this space for summary and/or additional notes:

AP®
AP®

Assuming the density of the fluid is constant, the pressure in a column of fluid is caused by the weight (force of gravity) acting on an area. Because the force of gravity is *mg* (where $g = 10\,\frac{\text{N}}{\text{kg}}$), this means:

$$P_H = \frac{F_g}{A} = \frac{mg}{A}$$

where:

P_H = hydrostatic pressure

g = strength of gravitational field ($10\,\frac{\text{N}}{\text{kg}}$ on Earth)

A = area of the surface the fluid is pushing on

We can cleverly multiply and divide our equation by volume:

$$P_H = \frac{mg}{A} = \frac{mg \cdot V}{A \cdot V} = \frac{m}{V} \cdot \frac{gV}{A}$$

Then, we need to recognize that (1) density (ρ*) is mass divided by volume, and (2) the volume of a region is the area of its base times the height (*h*). Thus the equation becomes:

$$P_H = \rho \cdot \frac{gV}{A} = \rho \cdot \frac{g\cancel{A}h}{\cancel{A}}$$

$$P_H = \rho g h$$

Finally, if there is an external pressure, P_o, above the fluid, we have to add it to the hydrostatic pressure from the fluid itself, which gives us the familiar form of the equation:

$$P = P_o + P_H = P_o + \rho g h$$

where:

P_H = hydrostatic pressure

P_o = pressure above the fluid (if relevant)

ρ = density of the fluid (this is the Greek letter "rho")

g = strength of gravity ($10\,\frac{\text{N}}{\text{kg}}$ on Earth)

h = height of the fluid ***above*** the point of interest

Although the depth of the fluid is called the "height," the term is misleading. The pressure is caused by gravity pulling down on the fluid ***above*** it.

* Note that physicists use the Greek letter ρ ("rho") for density. You need to pay careful attention to the difference between the Greek letter ρ and the Roman letter "p".

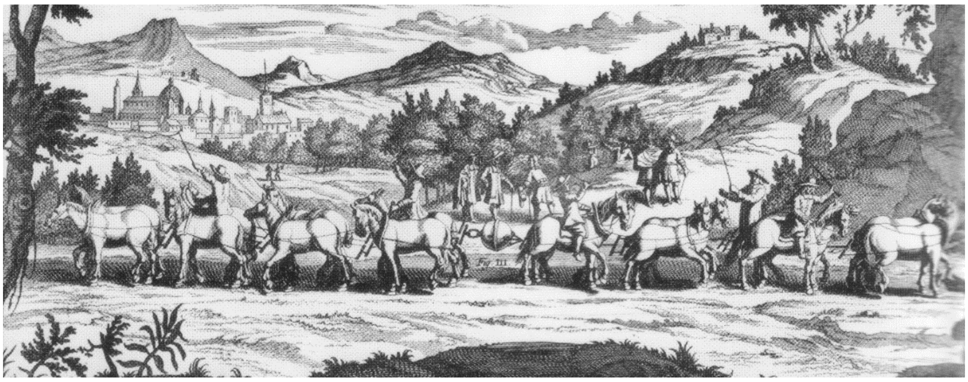
Use this space for summary and/or additional notes:

AP®

In 1654, Otto von Guericke, a German scientist and the mayor of the town of Magdeburg, invented an apparatus that demonstrates atmospheric pressure.

In 1650, Guericke had invented the vacuum pump. To demonstrate his invention, Guericke built an apparatus consisting of a fitted pair of hemispheres. Guericke pumped (most of) the air out from inside the hemispheres. Because of the pressure from the atmosphere on the outside of the hemispheres, it was difficult if not impossible to pull them apart.

In 1654, Guericke built a large vacuum pump and a large pair of hemispheres. In a famous demonstration, two teams of horses were unable to pull the hemispheres apart.



The hemispheres are called Magdeburg hemispheres, after the town that Guericke was mayor of.

Sample Problem

Q: What is the water pressure in the ocean at a depth of 25 m? The density of sea water is $1025\,\frac{\text{kg}}{\text{m}^3}$.

A: $P_H = \rho g h = (1025)(10)(25) = 256\,250\,\text{Pa} = 2.56\,\text{bar}$

Use this space for summary and/or additional notes:

AP®

Homework Problems

For all problems, assume that the density of fresh water is $1000\,\frac{\text{kg}}{\text{m}^3}$.

1. **(S)** A diver dives into a swimming pool and descends to a maximum depth of 3.0 m. What is the pressure on the diver due to the water at this depth? Give your answer in both pascals (Pa) and in bar.

   Answer: 30 000 Pa or 0.3 bar

2. **(M)** A wet/dry vacuum cleaner is capable of creating enough of a pressure difference to lift a column of water to a height of 1.5 m at 20 °C. How much pressure can the vacuum cleaner apply?

   Answer: 15 000 Pa

3. **(S)** A standard water tower is 40 m above the ground. What is the resulting water pressure at ground level? Express your answer in pascals, bar, and pounds per square inch. (1 bar = 14.5 psi)

   Answer: 400 000 Pa or 4 bar or 58 psi

Use this space for summary and/or additional notes:

AP®

4. **(M)** A set of Magdeburg hemispheres has a radius of 6 cm (0.06 m). Atmospheric pressure is 1 bar and all of the air inside is pumped out (*i.e.,* the pressure inside is zero).

   a. Calculate the force needed to pull the hemispheres apart. (The formula for the surface area of a sphere is $S = 4\pi r^2$).

      Answer: 4 500 N (which is almost 1 000 lbs.)

   b. Assume that the density of air is $1\,\frac{\text{kg}}{\text{m}^3}$. If the density of the atmosphere were uniform, how high above the Earth would the top of the atmosphere be?

      Answer: 10 000 m

   c. The actual height of the atmosphere is approximately 10^7 m (10 000 km), which means the atmosphere cannot have a uniform density. Why is it reasonable to assume that water has a uniform density, but not air?

Use this space for summary and/or additional notes: