Chapter 2 + Fluids

I will go over Chapter 2 in class and you must also read and study it. It is full of important material.

Static Pressure

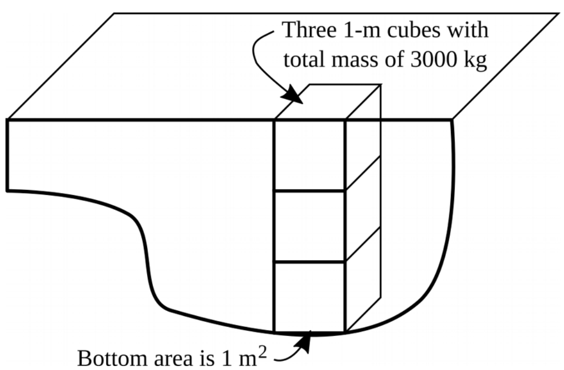
Unfortunately, the behavior of fluids is largely ignored by the text except in Section 22.1 in a chapter on the atmosphere. I will give some demonstrations and give a brief description of fluids and pressure here because I think it deserves more attention.

Pressure is force divided by area. If you place a 1 kg cube of lead on a table, it is unlikely to be damaged. Each side of the lead cube will be about 4.46 cm=0.0446 m wide spreading the $(1\,\text{kg})\cdot(9.8\,\text{m/s}^2)=9.8\,\text{N}$ force of the cube over an area of nearly $(4.46\,cm)^2=19.8916\,cm^2\approx 20\,cm^2=0.0020\,m^2$. It is the force divided by the area that can damage materials and therefore we define a quantity called pressure with units of pascal (Pa) which is a force divided by an area. The lead cube exerts a pressure

$$p=\frac{F}{A}=\frac{9.8\,\text{N}}{0.0020\,\text{m}^2}=4900\,\frac{\text{N}}{\text{m}^2}\stackrel{\text{def}}{=}4900\,\text{Pa}$$

If we take that lead cube and use it to push a 1-mm diameter needle with an area of only about $8\times 10^{-7}\,\text{m}^2$, the pressure will be 2500 times greater or 12.3 MPa! That is why needles and nails easily go into materials. It is pressure that matters when trying to deform, puncture, or blow up things.

We can now figure out the pressure at 3 m down below the surface of a swimming pool as shown to the right. Imagine a 1 m^2 area at the bottom of the pool. It will have the weight of a 3 m high column of water on it for a total water volume of 3 m^3. Since water has a density of about $\rho=1000\,\text{kg/m}^3$, 3 m^3 will contain 3000 kg of water. To get the force of this water on that 1 m^2 area, we multiply this mass by the acceleration of gravity, 9.8 m/s^2 and find that the weight is 29400 N. The pressure at the bottom is this divided by the 1 m^2 area so the pressure is 29400 Pa.



The fact that we chose 1 m^2 area is actually unimportant. If we had chosen 1 cm^2 or the area of a person's body, we would end up with the same pressure because the water weight *mg* and the area *A* that divides it would be reduced by the same factor. So the pressure below the surface of water turns out to only depend on *h*, the depth of the water.

$$p=\frac{F}{A}=\frac{mg}{A}=\frac{\rho V g}{A}=\frac{\rho A h g}{A}=\rho g h$$

where $\rho=1000\,\text{kg/m}^3$, $g=9.8\,\text{m/s}^2$, *V* is volume of the 3 cubes, and *h* is their total height.

If you swim to the bottom of a swimming pool, you will be squeezed by this pressure and your body (especially your lungs) made smaller until the internal pressure within your body has matched this pressure.

Even when we are not in water, there is the weight of the air all the way to the top of the atmosphere squeezing our bodies with a pressure of about 100 kPa, more than 3 times that calculated for the bottom of the swimming pool! We don't feel it because that same pressure is within our bodies pushing outward.

This air pressure allows us to use a straw or suction cup. With these tools, we reduce the pressure inside the straw or suction cup so that the atmospheric pressure on the outside pushes the water up the straw or presses the suction cup against a surface. Straws and suction cups will not work on the moon – no air, so no air pressure.

As we go higher up into the atmosphere, there is progressively less air above us squeezing us. At the altitude of the highest peaks in Yosemite National Park, 4000 m above sea level, the pressure is only 61% of the pressure in Clovis. If an ordinary plastic bottle is emptied and closed off at that altitude, the increasing air pressure as one returns to sea level will usually cause it to collapse abruptly after dropping down to about 2000 m altitude.

To summarize:

1. Pressure is force divided by the area against which that force is applied.

2. Pressure has units of pascal (Pa): $1\,\text{Pa} \stackrel{\text{def}}{=} 1\,\frac{\text{N}}{\text{m}^2} = 1\,\frac{\text{kg}\cdot\text{m}}{\text{m}^2\cdot\text{s}^2} = 1\,\frac{\text{kg}}{\text{m}\cdot\text{s}^2}$.

3. Atmospheric pressure at sea level is about 101 kPa = 101000 N/m^2. So each square meter feels a force of 101000 N which is equivalent to a mass of $m = \frac{F}{g} = \frac{101000\,\text{N}}{9.8\,\text{m/s}^2} = 10306\,\text{kg}$.

4. Modest forces on a small area produce large pressures and can damage things (high heels, needles. arrow points).

5. Modest forces on a large area produce small pressures and can be tolerated (seat cushions, bed of nails, water bed)

6. Pressure under water is determined by the weight of the water per unit area, 9800 Pa for each meter of depth. This comes to nearly a 1 MPa at a depth of 100 m and nearly 110 Mpa at 11000 m, the deepest place in the ocean.

7. The reduced pressure of a passing tornado can cause the air inside of a house to blow it apart.

Bernoulli Effect – Pressure of flowing fluids (Dynamic Pressure)

Bird flight, flapping flags, and ocean wave generation use the Bernoulli effect. If you blow air past the upper surface of a piece of paper held just below your lips, it will rise up and flap. A ball can be suspended in the exhaust air of a vacuum cleaner by reduced pressure of air flowing around it. Ocean waves grow because the wind tends to flow faster over the top of a small wave, reducing the pressure there, and making the wave bigger. A bird's wings have a contour that causes the air flowing above the wing to have reduced pressure, thereby helping lift the bird.

Rules Governing Buoyancy in Water and Air

1. Buoyant force on an object in water is equal to the weight of the displaced water.

2. Buoyant force is directed upward.

3. The weight of the object itself is directed downward.

4. If an object is floating, the object has settled down into the water until the buoyant force of the water exactly matches the weight of the object.

5. If an object is totally submerged in water, the buoyant force is determined by the volume of the object, the density of water, and the acceleration of gravity.

$$\text{mass of displaced water} = \frac{\text{volume of water displaced}}{\text{density of water}} = \frac{\text{volume of the object}}{\text{density of the water}}$$

$$\text{buoyant force} = \text{weight of the displaced water} = \text{mass of displaced water} \times \text{gravitational acceleration}$$

6. The above statements also apply to objects "submerged" in air (like a balloon) if the word "water" is replaced by "air."

7. An object "floating" in air rises to higher altitudes where the air is less dense, ultimately reaching an altitude where the reduced buoyant force matches the weight of the object. It then stops rising.

8. The water level in a glass with ice remains the same when the ice melts because the weight of the ice, and therefore the weight of the water it displaced, is the same before and after it melts. This also applies to floating Arctic Ocean ice and the ocean level, but not to ice melting from land and flowing into the ocean (e.g. Greenland or Antarctic ice).