# SAFE RETURN DOUBTFUL: WEEK 9

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# SUMMARY

## Climate science

1. **How do we know** adding ice to ocean will cause sea level rise? (The ice cubes in a glass concept).
2. How do we know **historical** temperature of ice?
3. How do we know the speed of ice flowing into ocean?

# ADDING ICE TO OCEAN AND SEA LEVEL RISE

The density of something is the mass divided by the volume:

$$\rho = \frac{m}{V} \tag{1}$$

The units can be kilograms per meter cubed, or $\text{kg}/\text{m}^3$. If we know the density of a material and the volume, we can know the mass of the object:

$$m = \rho V \tag{2}$$

(Examples).

The force of gravity, or weight (as we saw once before) is the mass of an object, times the gravitational *acceleration*, called $g$:

$$w = mg \tag{3}$$

The value of $g$ is 9.81 meters per second squared, or 9.81 $m/s^2$. When an object floats, the buoyant force must balance the weight. When a mass in kilograms is multiplied by $g$, the units of force are *Newtons.* (Examples).

**The buoyant force**

The buoyant force is an upward force placed on an object suspended in a liquid that is equal in magnitude to the weight force of the displaced volume of liquid.

Example, suppose a sailboat displaces 45 cubic meters of water. The weight force is equal to the mass of that water in the *upwards direction*. What's the mass of that water? $m = \rho V$, so $m = 1000$ kg/m$^3 \times 45$ m$^3$, so 45,000 kg. What is the *weight* of that water? $w = mg$, so $w = 45,000$ kg $\times 9.81$ m/s$^2$, or 441,450 Newtons (about 99,000 lbs).

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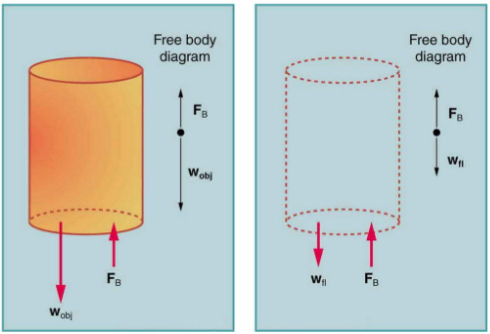


**Figure 1:** A diagram of the buoyant force balancing the weight.

Questions for table discussion:

- Given what you've seen, why does a ship made of metal float? Isn't metal more dense than water?
- What is the weight force in Newtons of a person with mass 55 kg?
- What is the weight of an ice cube that is a cube of 10 cm on each side, and the density of ice is 918 $kg/m^3$?

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Figure 2: An iceberg is mostly below the water. Can we determine what fraction of the iceberg is below the water, and therefore the displaced water?

Suppose a block of ice of height $V$ and horizontal area $A$ is floating in the ocean. The volume is

$$V = Ah \tag{4}$$

Let the density of ice be $\rho_{\rm ice}$, and let the density of water be $\rho_{\rm w}$. The weight of the iceberg is

$$w = mg \tag{5}$$
$$w = \rho_{\rm ice} V g \tag{6}$$
$$w = \rho_{\rm ice} A h g \tag{7}$$

**Table discussion:** What is the *weight* of an iceberg that has an area of 1 km by 1 km on top, a height of 1 km?

Continuing, the weight of the iceberg is

$$w_i = \rho_{\mathrm{ice}} A h g \tag{8}$$

How much water does the iceberg displace? Let the height *above* the water be $x_1$ and the depth below the water be $x_2$, such that $x_1 + x_2 = h$. The displaced water volume is

$$V_d = A x_2 \tag{9}$$

The displaced water mass is $m_w = \rho_w V_d$, so

$$m_w = \rho_w A x_2 \tag{10}$$

The weight of the displaced water just requires us to multiply by $g$, so

$$W_w = \rho_w A x_2 g \tag{11}$$

Thus, we have the weight of the displaced water, $\rho_w A x_2 g$, and the weight of the iceberg, $\rho_{\text{ice}} A h g$. According to the buoyant force principle, these two weights are **equal.** Thus,

$$\rho_w A x_2 g = \rho_{\text{ice}} A h g \tag{12}$$

Given that $h = x_1 + x_2$, let's simplify this...(board).

$$\frac{x_1}{x_2} = \frac{\rho_{\text{w}} - \rho_{\text{ice}}}{\rho_{\text{ice}}} \tag{13}$$

Equation 13 is the fraction of the iceberg that peaks above the surface.

$$\frac{x_1}{x_2} = \frac{\rho_{\mathrm{w}} - \rho_{\mathrm{ice}}}{\rho_{\mathrm{ice}}} \tag{14}$$

Equation 14 is the fraction of the iceberg that peaks above the surface. Given that you can see $\approx 10$ percent of an iceberg, and that 90 percent is beneath the surface, we know how much water is displaced.

$$V_{wd} = Ax_1 \left( \frac{\rho_{\mathrm{ice}}}{\rho_{\mathrm{w}} - \rho_{\mathrm{ice}}} \right) \tag{15}$$

What is the water level rise if we toss an iceberg into a giant bucket of water?

Suppose the giant bucket has a length and a width of $l$, so an area of $l^2$. What is the water level rise $\Delta y$?

Here's how to solve for it:

$$l \times l \times \Delta y = V_{wd} \tag{16}$$

$$\Delta y = \frac{Ah}{l^2}\left(\frac{\rho_{\mathrm{ice}}}{\rho_{\mathrm{w}}}\right) \tag{17}$$

What is the sea level rise if $l = 1$ km, $h = 1$ km, and $A = 1$ km$^2$? Recall that ice density is 917 kg/m$^3$, and water density is 1000 kg/m$^3$.

So that was an example of how adding ice to the ocean causes sea level rise. Here is a short video summary of research into Antarctic and Greenland contributions to sea level rise: `https://youtu.be/YRe1ymYR45k`

And here is how certain people view the science: `https://youtu.be/lPgZfhnCAdI`

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1. **How do we know** adding ice to ocean will cause sea level rise? (The ice cubes in a glass concept).
2. (Next time): How do we know **historical** temperature of ice?
3. (Next time): How do we know the speed of ice flowing into ocean?