Answer to Essential Question 9.2: We can apply the idea that the buoyant force acting on an object is proportional to the volume of fluid displaced by that object. When the block is half submerged, the buoyant force is 4.0 N up because the buoyant force and the spring scale, which exerts a force of 6.0 N up, must balance the downward 10 N force of gravity acting on the block. When the block is completely submerged, it displaces twice as much fluid, doubling the buoyant force to 8.0 N up. The spring scale only has to apply 2.0 N of force up on the block to make the forces balance. Diagrams and free-body diagrams for these situations are shown in Figure 9.11.

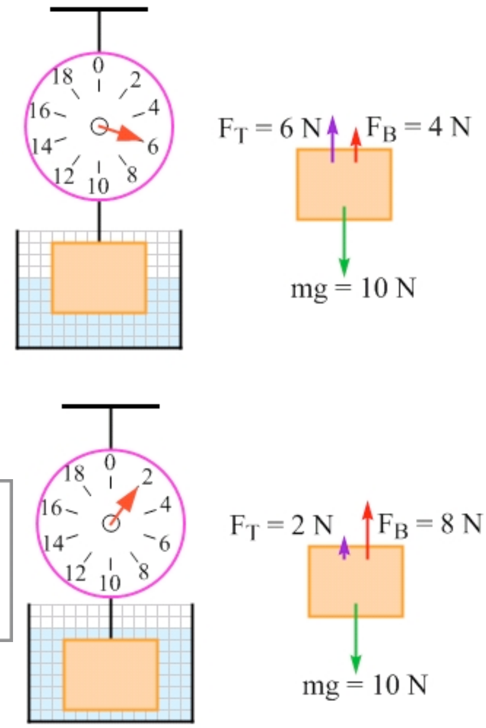

Figure 9.11: The top diagrams show the situation and free-body diagram for a block suspended from a spring scale when the block is half submerged in water. The bottom diagrams are similar, except that the block is completely submerged.

9-3 Archimedes' Principle

EXPLORATION 9.3 – What does the buoyant force depend on?

We know that the buoyant force acting on an object is proportional to the volume of fluid displaced by the object. What else does it depend on? Let's experiment to figure this out. We'll use a special beaker with a spout, as shown in Figure 9.12. In each case, we will fill the beaker to a level just below the spout, so that when we add a block to the beaker any fluid displaced by the block will flow down the spout into a second catch beaker. The catch beaker sits on a scale, so we can measure the weight of the displaced fluid. The fluid in the beaker will be either water or a second liquid, so we can figure out whether the fluid in the beaker makes any difference.

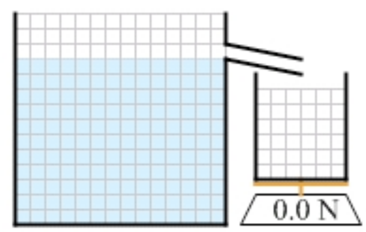

Figure 9.12: The beaker with the spout, and the catch beaker sitting on the scale. The scale is tared so it will read directly the weight of fluid in the catch beaker.

The blocks we will work have equal volumes but different masses. The weights of the blocks are 8 N, 16 N, and 24 N. Before we add a block to the beaker, we will make sure the beaker is filled to just below the level of the spout, and that the catch beaker is empty. If a block sinks in the fluid, we will hang it from a spring scale before completely submerging the block, so we can find the buoyant force from the difference between the force of gravity acting on the block and the reading on the spring scale. Also, the scale under the catch beaker is tared, which means that with the empty catch beaker sitting on it the scale reads zero and will read directly the weight of any fluid in the catch beaker.

The results of the experiments with water are shown in Figure 9.13, along with the corresponding free-body diagrams. In every case, ***the magnitude of the buoyant force acting on the block is equal to the weight of the fluid displaced by the block.***

Does this only work with water? Let's try it with the second fluid. The results are shown in Figure 9.13. Here we notice some differences - the 8 N block still floats buts displaces twice the volume of fluid it did in the water; the 16 N block now sinks; and the 24 N block still sinks but has half the buoyant force it had when it was in the water. Once again, however, the magnitude of the buoyant force on the block is equal to the weight of fluid displaced by the block.

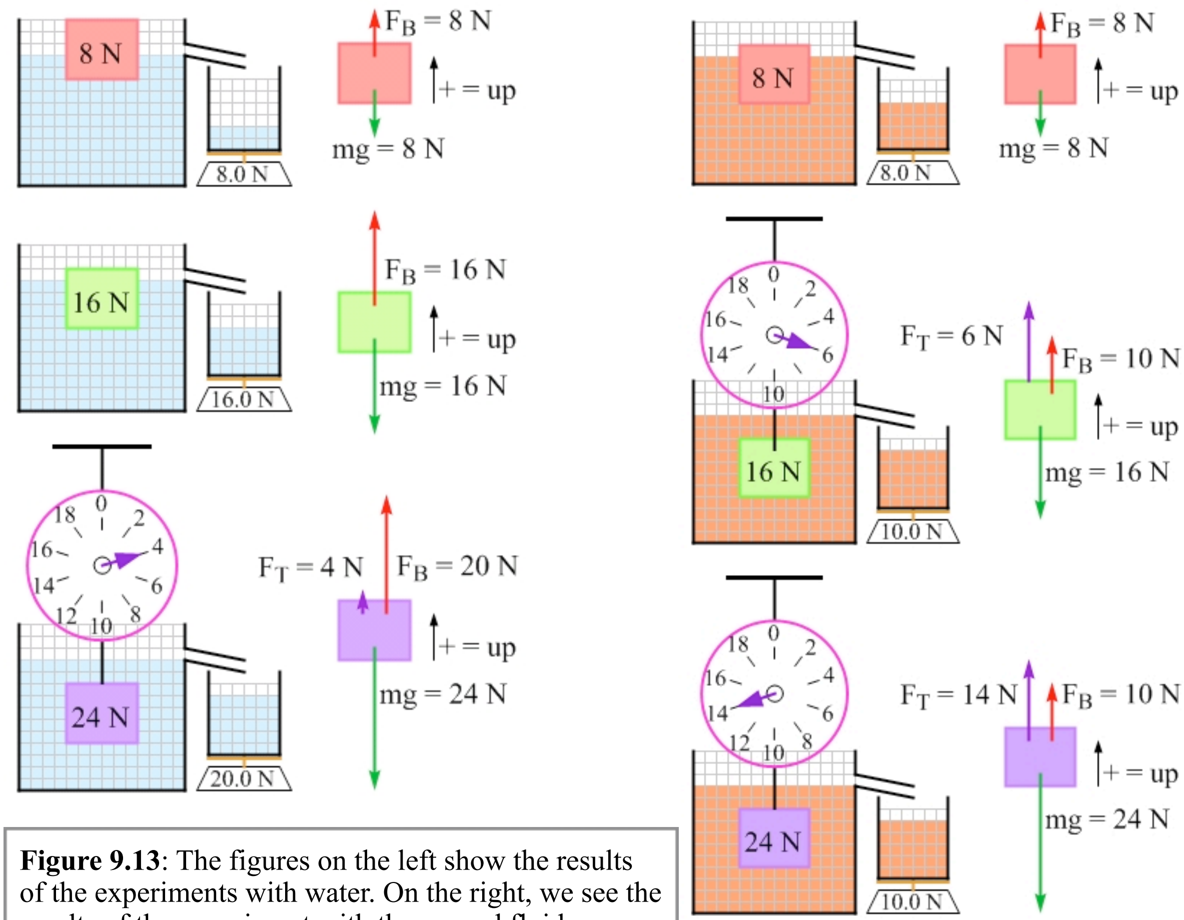

Figure 9.13: The figures on the left show the results of the experiments with water. On the right, we see the results of the experiment with the second fluid.

With the second fluid, we see that the buoyant force the fluid exerts on an object is still proportional to the volume of fluid displaced. However, we can also conclude that displacing a particular volume of water gives a different buoyant force than displacing exactly the same amount of the other fluid. Some property of the fluid is involved here.

To determine which property of the fluid is associated with the buoyant force, let's focus on the fact that the buoyant force is equal to the weight of the fluid displaced by the object:

$$F_B = m_{disp} g \,.$$

If we bring in mass density, for which we use the symbol ρ, we can write this equation in terms of the volume of fluid displaced. The relationship between mass, density, and volume is:

$$m = \rho V \,. \qquad \text{(Equation 9.2: **Mass density**)}$$

Using this relationship in the equation for buoyant force gives:

$$F_B = m_{disp} g = \rho_{fluid} V_{disp}\, g \,. \qquad \text{(Equation 9.3: **Archimedes' Principle**)}$$

Key Idea regarding Archimedes' Principle: The magnitude of the buoyant force exerted on an object by a fluid is equal to the weight of the fluid displaced by the object. This is known as Archimedes' principle. **Related End-of-Chapter Exercises: 4, 7.**

Essential Question 9.3: How does the mass density of the second fluid in Exploration 9.3 compare to the mass density of water?