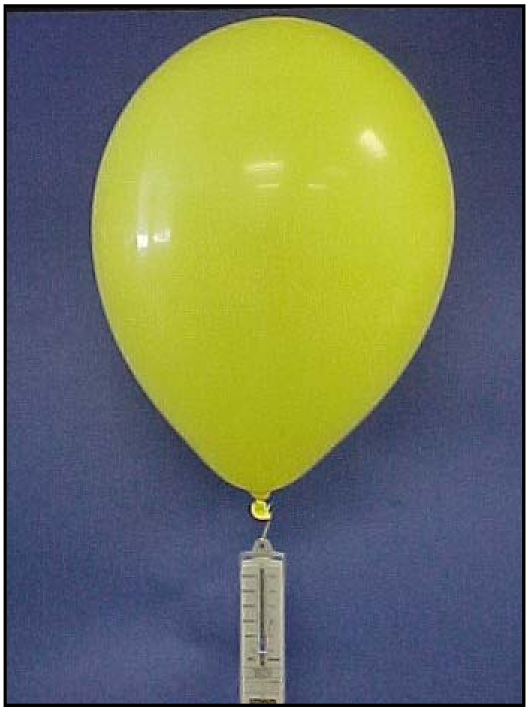
The Balloon and the Beach Ball



First: The Balloon

At the conclusion of the last e-mail, we said that the buoyant force of the air on a 200g mass with a volume of 25ml was too small to measure with our spring scale. Then we asked you to think about the buoyant force of air on a helium-filled balloon, an object whose weight is much less than that of the 200g mass and whose volume is considerably greater than that of the 200g mass.

The picture below shows that the yellow balloon exerts an upward force on the spring scale.

Why does the balloon exert an upward force on the spring scale when the 200g mass exerts a downward force on the spring scale?

To answer this question, let's think about the forces on the 200g mass and the balloon.

The Forces on the Balloon

There are *three* *forces* acting on *the balloon:*

1. The spring scale exerts a *downward* force (pulls down) on the balloon.
2. The gravitational force is a downward force on the "stuff" the balloon is made from, the rubber and the helium gas.
3. The air exerts a buoyant (upward) force on the balloon.

The Forces on 200g Mass

There are *three* *forces* acting on *the 200g mass:*

1. The spring scale exerts an *upward* force (pulls up) on the 200g mass.
2. The gravitational force is a downward force on the material from which the 200g mass is made.
3. The air exerts a buoyant force on the 200g mass.

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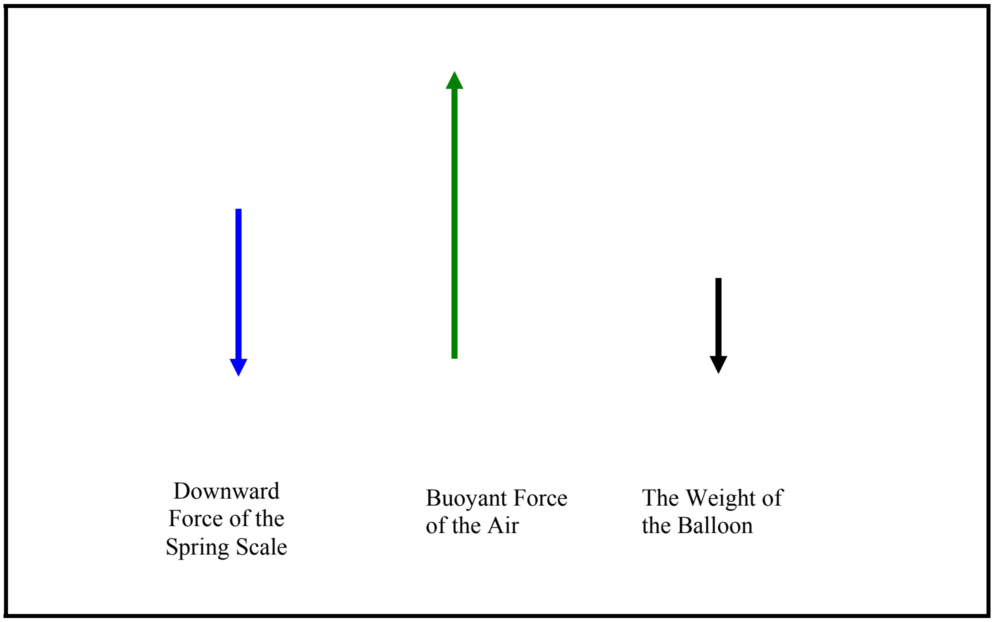
The diagram below represents the three forces on the balloon. The arrowhead shows the direction of the force, the length of the arrow shows the magnitude of the force.



Why did we draw the arrow representing the buoyant force of the air larger than either of the other force arrows?

We observe that the balloon is not moving. So the sum of the upward and downward forces on it must be zero. This means that if we add the length of the blue arrow to the length of the green arrow, it should be the same as the length of the black arrow but in the opposite direction.

Now think about what will happen to the balloon if the thread attaching it to the spring scale is cut. You know what happens: the balloon will move upward.

What are the forces on the balloon at the instant you cut the thread?

At that instant, there are two forces: the *buoyant force of the air* and the *downward force due to the balloon's weight*.

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The balloon moves upward because the sum of the forces on it (*the buoyant force of air* minus *the weight of the balloon*) is greater than 0 and acts in an upward direction.

Let's now think about how the forces on and motion of the balloon are related to the familiar behaviors of a beach ball.

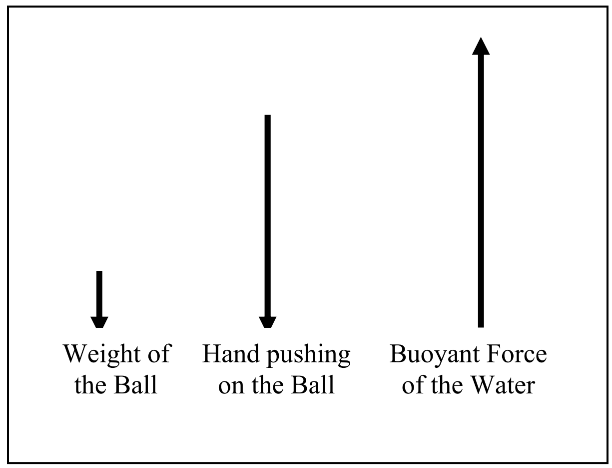
The Beach Ball

Imagine that you are in a swimming pool with a large beach ball. You push the ball underwater and hold it in place. When you stop pushing down on the ball, it flies upward, then lands on the surface of the water, where it floats.

Let's think about the forces on the beach ball while you are holding it under water, when you stop holding it down, and when it is floating on the surface of the swimming pool.

Three forces are exerted on the ball while you are holding it under water:

1. The downward force of gravity (the weight of the beach ball),
2. The buoyant force of the water
3. The downward push of your hand



While you are holding the ball under water, the sum of the downward forces equal the upward force. The ball does not move up or down.

When you stop pushing down on the ball, there are only two forces acting on the ball: the buoyant force of the water and the ball's weight. The buoyant force of the water is much larger than the downward force of the ball's weight. This net upward force results in the rapid motion of the beach ball upward.

•What about when a beach ball is at rest, floating on the water?
•What forces are acting on it then?
•How great are they relative to each other?

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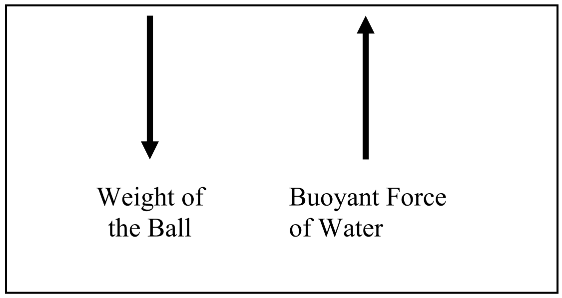
The Floating Ball



Two forces are acting on a floating ball:

1. The ball's weight
2. The buoyant force of the water

The weight of the ball is equal to the buoyant force of the water. The net force on the ball is 0; the ball does not move up or down, it just floats.

Let’s see…we’re talking about fluids and forces here…so where does Archimedes’ Principle fit?

Partial and Total Immersion

Archimedes’ Principle refers to objects partially and totally immersed in a fluid. When the beach ball is held under water, it is totally immersed in the water. When the beach ball is floating, it is partially immersed. The buoyant force of the water is different when the beach ball is partially immersed from when it is totally immersed.

When is the buoyant force of the water greater, when the ball is totally or partially immersed in the water?

To answer this question, we will use a small ball that is constructed in the same way as a beach ball, a plastic or rubber shell filled with air.

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When the ball is held under water, it displaces 25 ml of water. When it floats on water, it displaces 5 ml of water. The weight of the water displaced by the completely immersed ball is .25 N. The weight of the water displaced by the floating ball is .05 N. Therefore…

Consistent with Archimedes' Principle, the buoyant force on the completely immersed ball is greater than the buoyant on the floating (or partially immersed) ball. When the ball is floating, there is very little of it submerged, so very little water is displaced; consequently, there is little buoyant force acting upon it.

Remember: the buoyant force on the floating ball is equal to the weight of the water displaced by the tiny bit of ball that is underwater. However, the buoyant force on the completely submerged ball is much greater… think how much water must be moved out of the way to get the beach ball underwater!

Tying it Together

We've demonstrated Archimedes' Principle through the use of familiar examples. Students need to be able to tie a scientific principle to the evidence of it in daily life. Otherwise, it is common for students to hold two separate sets of beliefs: "school knowledge" and "world knowledge."

Some students may be able to memorize Archimedes' Principle and even answer multiple choice questions about it. At the same time, they may give explanations about real-world events that are incorrect, incomplete, and unrelated to the principles learned in class. For instance, a student may say that a helium balloon floats because the helium is simply "lighter than air" or the beach ball floats because it is "lighter than water." Our goal is to help students understand that what happens in the science classroom is the same thing that is happening in the "real world."

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