Up Up and Away on Beautiful Balloons: Scaling up from Party Favors to Scientific Payloads

How many helium filled balloons would it take to lift you? To lift a big telescope? Take a guess for each and record your guesses in your lab notebook. This lab will explore how good your guesses were, and how scientists determine the right size balloon to use for their experiments.

Introduction: Helium filled balloons are commonly seen at festivities and celebrations. In addition to being used for entertainment purposes helium filled balloons play an important role in many areas of scientific research. For example "small" six to eight foot diameter weather balloons are frequently launched to acquire many different types of metrological data. At the South Pole for example balloons are launched to monitor the amount of ozone in the atmosphere (See photo). These balloons provide information that other methods such as satellite remote sensing cannot, e.g., the amount of ozone at specific altitudes.

Ozone Balloon Launch
South Pole

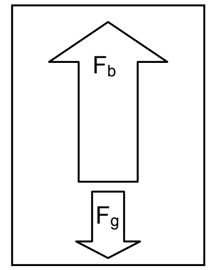
The beauty of a helium balloon as a launch vehicle is that it is simple, has no moving parts, and is relatively inexpensive. They can also go places where humans might not want to. Typical weather balloons contain a small radio transmitter, which is used to send the data back to the researchers. This is called telemetry: *The process or practice of obtaining measurements in one place and relaying them for recording or display to a point at a distance; the transmission of measurements by the apparatus making them (Oxford English Dictionary online http://www.oed.com).*

TopHat Launch
McMurdo, Antarctica

Much bigger balloons are used for bigger research projects. Researchers at the University of Chicago use the simple balloon for some of the most sophisticated experiments in modern physics. For example, Professor Stephan Meyer flew a telescope named TopHat over Antarctica in the austral summer of 2000-2001. This telescope was designed to look at light from the infant universe, microwave and infrared photons that had traveled for about 14 billion years and hold secrets of the physics of the early universe. As the name suggests, the TopHat telescope sat on top of the balloon rather than hanging underneath it. The reason for this funny geometry is that the experiment had to be so sensitive that the thin fabric of the balloon itself would have gotten in the way and been a big source of error (the small balloon in the photo was detached after launch).

Why do helium filled balloons rise? Or Archimedes' Principle

Floating in air is not a common experience for humans but floating in water is. The physics of floating in air or water are similar because both air and water are fluids. A fluid is a substance that can flow and will conform to the shape of a container that it is put in (e.g., honey is a fluid but a rock is not).



Something will float in a fluid when the buoyant force pushing it up (F_b) is greater or equal to the force pulling it down. The force pulling it down is gravity and is a function of the mass of the object

F_g = mass object x gravitational field strength (g) = weight (on Earth)

F_b = mass fluid displaced x g = weight fluid displaced

The more massive an object is the greater the force of gravity pulling it down. Everyone knows it is easier to lift a light mass than a heavy one. The buoyant force lifting the object depends on the amount of fluid that the object displaces, so it also depends on the volume of the object.

Archimedes' Principle: *When a body is fully or partially submerged in a fluid, a buoyant force F_b from the surrounding fluid acts on the body. The force is directed upwards has a magnitude equal to the weight, $m_f g$, of the fluid that has been displaced by the body* (Fundamentals of Physics 6th ed, Halliday, Resnick & Walker p. 330)

Floating in General from
http://www.howstuffworks.com/helium.htm/printable

Let's say that you take a plastic 1-liter soda bottle, empty out the soft drink it contains, put the cap back on it (so you have a sealed bottle full of air), tie a string around it like you would a balloon, and dive down to the bottom of the deep end of a swimming pool with it. Since the bottle is full of air, you can imagine it will have a strong desire to rise to the surface. You can sit on the bottom of the pool with it, holding the string, and it will act just like a helium balloon does in air. If you let go of the string the bottle will quickly rise to the surface of the water.

The reason that this soda bottle "balloon" wants to rise in the water is because water is a fluid and the 1-liter bottle is **displacing** one liter of that fluid. The bottle and the air in it weigh perhaps an ounce at most (1 liter of air weighs about a gram, and the bottle is very light as well). The liter of water it displaces, however, weights about 1,000 grams (2.2 pounds or so). Because the weight of the bottle and its air is less than the weight of the water it displaces, the bottle floats. This is the law of **buoyancy**.

Helium Flotation: Helium balloons work by the same law of **buoyancy**. In this case, the helium balloon that you hold by a string is floating in a "pool" of air (when you stand underwater at the bottom of a swimming pool, you are standing in a "pool of water" maybe 10 feet deep -- when you stand in an open field you are standing at the bottom of a "pool of air" that is many miles deep). The helium balloon displaces an amount of air (just like the empty bottle displaces an amount of water). As long as the helium plus the balloon is lighter than the air it displaces, the balloon will float in the air.

It turns out that helium is a lot lighter than air. The difference is not as great as it is between water and air (a liter of water weighs about 1,000 grams, while a liter of air weighs about 1 gram), but it is significant. Helium weighs **0.1785 grams per liter**. Nitrogen weighs 1.2506 grams per liter, and since nitrogen makes up about 80 percent of the air we breathe, 1.25 grams is a good approximation for the weight of a liter of air.

Therefore, if you were to fill a 1-liter soda bottle full of helium, the bottle would weigh about 1 gram less than the same bottle filled with air. That doesn't sound like much -- the bottle itself weighs more than a gram, so it won't float. However, in large volumes, the 1-gram-per-liter difference between air and helium can really add up. This explains why blimps and balloons are generally quite large -- they have to displace a lot of air to float.

Supplies/Resources:

- 11 inch Diameter Latex Balloons
- Helium Tank with Low Pressure Regulator (ask an instructor for help using this)
- String
- Balloon Clips
- Paper Clips
- Electronic Balance
- Set of Metric Masses (10gm, 20gm, 100gm, 200gm, 500gm, 1,000gm)

Experimental & Computational Challenges:

 # 1 Determine how much mass one balloon can lift.

- Describe the method that your group develops.
- Compare your results to those of the other teams.

 # 2 Determine how much mass 2 balloons can lift.

- Describe the method that your group develops.
- Compare your results to those of the other teams.

 # 3 Calculate and then test how many balloons are needed to lift a 20gram mass. (Share balloons with other groups for the test)

- Compare your calculation to the experimental results

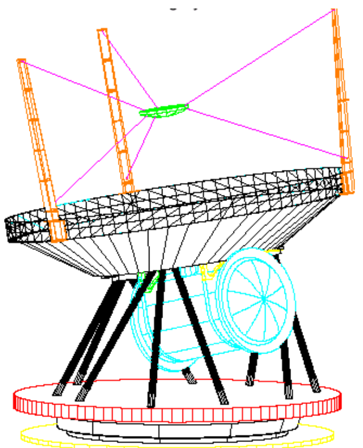
http://home.earthlink.net/~ninomiya/a.htm

#4 Based on your previous results, calculate how many balloons would be needed to lift yourself. (Note: there are about 2.2 kg in a pound)

- Show all calculations in your lab notebook.
  - Describe your calculation and any assumptions made.
  - Compare this to your guess at the start of the lab.

#5 Based on the description of the TopHat telescope below, calculate how many helium filled party balloons would be needed to lift the TopHat telescope.

- Describe your calculation & record it in your lab notebook.
- Compare your results to your initial guess.



TopHat Telescope w/o Shields

From: Tom Crawford
Subject: tophat balloon

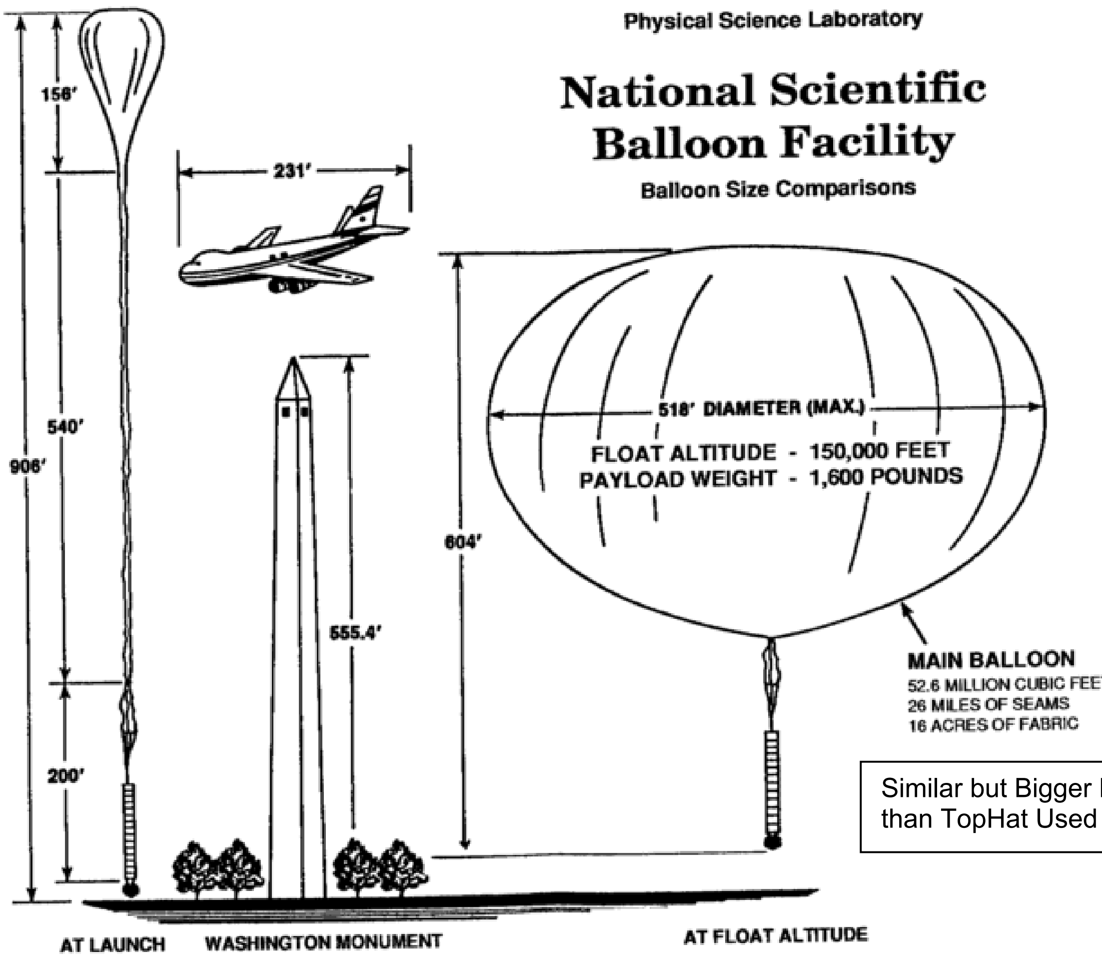
Balloon volume: 28.4 million cubic feet (at float i.e., 1/500 pressure of sea level)
Inflated height: 335 ft.
Inflated diameter: 424 ft.
Balloon weight: 3,600 lbs.
Float altitude: 118,000 to 130,000 ft.
Top package weight: 200 lbs.
Bottom gondola weight: 1,500 lbs.
Free lift: about 10%

TopHat Gondola – Pre-Launch McMurdo

#6 Compare the number of balloons you calculated were needed to lift TopHat and the actual volume of helium used for the TopHat Balloon which is about 56,800 cubic feet at sea level and 28.4 million cubic feet at float. Given that an 11 inch diameter balloon holds between 0.4 and 0.5 cubic feet of helium at sea level.

- Show your comparison calculation.
- Comment on the difference between sea level and float volumes.
- Calculate the buoyant force (F_b) on the TopHat balloon
  - Given that there are about 28.3 liters/cubic foot and that air weighs about 1.25 grams/liter.

Supplemental Background Information:



Similar but Bigger Balloon than TopHat Used

Source http://topweb.gsfc.nasa.gov/balloon/inside.html

The balloons are made out of polyethylene that is only 0.8 mil. thick. This is about half as thick as ordinary plastic wrap, most of which is 2 mil. thick. These balloons can carry a payload weighing as much as 8,000 pounds (3,630 kilograms) - about the weight of three small cars.

Scientific balloons are considerably larger than weather balloons. An inflated weather balloon is only 3 feet in diameter and carries about 6 pounds.

Balloons can fly to an altitude of 26 miles (42 kilometers), with flights lasting an average of 12 to 24 hours. Special Long Duration balloon flights can last for more than two weeks. When the balloon reaches 50,000 feet, the temperature drops to -70 degrees Celsius (-94 Fahrenheit). However, at the balloon's highest altitude it gets somewhat warmed up by the Sun and the temperature rises to about -40 Celsius (-40 Fahrenheit). Even though the temperature is still extremely low, there are often more concerns with the payload getting too hot than too cold. Since the air pressure is low (1/500ths of sea level pressure), cooling by air works much less well at ballooning altitudes than it does on the ground. So even though the outside air is very cold, it doesn't take heat away from the package very well, so the usual sources of heat (Sun, or the operation of electronics, etc. inside the package) can potentially cause the package to get very hot.

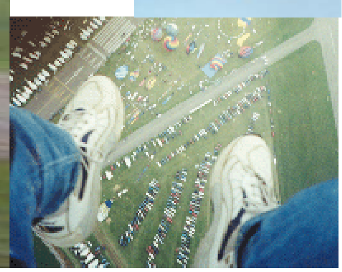
Commercial Venture

http://www.sky-walking.com/skywalk.htm

ADULT BALLOON "JUMBO"	JUNIOR BALLOON "MICRO"	KID BALLOON "MACRO"	THE DIVE BAG
Filling volume: 160m3 (Helium) Lifting capacity: approx.115 kg.	Filling volume: 120m3 (Helium) Lifting capacity: approx.80 kg.	Filling volume: 80 m3 (Helium) Lifting capacity: approx. 55 kg.	consits of PVC material, in which the rider is "seated"
Theoretical jump-height: to 50 mtrs. (150 ft.)	Theoretical jump-height: to 30 mtrs. (90 ft.)	Jumping height: recomm. max. 5 mtrs.(15 ft.)	touching surface, the weight is compensated...
to be operated anywhere on land or on water.	to be operated anywhere on land or on water.	to be operated anywhere on land and even indoors.	...the balloon starts to ascend again.
Age recommended: From 12 years on.	Age recommended: Kids from 12 to 17 yrs.	Age recommended: Kids from 3 to 12 yrs.	Age recommended: From 12 years on.
Operating area required: Approx. the size of a tennis square	Operating area required: Approx. the size of a tennis square	Operating area required: Not more than approx. 10x10mtrs.(50x50ft.)	Operating area required: Approx. the size of a tennis square

Rugged Individual:

http://home.earthlink.net/~ninomiya/a.htm



Conversion Factors:

- Cubic Feet to Liters multiply by 28.316847 liters/cubic foot
- Ounces to grams multiply by 31.103486 grams/ounce

Post Institute Teaching Notes:

1) In practice the electronic balance proved to be the major source of uncertainty. I think in future classes I would have the students see how much mass one, two and ten balloons can lift.

2) Another major source of uncertainty was that not all balloons were inflated equally. Averaging the lift of 1, 2, and 10 balloons and the results from different groups might help this.

3) Conceptually I think the degree of inflation and the buoyant force need to be made clearer. I would recommend an exercise comparing two differently filled water balloons asking which weighs more, then two differently filled air balloons and finally two differently filled helium balloons. This would help the students to realize that although the bigger helium balloon has more mass, it's greater volume provides more lift due to the fact that helium is lighter than the air that it displaces.