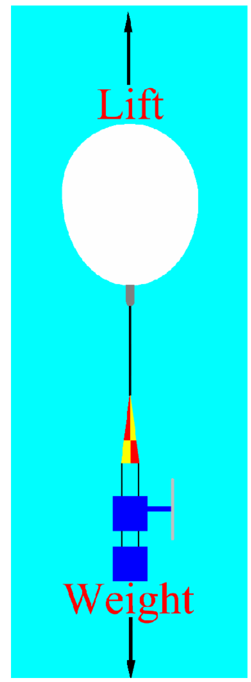
How Much Gas do I Need to Launch a Near Spacecraft?

In order for a near spacecraft to lift off, its balloon (launch vehicle) must displace a greater weight of air than the near spacecraft weighs. Generating more lift than weight is called **buoyancy**. We can calculate the buoyancy of a balloon by subtracting the density of the lifting gas from the density of the atmosphere and by multiplying by the volume of the balloon (the volume of the balloon equals the amount of gas used to fill it).

Density of the Atmosphere



Earth's atmosphere consists of 78% nitrogen (N_2), 21% oxygen (O_2), and 1% argon (Ar). All other gases appear in trace amounts and do not significantly affect the density of the atmosphere. Chemists use the term **mole** to refer to a collection of **6.022 X 10^{23}** objects, including atoms and molecules. This is no different than using the term dozen to refer to a collection of 12 objects. It's just a mole is more convenient when referring to a collection of very small atoms and molecules. At standard temperature and pressure (**STP**), one mole of every gas occupies a volume of **22.4 liters**. STP is the condition of 0^o C and 1 atmosphere of pressure. Even if you won't launch a balloon at STP, knowing the volume and mass of a mole of gas at STP is important to determining the buoyancy of a balloon. This is because both the lifting gas (using hydrogen or helium) and the atmosphere change in the same ways as conditions deviate form STP. Therefore, once you know the buoyancy of a balloon at STP, you know the buoyancy of the balloon at other temperatures and pressures.

Look at a periodic table of the elements to determine the mass (which we'll treat as weight in this case) of a mole of atoms. Nitrogen has a mass of 14 grams per mole. However, nitrogen is a diatomic gas and appears as N_2 in the atmosphere. This means a mole of nitrogen gas has a weight of 28 grams. Since oxygen exists as O_2 in our atmosphere, one mole of oxygen gas has a weight of 32 grams. Argon is a noble gas and therefore unreactive. This means the weight of one mole of argon is 40 grams.

Combining the weights and abundances of the three major gases in Earth's atmosphere and dividing by their volume allows us to calculate the density of the atmosphere.

Density = [(mass of N_2 * abundance N_2) + (mass of O_2 * abundance O_2) + (mass of Ar * abundance Ar)] / 22.4 liters

Density = [(28g * 0.78) + (32g * .21) + (40g * 0.01)]/22.4 liters

Density = [28.6 g]/22.4 liters

Density = 1.28 g/L

Now lets convert this to pounds per cubic foot since these are the units we're most familiar with and they're the ones we'll be measuring.

Density of Earths' atmosphere at STP = 1.28 g/L * (1 lb / 454g) * (28.3 liters / 1 cubic foot) or 0.08 pounds / cubic foot.

Buoyancy of Hydrogen and Helium
Hydrogen gas has a weight of 2 grams per mole and therefore a density of 2 grams / 22.4 liters. This is 0.006 pounds / cubic foot

Helium has a weight of 4 grams per mole and therefore a density of 4 grams / 22.4 liters. This is 0.012 pounds / cubic foot.

The buoyancy of hydrogen = (0.08 pounds / cubic foot) – (0.006 pounds / cubic foot) = 0.074 pounds / cubic foot.

The buoyancy of helium = (0.08 pounds / cubic foot) – (0.012 pounds / cubic foot) = 0.068 pounds / cubic foot.

Therefore, we have calculated that our near spacecraft requires one cubic foot of hydrogen for every 0.074 pounds of weight or one cubic foot of helium for every 0.068 pounds of weight.

Weight of a Near Spacecraft
One thing people forget to add to their calculation of lifting gas volume is the weight of the balloon. The lifting gas must be able to lift the balloon before it can even begin to lift the parachute, tracking modules, or BalloonSats. So let's total up the maximum weight we're allow to launch under the rules of **FAR 101**.

   1200 gram balloon (a typical balloon) or 2.6 pounds
+ 1 pound parachute
<u>+ 12 pounds of payload weight</u>
= 15.6 pounds

Amount of Lifting Gas
Now convert 15.6 pounds into cubic feet of lifting gas.

Hydrogen: 15.6 pounds * (1 cubic foot / 0.074 pounds) = **211 cubic feet**

Helium: 15.6 pounds * (1 cubic foot / 0.068 pounds) = **229 cubic feet**

What Size of Gas Bottles does a Near Spacecraft Need?
The largest tank of hydrogen is a **K tank**, which contains 196 cubic feet of gas. This means a single K tank does not contain a sufficient volume of gas to lift the maximum weight near spacecraft. The balloon needs another 15 cubic feet just to be **neutrally buoyant**. Neutrally buoyant means the balloon has just enough gas to negate its weight.

There is no extra gas to lift the near spacecraft off the ground. The balloon needs additional gas in order to ascend.

The largest tank of helium is a **T tank**, which contains 291 cubic feet of gas. Therefore, a single T tank of helium is more than enough to launch a near spacecraft.

The more gas a balloon contains above that to be neutrally buoyant, the faster the near spacecraft will ascend. An ascent rate of 1,000 feet per minute can be achieved with roughly three extra pounds of buoyancy. The amount of buoyancy (in pounds) greater than the payload weight is called the balloon's **pounds of positive lift** (PPL). Three PPL is generated by 41 cubic feet of hydrogen or 44 cubic feet of helium.

Ascending at a rate of less than 1,000 feet per minutes is viable; however, it increases the length of the mission and therefore the greater the chase distance to the recovery zone. Using significantly less buoyancy incurs the risk of the balloon becoming neutrally buoyant some time during the ascent. This results in the near spacecraft getting lost once its batteries have discharged and the tracking system stops transmitting position reports.

Therefore, assuming a maximum weight for the near spacecraft and three PPL, you need the following amounts of hydrogen and helium.

Hydrogen: 252 cubic feet
Helium: 273 cubic feet

Therefore, a hydrogen-filled balloon requires a **K tank** (196 cubic feet) plus a **Q tank** (65 cubic feet) and a helium-filled balloon requires a **T tank** (296 cubic feet)

Calculating the Amount of Gas for any Near Spacecraft
Putting all the pieces together, we find that we can calculate the amount of gas needed for any near space mission as follows.

Hydrogen: Add the amount of PPL, the weight of the balloon, the weight of the parachute, and the weight of the modules then multiply by 13.5.

Helium: Add the amount of PPL, the weight of the balloon, the weight of the parachute, and the weight of the modules then multiply by 14.7.

We can also see that hydrogen generates [(14.7 – 13.5) / 14.7] * 100% or 8.2% more lift than helium.