Why Does Helium Have 92% of the Lifting Power of Hydrogen if It Has Twice the Density?

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The title refers to an occasional question from a student after studying gas laws in general chemistry. The question refers to an oft-quoted statement that gaseous helium has more than 90% of the lifting power of hydrogen and, given its nonflammability, is the gas of choice for blimps and other gas-filled airships and balloons.

Some students pondering this statistic question its truth. After all, a quick calculation using the ideal gas law shows that helium has twice the density of molecular hydrogen. Volume for volume, it therefore has twice the mass. Why doesn't He have only about 50% of the lifting power of H_2? More advanced students suggest that non-ideality has an effect, but it is easy to show (using the van der Waals equation, for example) that even non-ideality does not account for the variance from the prediction based on density.

The science behind this comparison is based on buoyancy, not density. According to Archimedes' principle, an object immersed in a fluid experiences an upward buoyant force equal to the weight (i.e., mass times acceleration due to gravity) of the fluid displaced. While most students are familiar with the application of Archimedes' principle to submersion in water, they need to recognize that gases are also fluids. The rising of balloons filled with helium, hydrogen, hot air, etc., actually represents applications of Archimedes' principle of buoyancy.

If we apply this idea to determine the buoyant forces on 1 mole of both H_2 and He in air (and we will assume that the ideal gas law holds as a first approximation), using 28.8 g/mol as the average molecular weight of air:

1 mol H_2 = 22.4 L	displaces 22.4 L air	= 28.8 g of buoyant "force"
1 mol H_2 has a mass of		2.00 g

The resulting net upward force has a mass-equivalent of 26.8 g. Using a value of 9.80 m/s^2 for the acceleration due to gravity, this is

$$\left(26.8\text{ g}\right)\left(9.80\frac{\text{m}}{\text{s}^2}\right)\left(\frac{1\text{ kg}}{1000\text{ kg}}\right) = 0.263\text{ N}$$

1 mol He = 22.4 L	displaces 22.4 L air =	28.8 g of buoyant "force"
1 mol He has a mass of		4.00 g

The resulting net upward force has a mass-equivalent of 24.8 g, which is 0.241 N.

Therefore, every mole of He experiences a slightly smaller net upward force than H_2 does, and helium's upward force is

$$\frac{0.241\text{ N}}{0.263\text{ N}} \times 100$$

or 91.6% that of hydrogen. This is the origin of that statistic.