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The Answer to Rising Gas Prices … Nitrogen?

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It is claimed by the company NitroFill and the GetNitrogen Institute that filling car tires with nitrogen improves gas mileage considerably. The reason given is that oxygen leaks out of tires so that the increased rolling friction causes a reduced gas mileage. Because it is hard to do an actual road test, we report on a simple visual test of leakage from oxygen- and nitrogen-filled balloons. This experiment can be repeated in classrooms to address a controversial and topical issue, while at the same time highlighting hypothesis formulation, verification, and falsification in scientific experiments.

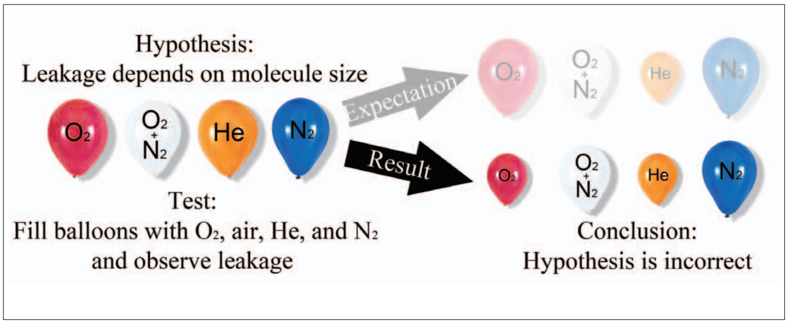

Fig. 1. Balloon test. A simple test for the leakage of different gasses from balloons is shown. Oxygen is found to leak at rates comparable to that of helium, and much faster than air and nitrogen. Perhaps surprisingly, molecular bond length is not the sole factor that determines leak rate.

During a time when gas prices can soar above $4 per gallon, it is reasonable to take every measure to improve gas mileage in our cars. It certainly was reasonable to the car mechanic who filled up the car tires of a UNL professor with nitrogen without his prior notice, and subsequently charged him $40. Being a physics professor, he got his money back, knowing that filling tires with 100% N_2 (nitrogen) should have no difference in gas mileage compared to 80% N_2 and 20% O_2 (oxygen), that is, regular air. The argument that won the money back is that the molecule size (bond length) for N_2 is within a few percent of that of O_2, and hence O_2 would not leak four times faster than N_2, which is what NitroFill claims on its website.[1] But race car tires, space shuttle tires, and Tour de France bike tires are filled with N_2. "High-purity nitrogen has been used for decades in Nascar, Formula One, the Tour de France, the U.S. Military and many other applications where safety and economy are paramount concerns."[1] Doesn't that mean something? Could companies such as NitroFill actually be right? That's a question to think about. So we wanted to find out if filling your tires with N_2 is actually worth it.

Helium leaks through latex party balloons at noticeable rates, which is why some helium party balloons are made with aluminum foil. The fact that helium leaks faster through latex balloons than air is typically ascribed to the small size of helium as compared to air molecules. Thus, if we want to fill latex balloons and keep them inflated for an extended time, filling them with air is better than filling them with helium. Similarly, if nitrogen is better for filling tires than air, air must leak faster than nitrogen. But because air consists for a large part of nitrogen, it is the oxygen in air that should leak strongly through the tire wall. To test this, party balloons were filled and color coded according to the type of gas used. Red for O_2, blue for N_2, white for air, and orange for He. Three balloons of each color were used. The balloons were then examined two days later to note any changes. The hypothesis was that leak rate depends on molecular size. The expectation was thus that the He balloons would deflate noticeably, while the other three would remain the same if there are no appreciable leak rate differences between them. The orange (He) balloons were noticeably deflated compared to the white (air) balloons. The blue (N_2) balloons and white (air) balloons were slightly deflated, but surprisingly enough the red (O_2) balloons had leaked almost just as much as the helium-filled balloons (Fig.1). This would lead to the conclusion that molecular bond length is not the sole factor that dominates leak rate. This was so unexpected that some attempts at falsification of the experiment were in order.

It was hypothesized that leak rate may be linked to the balloon color. Perhaps each color was treated differently when the balloons were manufactured. To test this new hypothesis, a balloon of each color was filled with the four gases. If our second hypothesis were true, then all the red balloons would have deflated noticeably more than the other colors in each gas group, independent of the type of gas filled. Once again the balloons were examined two days later, and, contrary to our second hypothesis, O_2 did indeed leak considerably more than N_2, independent of color. All of the O_2-filled balloons were deflated almost as much as the He ones were, while the other two again remained similarly sized. Thus, the color of the balloons was determined not to be a factor in the leak rates.

Perhaps O_2 degraded the latex and caused a leak. After all, oxygen is known to be more reactive (by oxidation) than N_2. To test this third hypothesis, both the red balloons from the first balloon test (which used to contain O_2) and the blue balloons (which used to contain N_2) were refilled with N_2. If the O_2 had in fact corroded the latex in the red balloons, then N_2

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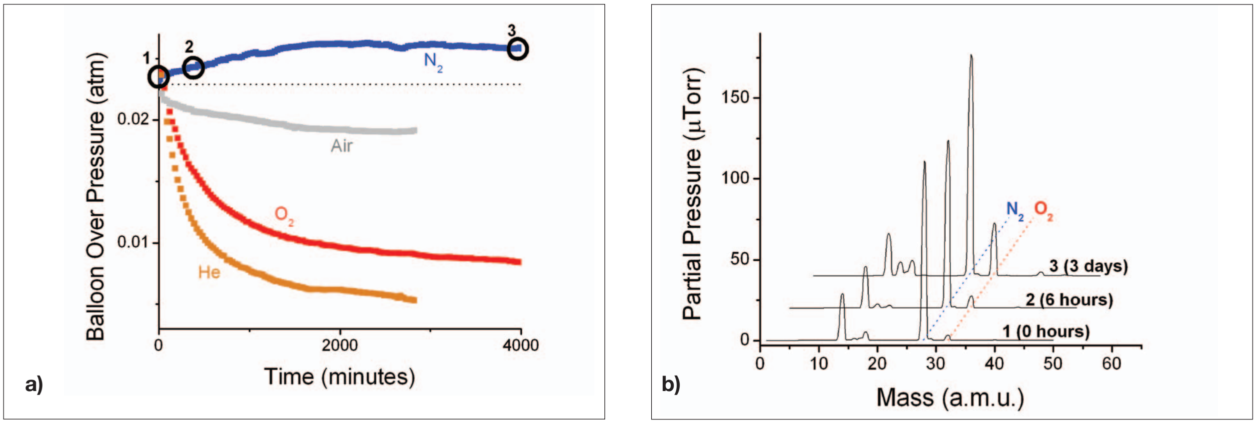

Fig. 2. Balloon leak data. (a) The balloon pressure was measured with a water manometer as a function of time. The data show that oxygen and helium leak much faster from a balloon than air and nitrogen. It is interesting to note that a nitrogen-filled balloon increases its pressure a bit. At the times indicated by the points 1, 2, and 3 (0 hr, 6 hr, and 3 d, respectively) on the nitrogen curve, a mass spectrum (b) was taken to identify the molecules in the balloon. The data show that oxygen (atomic mass unit 32) initially leaks into the balloon faster than the nitrogen (atomic mass unit 28) leaks out, increasing the total pressure.

would leak faster in the red balloons than in the blue ones. As usual the balloons were examined two days later, and the third hypothesis was also proven wrong; all four balloons were essentially the same size as they were two days before.

We also performed a more detailed study that requires more resources. A web camera run with free software[2] was used to record pressure as a function of time. A balloon was attached to an open water manometer, and pictures were taken at regular time intervals to monitor the change in water level as a measure of the pressure. Simultaneous temperature measurements were made, and atmospheric pressure data available through NOAA[3] showed the negligible influence of these parameters. Figure 2 (a) shows the leakage for different gases and confirms our main observations. It is amusing to note that an N_2-filled balloon initially increases its size and pressure a bit. Mass spectra taken with a residual gas analyzer indicate that O_2 leaks into the balloon [Fig. 2 (b)]. The ratio of N_2 to O_2 changes from initially 1 to 0, to the ratio found in air of about 4 to 1. Thus, oxygen leaks into the balloon against the leakage direction dictated by the total pressure difference. The partial oxygen pressure is higher on the outside than the inside of the balloon, which indicates that partial pressure and not total pressure governs leakage rates.

From all the experiments it was clear that O_2 did in fact leak noticeably quicker than N_2, as advertised by NitroFill. This is in stark contrast to a well-known fact. When a vacuum system does not pump down well, a residual gas analyzer is often used to measure the molecular composition of the residual gas in the vacuum system. The signature of an air leak (as opposed to, for example, water desorption from the vacuum walls) is the presence of both an N_2 and O_2 signal at a ratio of about 4 to 1. Leaks are often found this way in research laboratories. This means that it is common practice to assume that N_2 and O_2 leak at the same rate through the typical rubber and metal seals that are used for vacuum systems, clearly different than what we find for balloons. Still, real road tests[4,5] show a slight increase in leakage for dry air as compared to nitrogen. Our balloon experiments confirm that oxygen leaks faster through latex than nitrogen. It is this type of unexpected result that typically stimulates research questions. What physical properties control leakage? It appears that this is currently not known even to the modest accuracy required to answer a practical question: "Is it worth it to fill your car tires with N_2 as opposed to air?" *Consumer Reports* states: "Overall, consumers can use nitrogen and might enjoy the slight improvement in air retention provided, but it's not a substitute for regular inflation checks."[5] Despite the clear oxygen leakage for balloons, our balloon experiment is consistent with the conclusion given by *Consumer Reports*, because the air and nitrogen leak rates were indistinguishable for tires (3.5 ± 1.6 psi for air and 2.2 ± 1.2 for N_2). The increased wall thickness for rubber tires makes leak rates very slow and makes differences in leak rate a concern only for the most demanding circumstances.

The educational experience that this experiment provides is very rewarding. A controversial and topical question is formulated that relates to our everyday lives, a logically connected series of hypotheses can be posed and tested to reach a clear result. This reflects actual research much more than the many typical educational science experiments. For such experiments, a student often anticipates an answer that simply confirms a textbook result in a predetermined set of steps. The hypothesis is usually provided. In the current experiment the first hypothesis can be given, while the others are example hypotheses that students can formulate themselves. Falsification and verification are intricate parts of the experiment.

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