Talking like Donald Duck—C.E. Mungan, Fall 1999

It is a commonly known fact that if you fill your lungs with helium, your voice will sound unusually high pitched. Why? This is a nice question to discuss with introductory students because it ties in well to the subject of standing waves on strings and in pipes.

A student might begin by hypothesizing that the pitch of one's voice is determined by the harmonic frequencies of the vocal cords. Modeling a vocal cord as a string of length L fixed at both ends, the student concludes that the voice's frequency components are

$$f_n = \frac{n}{2L}\sqrt{\frac{F}{\mu}} \quad (n = 1, 2, 3, ...)$$

where F is the tension in the cord and μ is its linear mass density. Unfortunately, the student then immediately discovers to her dismay that if the helium-breathing person tries to talk in a normal way (i.e., exerts the same muscular tension on his vocal cords as he normally would), none of these harmonic frequencies f_n will change and hence it would seem that this model cannot explain the observed change in pitch.

"Oh," says the student after flipping through her textbook and discovering Conceptual Example 7 on page 514 of Cutnell & Johnson, "I forgot about the throat." Taking it to be a tube of length D open at one end and closed at the other end, its harmonic frequencies are

$$\nu_m = \frac{m\upsilon}{2D} \quad (m = 1, 3, 5, ...)$$

where υ is the speed of sound, given by

$$\upsilon = \sqrt{\frac{\gamma RT}{M}}$$

so that

$$\frac{\upsilon_{\text{He}}}{\upsilon_{\text{air}}} = \sqrt{\frac{\gamma_{monatomic} / (4\text{u})}{\gamma_{diatomic} / (0.79 \times 28\text{u} + 0.21 \times 32\text{u})}} = 2.93.$$

Thus we would expect the pitch to be 2.93 times higher when the voice cavity is helium filled.

The above solution is unsatisfying. After all, the frequency of any wave is always equal to the frequency of oscillation of the source (viz. the vocal cords) and is independent of the properties of the medium (viz. the gas in the throat). This explains why a red ball still appears red underwater. So why doesn't the human voice still sound the same under helium?

The answer is of course that my analogy here between the eye and the ear is a swindle. The eye is detecting a *traveling* wave scattered from the ball, but in contrast the wave in one's throat is a *standing* wave. If we want to compare apples with apples, imagine playing a xylophone in a room filled with helium that is large enough that no standing wave patterns are set up. Then the xylophone will sound perfectly normal! Or if you prefer to compare oranges with oranges, imagine that the light is being produced by a laser and that you shift the peak of the gain profile of the cavity. Of course, the emitted color will change accordingly. In fact, you can get a HeNe laser to emit in the green, yellow, or infrared, instead of the red, by suitably designing the cavity.

You see, one's vocal chords are not monochromatic but vibrate at a complex mix of harmonics n. Some of these lower harmonics are resonant with the voice cavity modes m and consequently get amplified. But by filling the throat with helium, we pushed the cavity modes to higher frequencies and thus preferentially amplify the higher harmonics of the vocal chords. And that's why you sound like Donald Duck. The harmonic frequencies in your voice have not changed, but the relative amplitudes of these harmonics have.