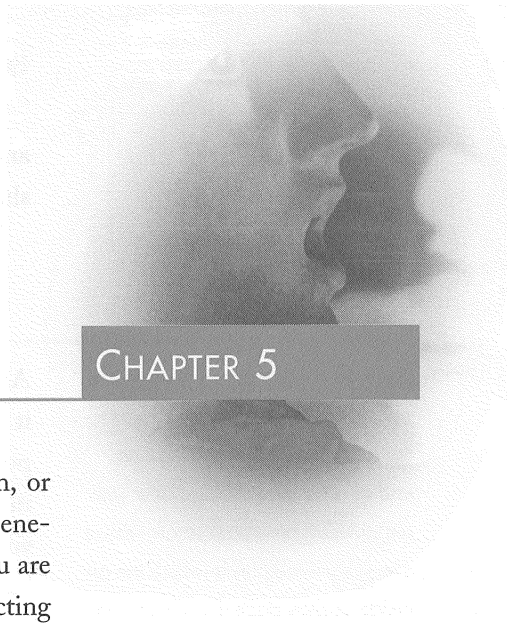
EXCELLENCE IN SINGING

multilevel learning and multilevel teaching

VOLUME 1: Beginning the process

CELUMBRA
Redmond, WA



THE AIR INSIDE THE BODY

CHAPTER 5

Your student's voice might be loud, soft, smooth, rough, high, or low. Maybe it is velvety, warm, and full. Or maybe it is steely, penetrating, and strong. Listening to these qualities in her voice, you are probably not thinking about the air. Yet without the air connecting to your eardrums from the bottom of your student's lungs, you wouldn't hear her voice at all.

The connection between your student's voice and your ears is as direct as a rope between two children: if the child at one end shakes the rope back and forth, she sends waves through the rope that push and pull on the child holding the other end. Likewise, when your student uses her voice, she essentially "shakes" the air back and forth at one end and sends waves through the air that push and pull your eardrums at the other end.

So how does your student shake the air, creating the tugs that propel across the room to your eardrums? She uses air itself. She brings air into her body, pushes and pulls on it in many ways. The ensuing chaos of the air inside her body ultimately transforms into acoustic ripples at her lips or nostrils. There, those ripples shake the outside air.

Whether your student's voice sounds luscious, mellow, full, weak, raspy, or thin depends on the form of rippling air at her lips and nostrils. Consequently, air is the substance of her art, the way clay is the substance of a potter's art. She moves it, shapes it, caresses it,

and, in doing so, delicately sets it in motion, shaping and reshaping the ripples at her lips and nostrils.

The Springiness of Air

Because air is a gas, thinking of it as a springy material may seem counterintuitive. Squeezing one end of a balloon, filling a tire with air, pushing on a basketball—these everyday examples in which the air inside pushes back if you push on it—might help you think of air as a springy substance.

Air is a springy material. If you push on it, it compresses; if you let it go, it springs back like a jack-in-the-box. When your student pushes and pulls the air inside her body, she uses its springy motion. For instance, she uses the springy motion to cause her vocal folds to open and close during phonation. The air springing back after being pushed provides the driving force to cause her vocal folds to vibrate, which chops the outflowing air into pulses, creating the acoustic ripples at her lips and nostrils we call voice.

The art of singing is the art of playing with the air inside the body. (See Figure 1 on Plate 1.) We can appreciate this if we breathe a different substance—helium, for instance. Helium springs back differently than air after being compressed, so if your student inhales helium, she would produce only high-pitched, Donald Duck–like sounds.

You help your student use air found in everyday singing contexts—air made of the common combination of oxygen, nitrogen, and a few other gases in the earth's atmosphere. The springiness of the air is more or less constant in the lesson studio, practice room, and performance hall.

The constancy of air helps us see teaching and learning singing as a stochastic process: the filter is the springiness of air; the random elements are the number of ways your student pushes, pulls, and shapes the air inside her body; and the results are the patterns of acoustic ripples at her lips and nostrils (the sounds). Because air is constant, the only way your student can improve her sound is to vary how she pushes, pulls, and shapes the air inside her body. The

more ways she can do that, the better the chance she has of producing her target sounds; the fewer ways, the worse the chance.

Singing with excellence means developing distinctions—this time in relation to how your student interacts with the air inside her body. For all the possible ways your student can use her body to interact with the air, the air responds according to the same rules. Scientists have described those rules and can now predict the air's motion with great accuracy. In short, they can predict the sound.

Air responds the same way for a beginning singer as it does for a master singer. Therefore, every singer has the same chance to create beautiful sequences of acoustic ripples in the air.

In this chapter, we examine what some of those rules mean for how to teach and learn.

Air in Motion

When your student uses her body to push and pull the air, she sets the air in motion. The rules that govern this motion are described in two separate fields of study: *aerodynamics* and *acoustics.* Aerodynamics describes how large masses of air move and interact with objects. It describes the air flowing in and out of the body; the jets of air pulsing through the vocal folds during phonation; the currents, vortices, and other complex motions of these masses of air.

Acoustics describes how air *particles* bunch up when compressed and expand when rarefied and how those movements become sound waves. (See the heading "Sound Waves," on page 219.) Though a sound wave may travel a great distance, the air particles themselves do not move very far. Instead, a *displacement* of air particles travels. To demonstrate displacement, teachers often use the analogy of knocking over the first domino in a row. Each domino doesn't move much, but you see a wave of the dominoes' displacement travel through the row. Teachers also use the analogy of a wheat field on a windy day: you see shimmering waves travel across the field as the wind blows, but the wheat stalks don't travel.

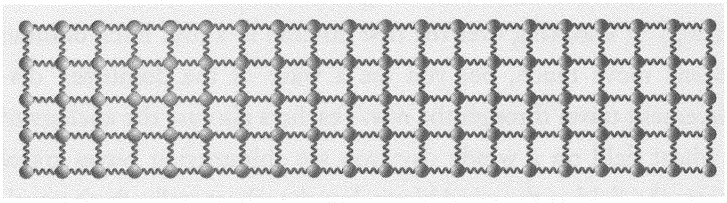
The first row bends, then the second row, then the third row, and so on. Only their displacement—the bending—travels.

The displacement of the air particles travels at the speed of sound, approximately 330 meters a second—much faster than the movement of the air while inhaling and exhaling. It also moves faster when moving through your student's vocal folds while singing. For instance, on A4, the air spurts in little jets through her vocal folds at 440 times a second. Yet the sound wave is faster: a single pulse begins a sound wave that ripples up and down the vocal tract several times before the single pulse has even finished coming through the vocal folds.

While singing, your student's body moves billions of air particles in and out of her body with relatively large and slow motions we call inhalation and exhalation. During singing, those motions, however, generate thousands of waves that flit through her vocal tract at the same time. The art of singing coordinates the two levels of motion in specific ways—the relatively slow spurts through the vocal folds synchronize with the acoustic ripples racing through the air particles. (See the heading "Source-Filter Theory," on page 246.)

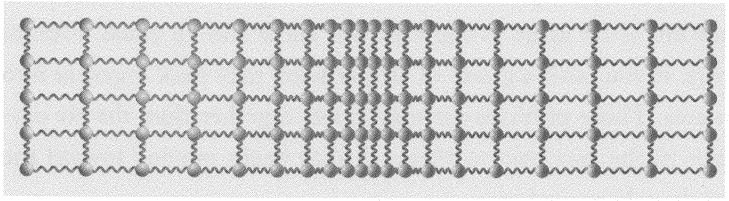
Also keep the context in mind: acoustics describes the motion of neighboring air particles. Teachers commonly present an image of the air's particles as microscopic marbles that are attached to each other with tiny springs.

Figure 1. Air particles with imaginary springs.



If you push the marbles toward their neighbors, the springs will coil tightly between them. If you pull the marbles away from their neighbors, the springs will stretch between them. In either case, if you let the marbles go, they will spring back and forth.

Figure 2. Air particles with imaginary springs: some bunched up, some stretched apart. If you let them go, you can imagine the springiness of the air particles.



The descriptions from acoustics typically involve one, two, or three examples of these back-and-forth motions. You must generalize the motion of a few neighboring air particles to the billions of neighboring air particles inside your student's body to more easily relate the concepts to singing.

When the springy back-and-forth motions of the air move slower than 20 times a second or faster than 20,000 times a second, they cannot be detected by our human nervous system.

The basic concepts that we discuss to describe the air's complex motion are the following:

- pressure
- disturbance
- oscillation
- sound waves
- resonance
- vowels

To look at these concepts through the eyes of physicists, see Ingo Titze's *Principles of Voice Production*[1] and Johann Sundberg's *The Science of the Singing Voice.*[2] In *Excellence in Singing*, we want to

help you develop an intuitive view of the air inside the body that is useful for singing.

Air's Search for Equilibrium

Like people in an elevator, air particles do not like to be too close. Consequently, they move toward and away from each other until they are as far apart as the area will allow and an equal distance apart. If you push a group of air particles, they pack together into an area. Those particles are now closer together than the air particles in the area next to them, so they begin moving toward the less densely packed area.

This image illustrates a principle you will see over and over: densely packed air particles (particles under higher pressure) always flow toward loosely packed air particles (those under lower pressure). You can describe this motion as the air particles' constant search for *equilibrium,* a stable state.

We see this motion in breathing. Here is the principle at work at different moments in the breathing cycle:

- At the end of your student's exhalation during quiet breathing (also called rest breathing or tidal breathing), the air particles find equilibrium. At that moment, the density of air particles inside and outside her body is the same, and the air stops moving.
- When she begins inhaling, she expands her lungs by expanding her rib cage and lowering her diaphragm. The air particles in her lungs begin to spread into the larger area. At this moment, the air particles in her lungs are less dense than the air particles outside. The higher-density air particles outside

the body flow in until the air particles inside and outside reach equilibrium.

- At the beginning of her exhalation, when your student begins to relax her rib cage and diaphragm, her lungs begin to shrink, due to a shrinking chest cavity, which packs the air particles into a smaller area. The air particles in her lungs are now more densely packed than the air particles outside. In their search for equilibrium, the densely packed air particles rush upward toward the less-crowded air particles outside until they reach equilibrium.

Pressure

When air particles are unevenly distributed, they generate pressure. "Pressure" is a physics term that means "force per unit area." For our purposes, air pressure is the number of air particles in one area relative to a neighboring area. Imagine the mouth and throat, the lungs and trachea, and the areas inside and outside the body, and consider the following principles about pressure:

- If the number of air particles per unit volume is the same in both areas, the pressure is the same in both areas. No air particles move toward the others.
- Where the number of air particles increases, the pressure goes up; where it decreases, the pressure goes down.
- Air particles move from higher-pressure areas to lower-pressure areas.

Consider the areas just outside and inside of the eardrum. Just as an ocean wave pushes water against the beach, a sound wave pushes the air particles against the eardrum. When this situation

occurs, the air particles outside the eardrum are more densely packed than the air particles inside the eardrum. As the air particles search for equilibrium, they push the eardrum inward, toward the less-crowded air particles on the inside of the eardrum.

At the next moment, the sound wave pulls air particles away from the eardrum, just as an ocean wave pulls water from the beach. Now the air particles inside the eardrum are more densely packed than the air particles immediately outside the eardrum. In their search for equilibrium, the densely packed air particles inside the middle ear push the eardrum outward, toward the less crowded air particles outside. Over and over, the air particles push the eardrum in and out. This motion, as we've pointed out, occurs many times a second—so fast, the motions are acoustic vibrations.

For singing, your student essentially disrupts the equilibrium of the air inside her body and uses the uneven pressures that result to do work. She uses the high pressure inside her lungs and trachea as a driving force to push the vocal folds apart and, with the help of the tissue's elasticity, to help suck them back together to cause vocal fold vibration, as we described in the preceding chapter. (See the heading "The Interaction between the Tissues and the Air," in v. 1, ch. 4.) She also uses the uneven pressures to push and pull the air itself, a topic we explore later in this chapter.

Disturbance

Once air particles find equilibrium, they stay there—and nothing happens. Your student needs to disturb the equilibrium to set the air particles in motion.

Your student disturbs the air particles inside her body by pushing and pulling on them anywhere along the air column. For instance, when your student phonates, she disturbs the air particles at her

vocal folds. When she pops her lips, she disturbs the air particles there. Once she uses her body to disturb the air particles, those air particles disturb the neighboring air particles, which disturb their neighbors, and so on, creating an acoustic wave.

The concept of disturbance helps show that your student's movements affect all the air inside her body to some degree. It explains why, with refined control, your student can solve a breath problem or a phonation problem with resonance, or a resonance problem with phonation. It explains why you can help your student introduce a difference anywhere in your student's body to change her sound.

The preceding chapter shows how your student disturbs the air particles at the vocal folds in two ways: (1) by the little pulses of air particles that pop through her glottis as she phonates, and (2) by her vocal folds themselves as they open and shut, like two hands clapping.[3] But she disturbs the air along the air passageway in many ways for vocal sound—for instance, with the tongue and lips for the consonants [t] and [p]; with the diaphragm, intercostal muscles, and abdominal muscles; or by expanding and contracting the chest cavity. In essence, she uses her whole body to disturb the air's equilibrium in complex ways.

Oscillation

After the air particles have been disturbed, they try to get back to equilibrium, but they overshoot it. You see many examples of other objects that overshoot equilibrium while trying to reach it: a pendulum, swing, and see-saw, for instance.

Imagine disturbing the equilibrium of people in an elevator by shoving them to the right side of the elevator. Using our definition

of pressure, we say the pressure increases on one side of the elevator and decreases on the other.

Uncomfortable, out of equilibrium, the people naturally step back toward the left. However, as they unpack, they overshoot and pack up on the left side. Squashed against the left side, they are out of equilibrium again.

Out of equilibrium, with all the empty space on the right side, they now peel off their pile one by one and move back to the right side. Again they overshoot and stack up on the right, leaving the left side empty. As they move, they make the pressure go up and down on each side of the elevator. If we were scientists, we would say that the people in the elevator were *oscillating* in pressure.

If we were to place our hands against the side of the elevator wall, we would feel it bend and spring back as the people bunch up against it and spread away from it. The elevator wall is like an eardrum and the moving people are like air particles, which bunch up each time a sound wave arrives.

Waveforms

Scientists use w*aveforms,* graphical representations, to describe the air particles' movement away from and toward equilibrium. The following waveform, for instance, describes the air particles' displacement over time. The straight line represents equilibrium. As the curving line arches above the straight line, the air particles move closer together, raising the pressure. As the curving line slopes below the straight line, the air particles move farther apart, lowering the pressure. Note that this chart describes the air particles in a single area.