INTONATION: WHAT YOUR TEACHER(S) NEVER TOLD YOU

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A bright and talented graduate student, about to complete her doctoral degree in violin performance and pedagogy and headed for her first full-time college teaching position, recently asked me if I could “explain the fluidity of tuning and intonation within a string quartet... I still don't feel like I have a complete grasp of how string quartets tune different intervals within a chord based on the harmonic progressions.”

The question she asked is the perfect example of how it is possible to complete an advanced degree in music performance never having been introduced to some of the basic facts of intonation! What follows is my response. Maybe it will become the beginning of a book on intonation that I have been meaning to write for decades!

* * *

We go through years of study using the tuning of the piano – equal temperament (ET) – as the reference for correct intonation. Some of us even use electronic tuners – ETs calibrated to ET – to check our intonation, not realizing that ET is a grid of twelve equal semitones that only approximates the true tuning of musical intervals. The 20th-century iconoclastic composer Harry Partch railed against such “ignorance” when he wrote about “the iniquitous determination of music education to withhold from students any adequate comprehension of the problems of intonation.” I’m not sure I’d characterize music educators as either iniquitous or determined – just sadly uninformed, inadequately informed, even misinformed, with regard to what constitutes the basis of good intonation.

The best book I’ve ever read on the subject of intonation is Christine Heman’s *Intonation auf Streichinstrumenten: melodisches und harmonisches Hören* (Intonation on String Instruments: Melodic and Harmonic Hearing), published by Bärenreiter in 1964. Unfortunately it is out of print, and to my knowledge it has never been translated into English. Well-meaning “authorities” before and after Heman have written on the subject of intonation; however, most of them overlook or misinterpret the basics, so as the saying goes, “don’t believe everything you read.”

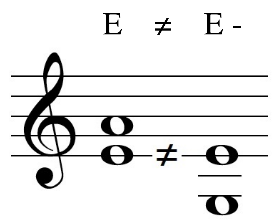
I’m always happy to sit down for an hour or so to talk about and demonstrate what it means to play melodically and harmonically in tune, and how this differs from equal temperament. It’s too bad that most teachers are unable to do this with their students. Violin pedagogue Kurt Sassmanshaus gives a good thumbnail sketch of the basics here: http://www.violinmasterclass.com/en/masterclasses/intonation.

I will go into more detail in the pages that follow.

When playing melodically (focusing on the “horizontal” succession of pitches) string players tend to follow the pattern of Pythagorean intonation (PI). The framework of PI is a series of harmonically pure (perfectly in tune, not tempered) perfect fifths, of which our open strings are obviously a part. The simple harmonic relations of pure perfect fifths (2:3), along with perfect fourths (3:4) and octaves (1:2) make these the acoustically “strongest” musical intervals upon which to base a system of tuning or intonation.

However, when the focus shifts to harmony (the “vertical” combinations of pitches in double stops and chords), we find that the major thirds and sixths of PI are slightly too wide, and the PI minor thirds and sixths are slightly too narrow, to sound perfectly in tune harmonically. We discover this when playing double stop thirds and sixths; if we are listening intently, we adjust, perhaps without even realizing that we have done so. Correctly tuned harmonies result in just intonation (JI), which includes harmonic ratios of the pure major third (4:5), major sixth (3:5), minor third (5:6), and minor sixth (5:8).

JI influences our tuning of harmonies in ensemble playing, to varying degrees depending on how much the focus is on melody and how much is on harmony at any given moment. While the tuning of the perfect intervals (P4s, P5s and P8s) should be the same melodically and harmonically, the tuning of thirds and sixths is not. Here is the classic example of the kind of harmonic adjustment needed in the latter case:



The E that is in tune as a double stop with open A (and is also in tune with open E) is not the same as the E that is in tune as a double stop with open G (and also in tune with open C). The latter E, which we will call E- (E minus) to distinguish between the two, is lower by an amount known as the syntonic comma (about 1/5 of an ET semitone).

Any time you play a double stop, your aim is to get it perfectly in tune – smooth, with no “beats.” As already mentioned, the P4s, P5s, and P8s should be the same whether played melodically or harmonically. If you have to adjust the intonation of a double-stop perfect interval, it’s because you simply weren’t in tune to begin with.

Tuning thirds and sixths is another matter. If you have to adjust, you might have been in tune melodically, but in the case of these intervals, being in tune harmonically is not the same thing. Remember E and E-? When you played E as a P4 with open A, then as a M6 with open G, the E that was in tune according to PI sounds out of tune with open G.

If we insist that there is only one correct tuning for each note – whether it be in PI or ET – we are doomed either to go through life playing harmonies out of tune or to be engaged in continual conflict with our ensemble partners over what to do about it. Let me tell you about a relevant experience I had playing in a string quartet in graduate school. At one point we came to a sustained C major chord involving the cellist playing open C. Our first violinist had an E. CONFLICT!!! This obstinate violinist was so insistent that his E was in the right place ("This is where my teacher told me to play E," he argued), and so convinced that the cellist's instrument must be out of tune (it was not), the episode ended up with the cellist in tears and all of us frustrated and baffled by the experience. In retrospect I am grateful for this unpleasant experience, because it set me on the path of discovering, five years later, what was going on. What a shame that not one of us in that graduate string quartet knew about the syntonic comma!

This unhappy quartet experience also was the first step in teaching me that the essence of beautiful intonation is not being "right," but being flexible, fluid, willing to adjust and agree. Many more years later, when I play duets with students, I sometimes begin by adjusting my intonation to theirs – even if they are wrong! – so that they can get used to hearing something they may seldom or never have had the opportunity to hear before, namely harmonically in-tune intonation. Later I will explain to them what I have been doing, and I ask them instead to adjust their intonation to mine. In real life, it should, of course, be a two-way street, and believe me, it is a delight to play duets with another player who understands this – and an annoyance to play with others who don't (as is too often the case, even in professional ensembles whose members are capable of arguing as ignorantly as our graduate quartet did)!

Let's take a look at specific examples of harmonic adjustments that are sometimes necessary in ensemble playing with string instruments. An A minor chord tends to sound best when it resonates with open A and E. (One of the first things beginners should learn is to recognize that when a note is in tune with an open string as a unison or octave, it will cause that string to ring or resonate.) However, whoever has the C, the third of this chord, may need to raise it up to, or at least up towards, C+. (Violists and cellists, in case you haven't already figured it out, you don't have to sit stubbornly on your open C and claim "open string rights." You can be courteous and cooperative and simply place your first finger on the nut and roll it forward far enough to get the C in tune with A and E.) Or, if this doesn't seem like the best solution, the violinists (they would be violinists, wouldn't they?) may be able to relinquish THEIR open string rights and finger E and A a bit lower. We can even be courteous all the way around, and meet somewhere in the middle to get the intervals of the chord in tune.

In a C major chord involving open C and G strings, open E may need to be abandoned in favor of a fingered E-. Again, adjustments from both sides may sometimes be preferred; the goal is simply to get the chord in tune, which is not possible combining the pitches of open strings C with A or E, or G with E.

NOTE: Adjustments of this kind to achieve harmonious intonation are sometimes incorrectly referred to as "tempered" intonation. This is a complete misunderstanding and misuse of the term! A temperament is a compromise of pure intonation necessary when pure intonation is not an option, as is the case with instruments of fixed pitch.

Here is a list of adjustments needed to achieve harmonious tuning of commonly encountered triads. Some will appear twice; these can be tuned more than one way, depending on whether the open string is the root, third, or fifth of the triad. A minus sign indicates lowering by a syntonic comma, a plus sign indicates raising by a syntonic comma, from the note's Pythagorean melodic tuning.

Open strings as the root or fifth of a chord					
F	A-	C	F	Ab+	C
C	E-	G	C	Eb+	G
G	B-	D	G	Bb+	D
D	F#-	A	D	F+	A
A	C#-	E	A	C+	E
E	G#-	B	E	G+	B

Open strings as the third of a chord					
Ab+	C	Eb+	A-	C	E-
Eb+	G	Bb+	E-	G	B-
Bb+	D	F+	B-	D	F#-
F+	A	C+	F#-	A	C#-
C+	E	G+	C#-	E	G#-

Notice that all the sharps, and sometimes A, E, and B, are lowered by a comma, while all the flats, and sometimes F, C and G, are raised by a comma, when tuning harmonies with open strings. Low sharps and high flats? Isn't that a bit counterintuitive? It does indeed run counter to our PI melodic preferences (more about that later). However, it might have been perfectly natural for 18th-century players, who were accustomed to tuning their thirds pure, or more nearly so. They were not brought up in an environment permeated by ET, in which one seldom has a chance to hear and appreciate the beauty of purely tuned harmonies – especially thirds.

The degree to which we make adjustments in the direction of pure JI harmonies depends on the musical *context*. Sustained chords, especially if played with little or no vibrato, sound best in just intonation. A resonant performance space or the ringing of open strings could also incline us towards just intonation. When harmonies are more fleeting or attention is more on melodic movement, only slight adjustments in the direction of just intonation may be a better choice. If the duration of the harmony is so brief that the beating of Pythagorean thirds would not be noticeable or objectionable, perhaps no adjustment toward just intonation would be called for.

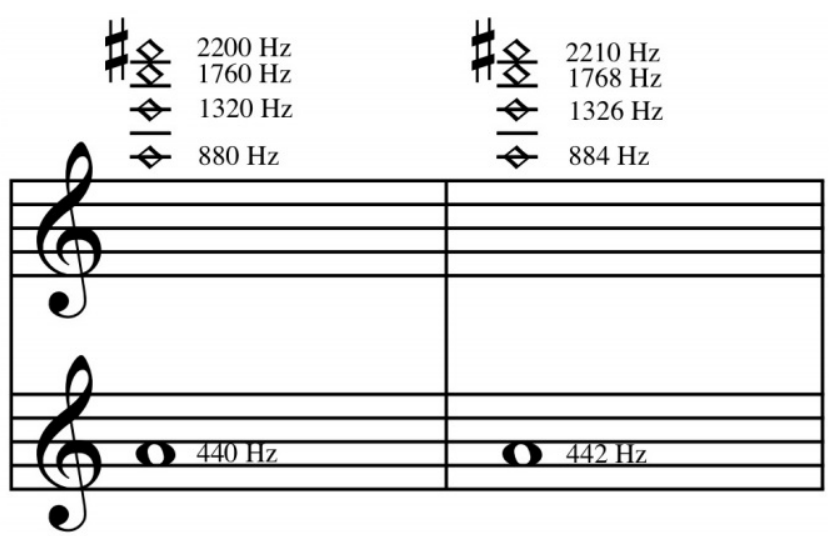
Musical *effect* also needs to be considered. In the 18th century, the tuning of keyboard instruments was "well tempered" but *not* equal tempered. There is a difference. Bach's *WTC* was not a demonstration of the virtues of equal temperament, in which all semitones are equal and every key sounds the same. Using one of the many unequal temperaments of Bach's time (and even into the 19th century!), it was possible to play in all keys, with the added feature that the keys with fewer sharps or flats sounded more harmonious than the others. Due mainly to the subtly different tunings of the thirds, each key actually had its own character or *Affekt*. Composers of the period consciously exploited these differences, subtleties unfortunately lost in modern performance.

This is not to say that we should try to sound less harmonious when playing in remote keys! (Many of us will do this without even trying!!) But we can make artistic decisions, such as preferring a "brighter" or "darker" sound rather than aiming to make every moment sound serenely harmonious in JI (or, on the other hand, limiting ourselves to PI, or, if it is actually possible, learning to play in the carefully calculated mistuning of ET).

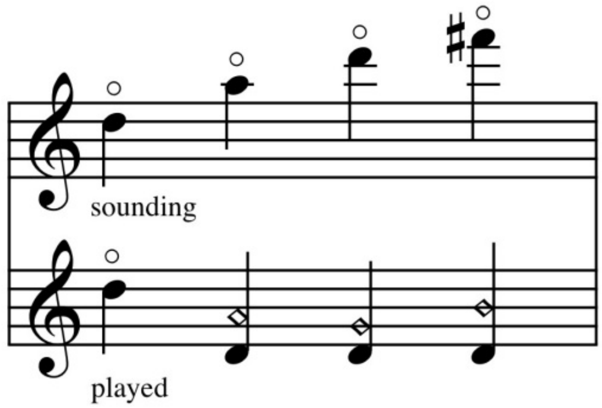
I want to emphasize that we do not play in JI by saying, "Okay, here I must play C higher," or "Here I must play E lower." The important thing is to understand that pure or just major thirds and sixths are not quite as wide, and pure or just minor thirds and sixths are not quite as narrow, as in either PI or ET. Knowing this, we are able to anticipate the direction in which intonation may need to be inflected, but it is only by intently listening and making artistic decisions that we will achieve the desired result.

First, you need to realize – and no doubt on some level you already do – that every musical pitch is actually a spectrum of pitches called a harmonic series. There is the fundamental – the pitch we "hear" – and above it an endless number of harmonics or partials. The frequency of each partial is a whole-number multiple of the frequency of the fundamental.

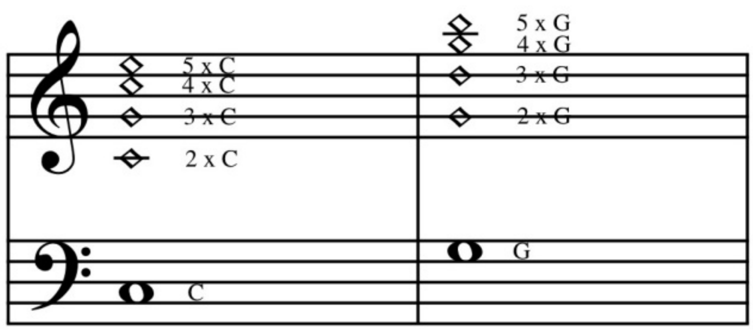
When we tune our A string to a reference pitch (using a tuner is okay for this), we are adjusting the fundamental and all its partials to match the reference pitch. To do this, we listen for "beats." If our A is sharp, say 442 Hz instead of 440, we will hear two beats per second. But if we listen intently, we may also be able to hear four beats per second an octave higher, six beats a second still higher, and so on. Learning to hear beats between harmonics helps us tune with greater precision.



Many string players are unaware of the natural harmonics of their open strings (other than the octave harmonic) and do not know how to play them. Here is an example of the most useful harmonics on the D string. The diamond shaped note heads show were to touch the finger to the D string to produce the indicated harmonic. With practice you can learn to hear harmonics when tuning open strings (when bowed together), double stops, and chords.



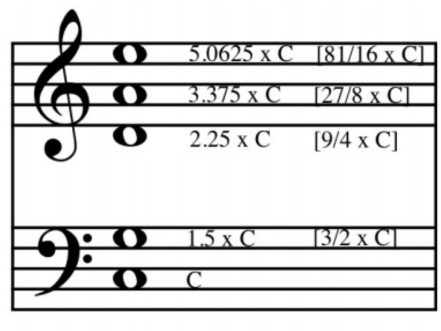
When tuning open strings, the third partial of the lower string should match the second partial of the upper string. When they do not quite match, we hear beats as when we tune our A in unison with a reference pitch. As we get closer to being in tune, the beats slow down, and they stop when we have a perfectly pure P5.



Notice that both the C and G strings have a G harmonic. When the two strings are perfectly in tune with each other, their G harmonics match, and the sounds of the two strings blend smoothly when played together. When the two strings aren't quite in tune with each other, their G harmonics clash, and we hear, or at least feel, a roughness, and if we listen intently, we hear a pulsing or beating. As we get the string closer and closer in tune, the beats slow down; when they stop, we're in tune.

Notice in the C harmonic series that the interval from the 2nd harmonic partial (C) to the 3rd harmonic partial (G) is a perfect fifth (P5), the interval between two open strings. In a P5, the frequency of the upper note is 3/2, or 1.5 times that of the lower note. Every time we go up a P5, as from one string to the next, the frequency increases by 1.5 times.

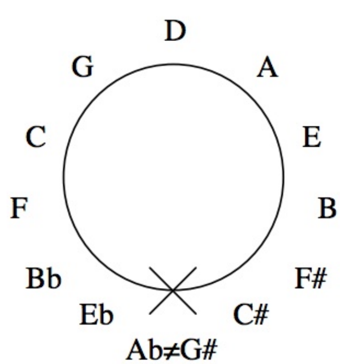
Let's look at the tuning of the open strings of viola and violin:



Multiplying the frequency by 1.5 each time we go up a string, we arrive at an E that is 5.0625 times the frequency of C. Now, wait a minute! Didn't we just see that the E in the harmonic series of C is exactly 5 times C? That's right! There are two ways to tune E. We saw this when we had to use "E" with open A but "E-" with open G in double stops. The harmonic E, which I call E-, is a bit lower in pitch than the E arrived at by tuning a series of P5s such as the open strings. The differenced is small, but you can hear it, and you can feel how you need to move your first finger to get from E in tune with open A (and with open E) and E- in tune with open G (and with open C).

This difference between E and E- (and other such pairs of notes) is called the s***yntonic comma***. We will often have to deal with it when playing double stops and chords. Knowing that it exists (and surprisingly, most musicians do not know!) will help us.

If we continue tuning by P5s in both directions from the open strings, we eventually arrive at a pair of ***enharmonic*** notes – notes of different names that most musicians consider to be two names for the same note – for example, G sharp and A flat – because on the piano both notes are played by the same key. However, if we tune by true or pure P5s of the ratio 3/2, G sharp comes out slightly higher than A flat!



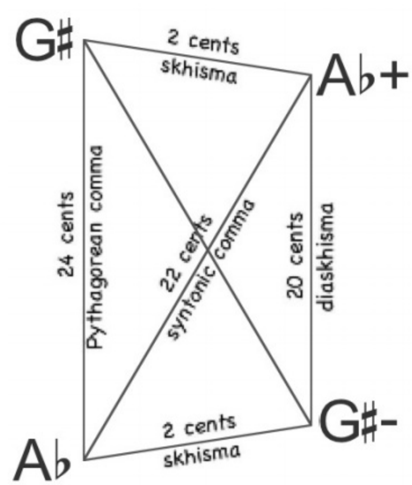
Why don't A flat and G sharp turn out to be the same, as they are on the piano? It's because powers of 1.5 will never be quite equal to powers of 2. To say it in musical terms, no number of *pure* P5s will ever exactly equal any number of P8s (octaves). Specifically, the twelfth power of 1.5 (twelve P5s) is 129.746337891, greater than 128, which is the seventh power of 2 (seven P8s). The so-called “circle” of fifths that should neatly close on the same pitch (albeit with a different name) is not a circle, but a spiral!

The pitch difference between a pair of ***enharmonic*** notes such as A flat and G sharp is called the ***Pythagorean comma***, which is only a tiny bit larger than the syntonic comma. We call the scale generated by pure P5s ***Pythagorean intonation***. This is the scale that we use most of the time. We also call it ***melodic intonation***. When we sometimes depart from it to play double stops and chords involving notes such as E-, we are using ***just intonation***, which we also call ***harmonic intonation***.

Seeing that enharmonic pairs of notes such as G# and Ab differ in pitch by almost exactly the same amount as pairs of melodically and harmonically tuned notes such as E and E-, we can visualize an enharmonic cluster of pitches as shown at the bottom of this page, melodic and harmonic intonation operating in tandem.

How does a piano tuner deal with these differences when tuning a piano? Isn’t he trying to get the piano exactly in tune? Actually, no. The piano tuner is setting up a tuning called equal temperament (ET), which is actually a carefully measured mistuning! Equal temperament has 1.4983071 P5s instead of 1.5 P5s. Each ET P5 is 1/12 of a Pythagorean comma narrower than a true or pure P5, so that the “circle” of fifths can end exactly where it began, and Ab and G# turn out to be the same. The resulting ET scale has twelve equal half steps or semitones, making it possible for the piano to be played in all keys, both sharp and flat, and the ET P5 is so close to the true or pure P5 that its mistuning is almost inaudible, so it might seem to be the ideal solution. Even though no ET interval is exactly in tune (except the P8), we accept ET on the piano because we’re used to it, and as it never gives us perfection, we don’t realize what we’re missing! Yes, it may be the best solution for pianos and other instruments of fixed pitch (the pitch cannot be changed by the player), but string players and other musicians who can adjust their pitch are always searching for what sounds best, and as we have seen, that requires making adjustments!

Here’s a diagram that could be considered a magnified map of a “single” note. We often talk of the twelve tones of a scale of half steps (a chromatic scale), but it would be more correct to speak of twelve *zones*, not tones! Each zone includes a pair of enharmonic notes in Pythagorean (melodic) intonation and a pair of enharmonic notes in just (harmonic) intonation. The sizes of commas and other intervals are given in ***cents***. There are 100 cents in each semitone of ET (that is, from one note on a piano to the next). (Do not confuse cents with frequencies. Every octave is 1200 cents, but the frequency from lower to upper note of an octave is always doubled. A 220 Hz to A 440 Hz is an octave; so is A 440 Hz to a 880 Hz, or A 110 Hz to A 220 Hz, but all are 1200 cents in size.)



You might find it interesting to compare the sizes of the intervals between notes in the Pythagorean, just, and ET scales in C major. Numbers are rounded to the nearest cent.

	C		D		E		F		G		A		B		C
ET		200		200		100		200		200		200		100	
Pyth		204		204		90		204		204		204		90	
	C		D		E-		F		G		A-		B-		C
Just		204		182		112		204		182		204		112	

To play in tune, we obviously do not need to memorize numbers. I provide the numbers only to illustrate the kinds of adjustments that we sometimes need to make. For example:

1) Pythagorean whole steps are slightly larger, half steps noticeably smaller, than in ET.
2) Just intonation has two sizes of whole step, and larger half steps than Pyth. or ET.
3) The just scale has E-, A-, and B-, each of which is quite noticeably lower than E, A, and B in either Pythagorean intonation or equal temperament.
4) A- is in tune harmonically with E-, C, and F, but not in tune with D. To be in tune with D, A- has to be adjusted to A.

In conclusion, I would like to say that I was pleased to see the doctoral student mentioned at the beginning of this essay refer to “the fluidity of tuning and intonation.” While she may not feel she has a “complete grasp,” she does recognize that good intonation is fluid.

I haven’t specifically answered her question as to “how string quartets tune different intervals within a chord based on the harmonic progressions.” Do they actually do this? I was about to end this essay on a negative note when I remembered a classic harmonic progression that has sometimes been used as an argument against the practicality of playing in just intonation, but which actually demonstrates beautifully what she referred to as “the fluidity of tuning and intonation…based on the harmonic progressions.”

The argument goes like this: In the key of C, the IV chord in JI would be F A- C. The ii chord would then “have to be” D- F A- (keeping the common tone A- and lowering D to D-), since D F A- would have a root that’s a comma out of tune with the other chord tones. Then the V chord would “have to be” G- B-- D-, and the I chord would be C- E-- G-, a comma too low! The solution to this dilemma is ridiculously obvious: instead of lowering D to D- in the ii chord, why not raise A- to A? Then the ii chord will be D F+ A, much preferable to string players who love to be in tune with their open strings. The interesting point here is that this requires a member of the quartet (the violist, of course!) to change the pitch of a common tone from A- to A! The effect of the comma shift in this progression is actually quite lovely, and even more so when progressing from IV to V/V (from F A- C to D F#- A, the F rising to F#- and the A- rising to A) – impossible in ET!

I hope this introduction to the “wonders of intonation” (not, as Partch wrote, “the problems of intonation”) will be ear-opening, inspiring, and helpful as you learn to play ever more beautifully in tune, in both solo and ensemble situations.