This is the English-language version of Historické hluboké žesťové nástroje z okolí Vltavy: Michálkovai ventilová ofiklejda, *Výběr* 60 (2023), *translated by Lenka Absolonová, reproduced here by kind permission of the publishers.*

Historical low brass instruments from near the Moldau: A valved ophicleide from Michálek[1]

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The industrial revolution spearheaded a period of great change in every aspect of European life. The growth of commercial enterprises had a dramatic influence on society, nowhere less so than in the realm of music. New manufacturing processes resulted in technical innovations which enabled a plethora of new design possibilities. This led to fierce competition regarding the application of such technologies to instruments both old and new, with the most dramatic and rapid developments taking place in the families of brass instruments. Previously restricted to soloists with exceptional embouchure control owing to reliance upon the 'natural' overtone series, pursuits of technical virtuosity entered mainstream practice through the invention of the valve, which enabled significantly more reliable, controllable, and consistent tone production, as well as the creation of brand new instrument families. New bore sizes and bell forms could now be experimented with, particularly with regard to larger and thus lower-pitched instruments. Steam-powered machinery would eventually lead to the rampant gigantification of low brass instruments that has continued to this day, yet already in the first decades of the nineteenth century, soon after the valve's first application to brass instruments, manufacturers in the Austro-Hungarian empire realised the potential they had enabled for the creation of new instruments primarily designed to amplify production of low-register sound. The Městské muzeum Týn nad Vltavou is fortunate to have in its collection one of the earliest of such instruments, known today as a valved ophicleide (Figure 1), from the manufacturer Anton Michálek. Having been restored in 2022, thanks to generous funding from the museum and Steven Klimesh of Spillville, Iowa (USA), the organological, musical, and societal contexts of this instrument can be assessed, along with quantitative study and recordings of contemporaneous orchestral, operatic, and military repertoire.

Low brass instruments of the early nineteenth century

Over the course of the early nineteenth century, instruments of the tuba family underwent significant transformations in terms of overall form, mechanisms for pitch alteration, and resonant capabilities. These processes began with the earliest low-pitched brass instrument to feature a method of creating specific, reproducible pitches: the serpent (Figure 2). A rudimentary S-shaped medieval instrument constructed from leather-covered wood and assisted in pitch control by means of six finger holes, the serpent was in widespread use in France by the late seventeenth century, primarily functioning as a support for the plainchant of church choirs.[2] By the late eighteenth century, the instrument had found its way into military bands across Europe—in Germany by around 1773, in France at the latest from 1795, in Russia by the mid-eighteenth century, and in Austria from "around the end of the [eighteenth] century"[3]—with composers such as Joseph Haydn including it in their works for military band, although Haydn, like many others, generally used the instrument to simply double the second bassoon in octaves or unison. The serpent was commonly seen in comparison with, or treated as part of the bassoon family; upon replacing the serpent in the orchestra of the Opéra de Paris in 1804, it was said that the contrabassoon creates "a reedy sound without force or clarity" and "is much inferior to the serpent,"[4] while in Germany in 1807, the "snake tube" [*Schlangenrohr*] or "Serpentin" was described as "a type of bassoon" that is "less dulcet […] but stronger."[5] Such

assimilations were strengthened by contemporaneous developments of upright forms of serpent with additional key-covered holes, known today as bass horns, and designed to improve ergonomics, reliability of intonation, and structural stability. Beginning with the *serpent droit* created by J. J. Régibo in 1789 (equated with the contrabassoon by Castil-Blaze in his 1821 dictionary),[6] other variations included the *serpent Forveille* (in metal with a wooden bell), *basson russe* (in wood, often with a dragon-head metal bell), and the *ophimonocleide* (of wooden body and a metal bell with one key) (Figure 3). In Italy, the *serpentone* gave way to a form of bass horn known as a *cimbasso*, a portmanteau of *corno in basso*, which has been used inconsistently by composers, performers, and publishers ever since.[7] In Paris in 1817, Jean Hilaire Asté (Halary) invented the ophicleide, a new form of bass horn that found immediate success due to improved levels of intonation via acoustically optimised key sizes and positioning (Figure 4). However, while the instrument was also popular in the Germanic states, England, and Italy,[8] it was generally used as part of the bassoon section, and not as a unique instrumental voice. It took a new invention to enable development of the tuba family outside of France: the valve.

In 1814, Heinrich Stölzel created the first successful piston valve, and for this he was granted a patent in 1818.[9] The earliest reference to a valved low-pitched brass instrument is found in a Viennese advertisement from Wenzel Riedl in 1829, describing "the newly invented bass bombardon with 12 keys, or with valves."[10] This instrument was patented in 1833 (Figure 5), although by this time a valved "Bass Bombarton [*sic*] or Harmonie-Bass" from Joseph Felix Riedl (possibly brother of Wenzel)[11] potentially already existed (Figure 6).[12] Following the double-reed *pommer* or *bombard* of the shawm family (described in 1795 as a "bombardo"), the name *bombardon*, similarly onomatopoeically derived from 'booming' sounds, was used to refer to keyed bass brass instruments with a "vigorous tone."[13] Othmar Berndl noted in 1833 that (Wenzel) Riedl "invented the Bombardon ten years ago in Warsaw […] at this time it had a different form and twelve keys."[14] These keyed bombardons were differentiated from keyed ophicleides due to their narrower bore and wider flared bell (Figure 7), although they were also described by some at the time as ophicleides, and quantitative analysis has shown that "there is a clear overlapping".[15] From the mid-1830s onwards, the name *bombardon* was used almost exclusively to refer to valved instruments; Berndl wrote that "the bombardon, as it is now found, has no keys, but rather three valves."[16] Wenzel Riedl's patent described the "invention and development of the Bass-Bombardon, through use of chromatic valves,"[17] and included three double-piston valves, invented in 1821 in Leipzig by Christian Friedrich Sattler. In 1830, Viennese manufacturer Leopold Uhlmann developed a new mechanism of engaging such valves, a solution that would prove so popular that all such double-piston valves built since are known as 'Vienna valves.' These were used by both W. and J. F. Riedl on their new instruments, although in 1835, J. F. Riedl would patent the now-ubiquitous rotary valve. After first copying French keyed ophicleides, Uhlmann created a new instrument by applying his valves to such designs, instruments named *Maschin-Ophikleïden* (valved ophicleides) in their first published reference in 1834,[18] and later also referred to as bombardons,[19] today known by some as "Wiener bombardons" (Figure 8).[20] The instrument in Týn nad Vltavou takes the overall form of this Uhlmann model of valved ophicleide.

Uhlmann's design did not have a long reign: in 1855, Karl von Schafhäutl wrote that the bombardon used to have a narrow bore with the valves at a right-angle to the axis of the instrument (W. and J. F. Riedl's designs); the "valved ophicleide, later bombardon" had a wider bore with an upright valve mechanism (Uhlmann's design); and "today, they all are arranged like the bass horns" (valves perpendicular to the body of the instrument).[21] Instruments which evolved from valved ophicleides and bombardons have been used in military settings across Europe ever since, but it is difficult to ascertain their use in contemporaneous orchestral literature. In 1834, Eduard Freiherr von Lannoy noted that "valved ophicleides have great advantages for military music […] the shape, setup, and strap attached to the instrument make it easy to carry, both for infantry and cavalry. The keyed ophicleide, however, is preferred in every other respect, and in an orchestra it is far more useful, indeed certain passages, could be played only with a lot of effort with a valved ophicleide."[22] Gerhard Zechmeister proposes that Franz Fretzer, *Bombardon-Bläser* with the Vienna

Philharmonic from 1834, would have used a valved instrument, yet it is quite possible that Fretzer used a valved instrument in his military band, and a keyed instrument in the orchestra.[23] Despite possessing a wider bore than W. and J. F. Riedl's instruments, Schafhäutl described valved ophicleides as *Halbinstrumente* or half-instruments,[24] as the narrower bore demanded by double-piston valves meant that they could not produce low resonant frequencies with rich spectral content, thereby only effectively utilising half of their resonant length. As military bands and orchestral composers demanded ever-stronger production of low frequency resonances, such low-pitched double-piston-valved instruments were soon replaced by wider bore instruments (*Ganzinstrumente*) with single pistons, notably the bass tuba (Figure 9), which was patented by Wilhelm Wieprecht and Johann Gottfried Moritz two years after the development of their *Berliner-Pumpe* piston valves in 1833.[25]

The Michálek ophicleide: military and biographical contexts

In the late-eighteenth and early-nineteenth centuries, military bands across Europe increased not only in terms of physical size, but also in societal importance, professionalism, and financial investment. Competitive performances, hosted at World Fairs such as those in London in 1851 and Paris in 1867, were dominated by bands from France, Prussia, and Austro-Hungary, the latter of which, in the shadow of the Napoleonic wars, had increased its bands' size to 34 men by the early nineteenth century, and boasted over 130 active ensembles across the empire.[26] Covering an area of land ranging from present-day northern Italy to western Ukraine, Eva Vičarová argues that a "Czech element" contributed the greatest share to the success of the Austrian military bands in that so-called "golden age," with Czech musicians constituting as much as two-thirds of the members of all military orchestras,[27] and notable musical commentator Eduard Hanslick writing that "the Slavs, in particular the Bohemians, are born musicians, and invaluable to every [military] orchestra."[28] Bandmasters, meanwhile, had "the rights of civilians and obligations of military persons," giving them the flexibility to experiment with both repertoire and instrumentation.[29] Such repertoire was produced notably by three generations of composers who originated from South Bohemia, each named Karel Komzák. The eldest was born in Netěchovice near Týn nad Vltavou in 1823, though Karel II, born in Prague in 1850, and master of the 84th Infantry Regiment Band in Krems near Vienna from 1882–88, is the most well-known today.[30] While scholars have struggled to establish exactly which of the father, son, or grandson composed which piece,[31] taken as a whole, the family played a significant role in establishing and propagating the Bohemian style of marches, waltzes, mazurkas, polkas, gallops, quadrilles, and other dance forms popular with such bands at home and abroad to this day.

The valved ophicleide held by the Městské muzeum Týn nad Vltavou is signed by "Ant. Fer. [Anton Ferdinand] Michalek" (Figure 10). Born in Prague in 1817, Anton Michálek was granted authorisation to manufacturer and sell woodwind and brass instruments from 1844, with an 1847 record of his business (alongside those from other known manufacturers of valved ophicleides including Eduard Bauer and August Heinrich Rott) providing an address in the city's third district on Brückengasse (today Mostecká), No. 48.[32] Beyond a singular E-flat clarinet in the collection of Thomas Reil dated to ca. 1857, little else of Michálek's output is recorded.[33] By 1859, Mostecká 48 had new occupant, and Michálek's business was no longer officially registered, suggesting that he was no longer active (at least in Prague) by this time.[34] Not to be confused with later valved ophicleides in tuba form (often unhelpfully labelled as a "Tuba" or "Basstuba"),[35] records exist of fourteen other valved ophicleides of Uhlmann's design in museums in Brussels, Oxford, Salzburg, New York, Paris, Washington, D.C., and Modena. There are undoubtedly further instruments currently undocumented lying in private collections or local musicians, such as one from A. H. Rott, which forms part of the collection in the regional museum in Český Krumlov.[36] Following a workshop in 2017 in České Budějovice given by Michael Pircher (Professor of Tuba at the University of Music and Performing

Arts Vienna), a copy of Michálek's valved ophicleide (with some alterations, including the addition of a fourth valve) was commissioned from Votruba Musik of Vienna (Figure 11), where it is currently displayed

While the Michálek instrument is similar in design to those made by Uhlmann (Figure 12), some differences can be observed, such as Michálek's folded third and wider first valve slide designs, and a narrower tuning slide. The developments in bombardon design, as noted above by Schafhäutl, resulted as much from attempts to address ergonomic difficulties as they were to promote greater volume or pitch control. Uhlmann's inclusion of a strap, as described above by Lannoy, would certainly help in this pursuit, yet his diagonal touchpiece arrangement was altered by Michálek to a parallel design, perhaps to enable a more comfortable right hand playing position. While it is possible to speculate about such attempted developments of Uhlmann's design, little is known of this specific instrument's provenance. It was given to the museum in 1934 by the nearby Čihovice agricultural vocational school, and since 2015 has been on display as part of their permanent exhibition. Given that there are no records of such instruments being produced by Uhlmann or others after 1850, it is unlikely that the Michálek instrument was produced after this date. Herbert Heyde estimates that valved ophicleides may have been in widespread use as late as 1865, but does not provide any illustrated sources for instruments of this design produced after 1848.[37] He also suggests that they were used in Bohemia even later in the century, citing a price list from Rott of ca. 1880 including a "Bombardon (Ophicleide) in F or E-flat with four valves";[38] however, given that Schafhäutl lists a "Bombardon in F with four valves" from the same manufacturer at the Munich exhibition of 1854,[39] it is quite possible that the same name was being maintained decades later for what by then could have been a very different instrument. The wider-bore bombardon designs of Václav František Červený would soon dominate instrumental design following their success at the exhibitions not only in Munich in 1854 (where Schafhäutl praised a "bombardon of the largest bore size with four valves" as producing an "extraordinarily strong tone and very accurate tuning"), but also in Paris in 1855, London in 1862, and Vienna in 1873 (Figure 13).[40] His *Kaiser-Bass* instruments, patented in 1884, proved so popular that their design was soon copied across central Europe, and is still mirrored closely in many instruments commonly used today (Figure 14). This places further into question the suggestion of continued employment of Uhlmann-style valved ophicleides half a century after their invention, although continued provincial use of earlier instrument designs can never be fully ruled out.

The Michálek ophicleide: organological and musical perspectives

The Michálek valved ophicleide was overhauled in 2022 by Stanislav Fořt of Kraslice, whereby the leadpipe was replaced, sections of the bell were patched, and a clock spring was replaced. In order to undertake this work, the instrument was unsoldered at the connecting rings and later reassembled while maintaining the original bore profile and overall instrument length. Following this restoration (Figure 15), it has been possible to produce assessments from both musical and organological perspectives. Data was taken on 5 January 2023, measuring the bore diameter of the instrument at both ends, as well as at a series of points along the length of the tube. Such geometrical data can be used to establish the bore profile of the instrument (Figure 16), and calculate the relative spectral content that can be produced, quantifying the extent to which it can theoretically create 'bright' or 'brassy' sounds relative to other brass instruments. As well as the measurement data collected, it is necessary to know the equivalent cone length, or the theoretical length of a pure conical shape with the same fundamental pitch of the instrument.[41] The Michálek instrument has a fundamental pitch of F1, and was built for use in the Austro-Hungarian military bands, which, at the time, had a tuning pitch of A=461Hz, almost a semitone above the modern international pitch standard of A=440Hz.[42] Through calculations made with this data, it is possible to determine the Brassiness Potential Parameter (BPP) of an instrument, a figure between 0 and 1 representing the least and most brassy sounds possible, respectively.[43] For example, early nineteenth-century instruments with a bright, brassy sound, such

as trumpets and trombones, have BPP values of between 0.7–0.85, while early low register instruments, such as serpents and ophicleides, have BPP values of between 0.25–0.35.[44] Measurements of the Michálek instrument produced a BPP valve of 0.47, which places it within the range of similar models that have been measured and collated thus far.[45] This is a figure similar to that calculated for modern euphoniums, although BPP does not take into account the greater bell flare on the valved ophicleide, which contributes significantly to the overall sound qualities of the instrument.[46] Such data is being included in a new metric, the Spectral Enrichment Factor, which is currently under development.[47] The full data on this instrument can be downloaded here.

On 5 January 2023, recordings of excerpts from orchestral and band repertoire contemporaneous to the creation and common usage of the instrument were made, and can be viewed here. Richard Wagner's *Der fliegende Holländer* (1843) includes a part for ophicleide, as he had envisaged a premiere at the Opéra de Paris where the instrument would be present, however, the work was eventually premiered in Dresden, most likely using a bass tuba. As in his earlier overture *Ein Sommernachtstraum* (1827), Felix Mendelssohn originally wrote for the English bass horn in his *Musik zu Ein Sommernachtstraum* (1843), but for the first printing in 1848 (in line with the publishing of the overture in 1832 (parts) and 1835 (score)), this was changed by the publishers to ophicleide. Robert Schumann only included the *Ophicleïde* in three scenes in *Das Paradies und die Peri* (1843), while Friedrich von Flotow used the instrument far more extensively in *Martha* (1847), though twentieth-century editions of such Germanic music often substitute ophicleide with tuba.[48] In northern Italy, valved ophicleides were "an immediate success,"[49] in no small part due to the control of the region by the Austro-Hungarian empire until 1859. An Uhlmann-style valved ophicleide built by A. Apparuti in 1841 held by the Museo Civico in Modena may well be similar to those used in Giuseppe Verdi's Italian premieres of this period, such as *Rigoletto* (1851).[50] This repertoire could have been performed using the Michálek instrument, although the performer would have had to transpose the part due to orchestral pitch at the time being a semitone lower at A=435Hz. Based upon an 1851 account from Julius Rühlmann, Heyde argues that the presence of valved ophicleides in the Hofkapelle in Dresden is reason enough to assume that such ophicleide parts "were evidentially not envisaged for keyed instruments",[51] although Rühlmann only mentions orchestral and operatic repertoire in his following entry regarding the bass tuba.[52] According to Lannoy's assessment above, keyed ophicleides were perhaps more likely to have been found in symphonic orchestras and opera pits, with records showing keyed instruments being built and used across the German, Austrian, and Italian empires over the early-to-mid nineteenth century. With regard to military bands such as those that would have performed Karl Komzák I's *Trauer Marsch* and *Polka "Vesnická"*, it is impossible to know for sure which low brass instrument would have been used when and where. As with most composers of the era, the Komzáks wrote *Basso* almost exclusively in their scores (although in later repertoire there are isolated uses of *Helikon* (a circular form of wearable lower brass instrument) and *Tuba*) (Figure 17),[53] thus allowing the performer to use whichever low brass instrument happened to be available to them. These *Basso* parts would certainly have been played using the Michálek instrument during the period when it was employed by the military band to which it belonged. There is no surviving mouthpiece accompanying Michálek's instrument, and a modern trombone mouthpiece was used for this recording. Following a design published in 1855,[54] a new mouthpiece has been commissioned, which can be used for any future performances or recordings, and be displayed with the instrument.

The valved ophicleide in Týn nad Vltavou is an important example of a short-lived, but highly influential design of instrument. While they may have only been built and commonly used for around fifteen years, this separation between keyed and valved low brass instruments and their respective conical and flared bell designs formed the first clear division between instruments that would soon evolve into the tubas that were used in orchestras across Europe until the early twentieth century, and bombardons that would be used

internationally in military bands (and later orchestras) until this day. While little is known today of Anton Michálek and his instruments, quantitative data helps place this instrument within a context of similar models known to be in existence, a practice that can be repeated as further specimens are revealed and more biographical material is found and verified. Through restoration, it is also one of very few, if not the only such instrument in playable condition today, which allows for further experimentation with contemporaneous repertoire, in particular with regard to local military band music. It is hoped that this historical-, practice-, and data-driven assessment can form a template for investigations of similar rarely studied instruments currently lying dormant in both museums and private collections across the world.

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24 Schafhäutl, “VI. Gruppe – III. Abtheilung: Blasinstrumente,” 170–73.
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32 Michálek's year of birth is confirmed by the 1844 census (Archiv hlavního města Prahy: http://katalog.ahmp.cz/pragapublica/ [accessed 14 January 2023]). Martina Maříková, Inventáře Archivu hlavního města Prahy (Prague: Magistrátem hlavního města Prahy I., Směnečný a obchodní soud, 2007), 192; *Adressbuch der königlichen Hauptstadt Prag für das Jahr 1847* (Prague: Gottlieb Hasse Söhne, 1847), 253.
33 Albert Rice, "Small Clarinets: History, Instruments, and Music" in *The Galpin Society Journal* 70 (March 2017), 135–168, here 162.
34 Nikolaus Lehmann, *Adressbuch der Königlichen Hauptstadt Prag, der Stadtgemeinden Karolinenthal, Smichow und der Bergstadt Wyšehrad, Volume 1* (self-published, 1859), 2:22.
35 For example, see the "Tuba" from Josef Štasný (Národní Museum [Prague], E420), and the "Basstuba" from Franz Rehbock (Germanisches Nationalmuseum [Nuremberg], MI224), respectively. Such tuba-formed instruments were also known until around 1850 as "Chromatic Basshorns" or "Corno basso" (Herbert Heyde, *Das Ventil-Blasinstrument: Seine Entwicklung im deutschsprachigen Raum von der Anfängen bis zur Gegenwart* [Wiesbaden: Breitkopf und Härtel, 1987], 226). Jean-Georges Kastner's referral to Uhlmann's instrument as a "Bass-Tuba" (Jean-Georges Kastner, *Manuel général de musique militaire* [Paris: Typ. Firmin Didot frères, 1848], Pl. XVI, Nos. 7, 8) was, as Heyde noted, the result of a "misunderstanding" (Heyde, *Das Ventil-Blasinstrument*, 226).
36 A study from Ignace de Keyser (Keyser, "The keyed ophicleide," 74) tabulates only 12 such instruments, excluding the Uhlmann instrument illustrated by Heyde (Heyde, *Das Ventil-Blasinstrument*, Photo 126). Hypotheses that the instrument in Český Krumlov originated in the local Schwarzenberg Guard Band have yet to be substantiated.
37 Heyde, *Das Ventil-Blasinstrument*, 225.
38 Ibid., 227.
39 Schafhäutl, "VI. Gruppe – III. Abtheilung: Blasinstrumente," 200.
40 Ibid., 200–01; Edmund Schebek, *Bericht über die Orchester-Instrumente auf der Pariser Welt-Ausstellung im Jahre 1855* (Vienna: aus der k. k. Hof- und Staatsdruckerei, 1858), 26–29; Wilhelm Hamm, *Illustrirter Katalog der Londoner Industrie-Ausstellung von 1862* (Leipzig: F. A. Brockhaus, 1863), 133; Oscar Paul, "Musikalische Instrumente" in *Amtlicher Bericht über die Wiener Weltausstellung im Jahre 1873* (Braunschweig: Friedrich Vieweg und Sohn, 1874), 654; Eduard Schelle, *Officielle Ausstellungs-Bericht der Wiener Weltausstellung 1873 (Gruppe XV)* (Vienna: aus der k. k. Hof- und Staatsdruckerei, 1875), 70–71.
41 Arnold Myers, "The typology and timbre of the tuba" in *Vom Serpent zur Tuba*, 159–74, here 170.
42 While this pitch was not standardised until later in the century, A=461Hz was perhaps particularly commonly used for military bands in the Czech lands given advocation at the Vienna conference of 1885 by no less than Karl Komzák (Andreas and Anna Zenker, "Wissenswertes über die Hohe Stimmung" in *Festschrift zum 25-jährigen Bestandsjubiläum der Emaus-Jünger* (Ebenau: self-published, 2013), 56–59, here 57.
43 Murray Campbell, Joël Gilbert, and Arnold Myers, *The Science of Brass Instruments* (Cham: Springer Nature, 2021), 280–84.
44 Arnold Myers, "Timbre" in *The Cambridge Encyclopedia of Brass Instruments*, ed. Trevor Herbert, Arnold Myers and John Wallace (Cambridge and New York: Cambridge University Press, 2019), 401–402, here 402.
45 Keyser, "The keyed ophicleide," 74.
46 Heyde commented that "it is correct to say that the scale of the euphonium is based on Uhlmann's ophicleide and that the traditional bombardon dimensions were strongly influenced by the valved ophicleide […] however, it is incorrect to see Uhlmann's instrument as in any way the progenitor of the euphonium and bombardon", an hypothesis worthy of further organological and musical study (Heyde, *Das Ventil-Blasinstrument*, 225).
47 Arnold Myers, Joël Gilbert, and Murray Campbell, "Spectral enrichment prediction as an approach to the comparison of brass instrument designs," paper presentation at *ViennaTalk2020: Fourth Vienna Talk on Music Acoustics*, Universität für Musik und darstellende Kunst Wien, 11–14 September 2022.
48 See, for example, Friedrich von Flotow, *Martha, oder Der Markt zu Richmond* (Leipzig: Breitkopf und Härtel, n.d. [ca. 1940]).
49 Meucci, "The Cimbasso and Related Instruments," 149.
50 Illustrated in ibid., 175.
51 Heyde, *Das Ventil-Blasinstrument*, 227.
52 Julius Rühlmann, "Ueber Messinginstrumente mit Ventilen," *Neue Zeitschrift für Musik* 35, no. 1 (04 July 1851): 9–11, here 10–11.
53 See his *Polka francaise* (Helikon) or *Polka Tremblante* (Tuba). To this day, composers often leave their terminology vague enough to allow their lowest brass parts to be performed on whichever instruments happen to be present.
54 Friedrich Zamminer, *Die Musik und die musikalischen Instrumente in ihrer Beziehung zu den Gesetzen der Akustik* (Gießen: Ricker, 1855), 310.