A Beam Compass by Christoph Trechsler the Elder and the Origin of the Micrometer Screw

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From the time of its founding in 1560 by the Elector of Saxony, Augustus I (1526–86), the Dresden Kunstkammer's collections were heavily oriented toward the scientific and technological interests of this remarkable prince. By the end of his reign, the Kunstkammer contained what has been described as the most "comprehensive collection of technical tools and scientific instruments in the world."[1] This technological bent continued during the reigns of Augustus's immediate successors—Christian I (1560–91), Christian II (1583–1611), and Johann Georg I (1585–1659). The Kunstkammer served as a repository for a great variety of instruments ranging from surveyors' quadrants, hodometers, and compasses to mathematical instruments, gunners' levels, terrestrial and celestial globes, and the most elaborate of astronomical clocks.[2] It also employed mathematicians and instrument makers who contributed to the scientific and technical development of Saxony.[3]

This prosperous central European state had, in fact, protracted experience with the technologies of both mining and metallurgy. Silver mines were opened in the Saxon Erzgebirge during the twelfth century, and this was followed by the discovery and exploitation of rich deposits of iron, copper, and tin. Saxon preeminence in mining and metallurgy is reflected in Georgius Agricola's *De Re Metallica*, a classic treatise that was first published in Basel in 1556 and afterward reprinted in numerous editions in three languages. Agricola's account of the methods used in his native Saxony in the first half of the sixteenth century was, in fact, the standard work on the subject for nearly two hundred years.[4] The local production of high-quality metals for Dresden's armorers, toolmakers, and instrument makers expanded considerably with the opening of Saxon coal mines in the latter half of the sixteenth century.

Among the highly skilled craftsmen who flourished in Dresden—because of the convergence of a plentiful supply of high-quality materials, a strong scientific and technical tradition, and the enlightened patronage of a succession of rulers—was Christoph Trechsler the Elder, who produced some of the most beautiful and most precise instruments of his time. Trechsler, born in 1546,[5] was the son of Lorenz Trechsler, a Dresden gunsmith. He married in 1571, and his earliest signed and dated instruments were made in the following year. By the end of the century he was employed by the Kunstkammer as a geometrician (*Geometrischer Arbeiter*) as well as by the Dresden Armory (*Zeughaus*), where he was one of the participants in the building of an early version of the machine gun in 1595. From 1602 until 1605 he was administrator of the gun collection belonging to the Kunstkammer, and from 1605 until his death in 1624 he held the title of Mathematical Instrument Maker (*Mechanikus*) to the Kunstkammer.[6]

Trechsler's son Christoph was also an instrument maker. The date of his birth remains uncertain, but instruments made by his father were signed with the initials C.T.D.E.M. (Christoph Trechsler der Ältere Mechanicus) in 1611, apparently for the first time, and presumably to distinguish the work of the father from that of his son.[7] There are few instruments by the son, but a comparatively large number signed with the father's initials still exist, even after the destruction of Dresden in 1945. Among the survivors is a traveling set of instruments for drafting, measur-

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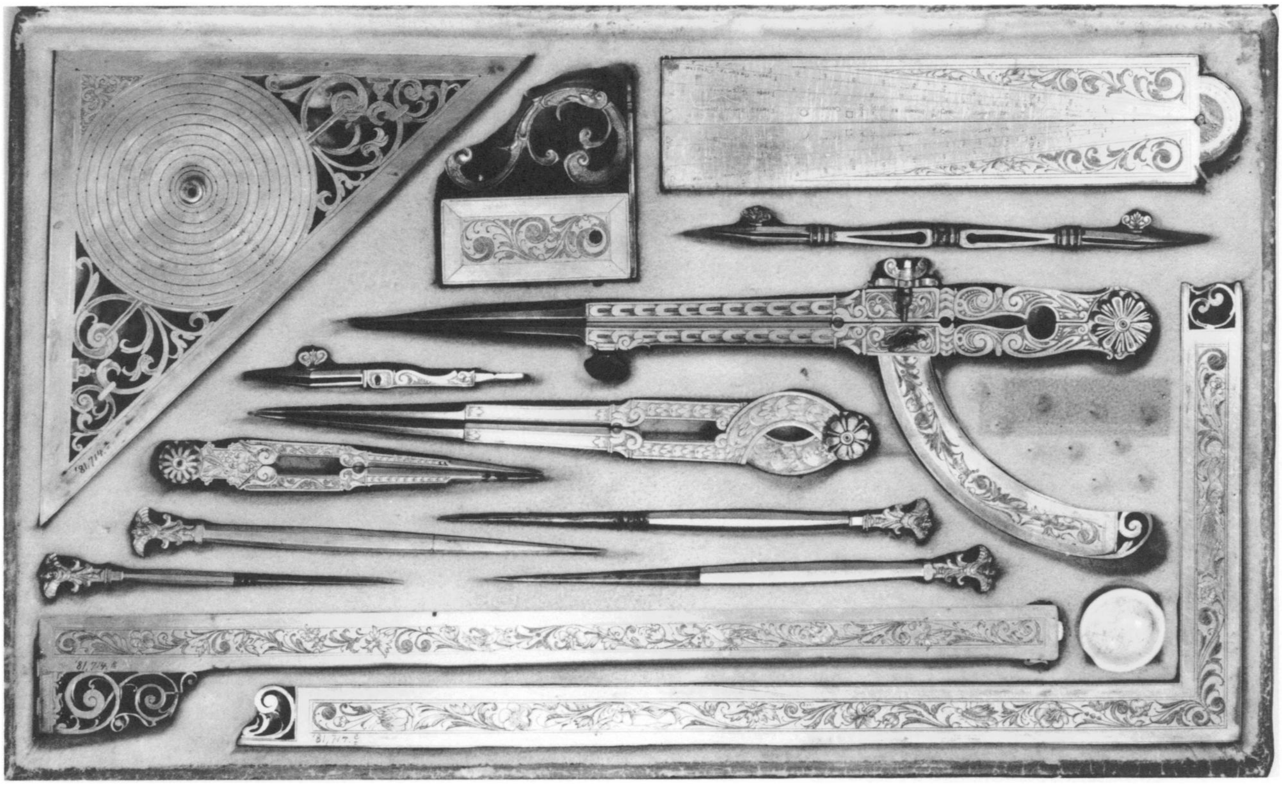
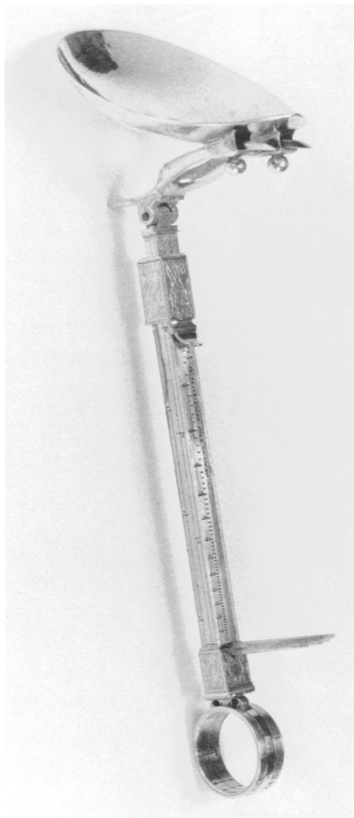


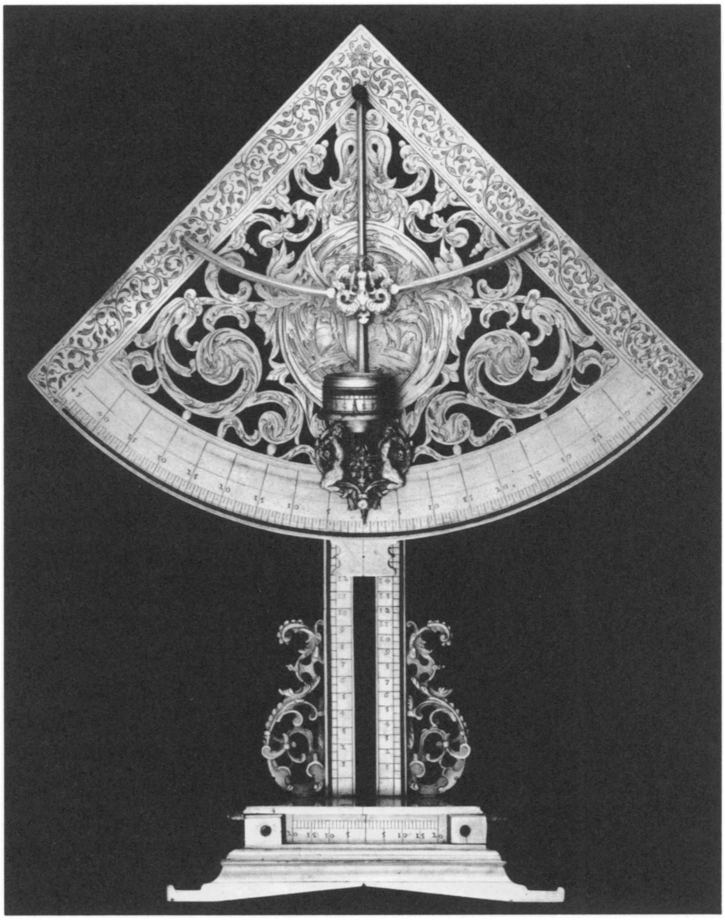
1. Set of mathematical instruments signed by Christoph Trechsler the Elder and dated 1619, German (Dresden). Gilded brass and steel. Berlin, Kunstgewerbemuseum, Staatliche Museen Preussischer Kulturbesitz, inv. no. 81,714 (photo: Kunstgewerbemuseum)

2. Combination spoon, fork, and sundial signed by Christoph Trechsler the Elder and dated 1583, German (Dresden). Silver, L. 7⅝ in. (19.3 cm.). Berlin, Kunstgewerbemuseum, Staatliche Museen Preussischer Kulturbesitz, inv. no. K 9506 (photo: Kunstgewerbemuseum)

ing, and calculating that is now in the Kunstgewerbemuseum in Berlin (Figure 1).[8] Trechsler also made sundials of various sorts, including a whimsical "astronomical spoon" (Figure 2), also in Berlin, which is really a combined spoon and fork with a handle in the form of a calibrated scale and with a retractable gnomon that serves as a vertical sundial. Attached to the top of the handle is another sundial, a tiny local ring dial usable for 51° north,[9] the latitude of sixteenth-century Dresden.

Gunners' levels are the most numerous of the instruments that still exist, and Trechsler made a large variety of them in gilded brass. They were often splendidly decorated with pierced scrollwork and engravings of martial scenes, military trophies, or with the owner's coat of arms. Instruments in the collection of the Adler Planetarium in Chicago (Figure 3)[10] and the Astronomisch-Physikalisches Kabinett of the



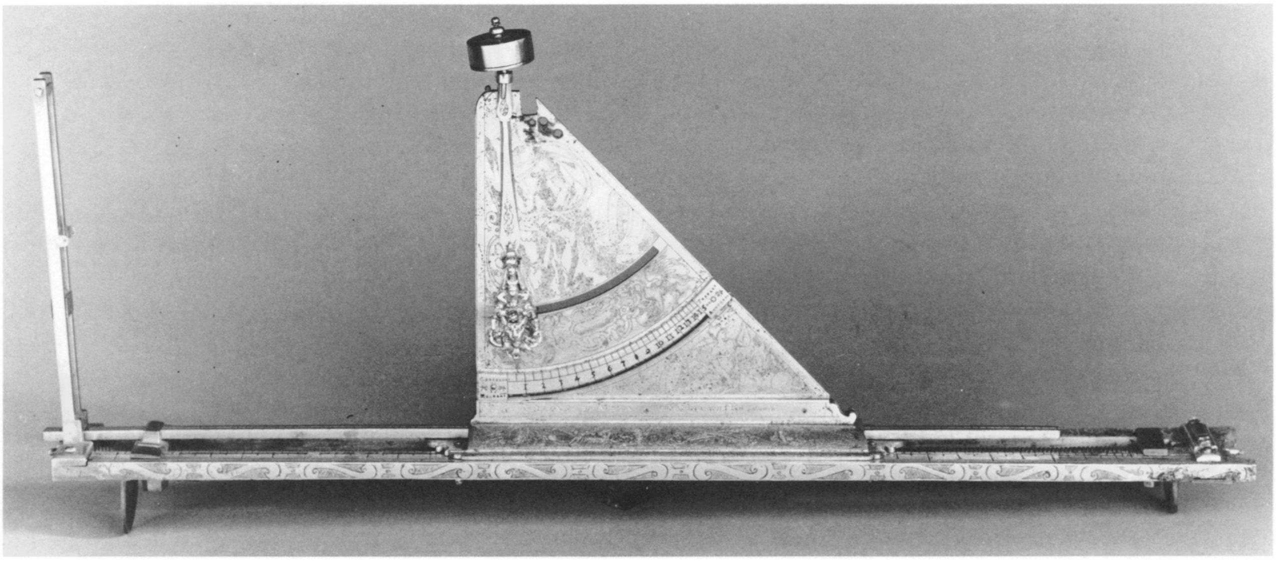


3. Gunner's level signed by Christoph Trechsler the Elder and dated 1609, German (Dresden). Gilded brass, H. 9½ in. (24 cm.). Chicago, The Adler Planetarium, inv. no. M-200 (photo: The Adler Planetarium)

Hessisches Landesmuseum in Kassel (Figure 4)[11] are typical examples of this class.

Among the most impressive instruments in the Staatlicher Mathematisch-Physikalischer Salon in Dresden is the etched and gilded brass hodometer (Figure 5) that could be attached to a wagon or some other moving vehicle.[12] By recording the number of revolutions of a wheel and, thus, the distance traveled, the instrument could register up to twenty Saxon miles, as well as smaller divisions thereof, on three concentric scales that rather closely resemble the chapter rings of clocks. The scroll, mask, and lambrequin ornament and the decorative leaf-shaped hands of the hodometer rival those found on the better clocks of the period.

More remarkable, still, was a universal measuring instrument that Trechsler constructed in 1609 for the mathematician Lucas Brunn (ca. 1575–1624). Brunn was a student in Leipzig from 1598 until 1601 and later studied with the Nuremberg mathematician and instrument maker Johann Praetorius (1537–1616). Brunn's publications include the *Praxis Perspectivae* (Nuremberg, 1615) and a *Euclidis Elementa practica* (Nuremberg, 1625), but he also left manuscripts on mathematics, astronomy, and astrol-



4. Gunner's level signed by Christoph Trechsler the Elder and dated 1599, German (Dresden). Gilded brass, L. 15¾ in. (40 cm.). Kassel, Astronomisch-Physikalisches Kabinett, Hessisches Landesmuseum, inv. no. 1104 (photo: Staatliche Kunstsammlungen Kassel)

5. Hodometer signed by Christoph Trechsler the Elder and dated 1584, German (Dresden). Gilded brass, H. 16½ in. (42 cm.). Dresden, Mathematisch-Physikalischer Salon (photo: Mathematisch-Physikalischer Salon)

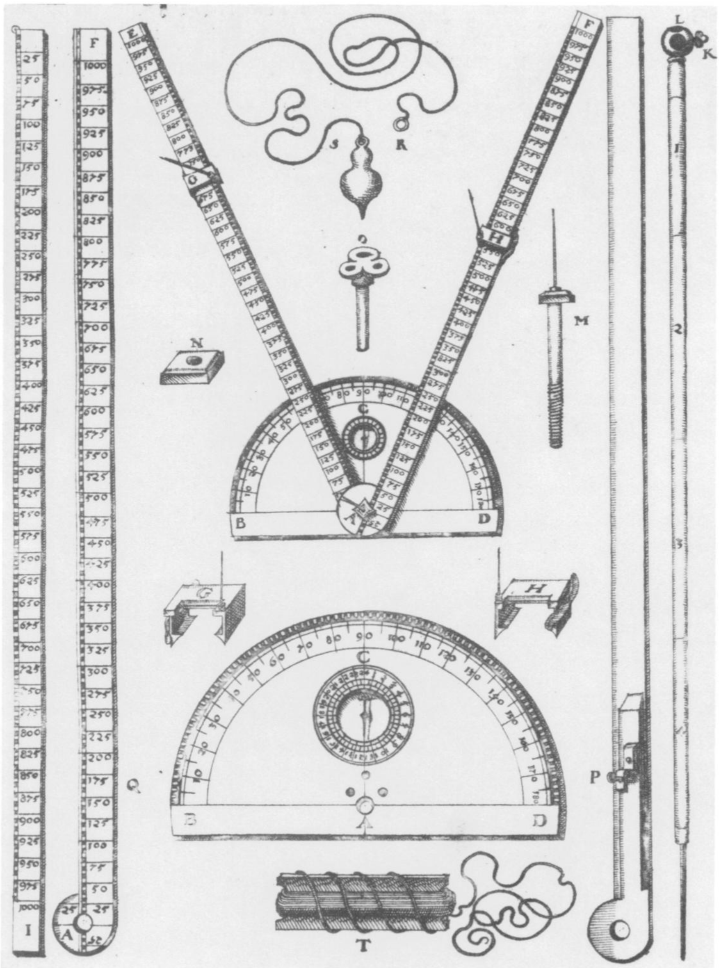
ogy that are to be found in the Sächsische Landesbibliothek in Dresden. Sometime after 1611, he was appointed mathematician to Elector Johann Georg I. Brunn's duties as court mathematician included tutoring the young prince who would become Elector Johann Georg II. In 1619 Brunn obtained an official position in the Dresden Kunstkammer,[13] and in that year he gave his universal measuring instrument to the Kunstkammer.[14]

The instrument entered the collection of the Mathematisch-Physikalischer Salon when the collections of the Kunstkammer were dispersed, and it remained there until 1945, when it was destroyed in the bombing of Dresden. A detailed description of it has been published by Herbert Wunderlich, however, who based his work on prewar photographs and notes made from Brunn's own manuscript description.[15] The instrument consisted of two movable arms that were attached to the midpoint of the diameter of a calibrated semicircle. By manipulating the two arms, it could be made to simulate two sides and an angle of any small, measurable triangle. Using the principle of similar triangles, one could use the measurements of the small triangle to calculate those of a larger triangle of which one or more of the sides was difficult or impossible to measure directly. The instrument could also be used in other ways for problems in land surveying, geometry, and astronomy, hence its title.

As Wunderlich demonstrated, Brunn's universal measuring instrument was very similar to another instrument (Figures 6, 7) invented by the Swiss instrument maker Leonhard Zubler (1563–1609) and described in Zubler's *Novum Instrumentum Geometricum*, first published in Zurich in 1603.[16] Both Zubler's and Brunn's instruments belong to a class that proliferated in the sixteenth and early seventeenth centuries and have been referred to as "universal gadgets." This class was soon to be superseded by a variety of specialized instruments that were much more closely adapted to the special needs of each field of scientific investigation.[17] Brunn's instrument was an improvement on Zubler's in that it was capable of much more precise measurements. In the inventory of the Dresden Kunstkammer made in 1620, a ruler was listed with Brunn's instrument, but it, too, was destroyed during World War II. Surviving photographs of details of the ruler (Figure 8) show it to have had calibrated scales with diagonal lines, or transversals, as they are called, to facilitate reading the fine divisions of the units of measurement. Its most remarkable feature, however, was the slide, which could be moved along the surface of the scale on one side of the ruler and was capable of subdividing each of the basic units of the scale into sixty parts. In addition, the slide was fitted with a micrometer screw that was—in theory, at least—capable of further subdividing each sixtieth part of the basic units by another sixty. A second micrometer screw on the other side made further subdivisions of one hundred parts.

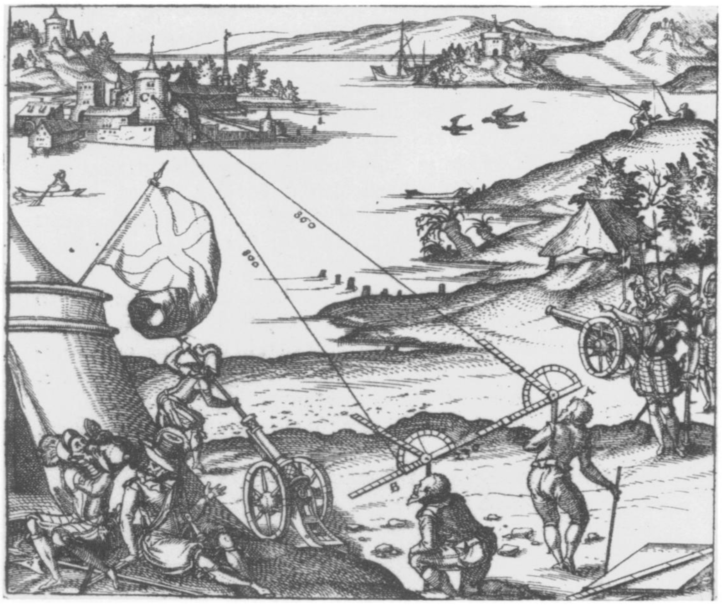
The ruler was signed with the initials of Christoph Trechsler the Elder and dated 1609 and with the initials of Christoph Trechsler the Younger and the date 1619. Because Brunn is known to have used the

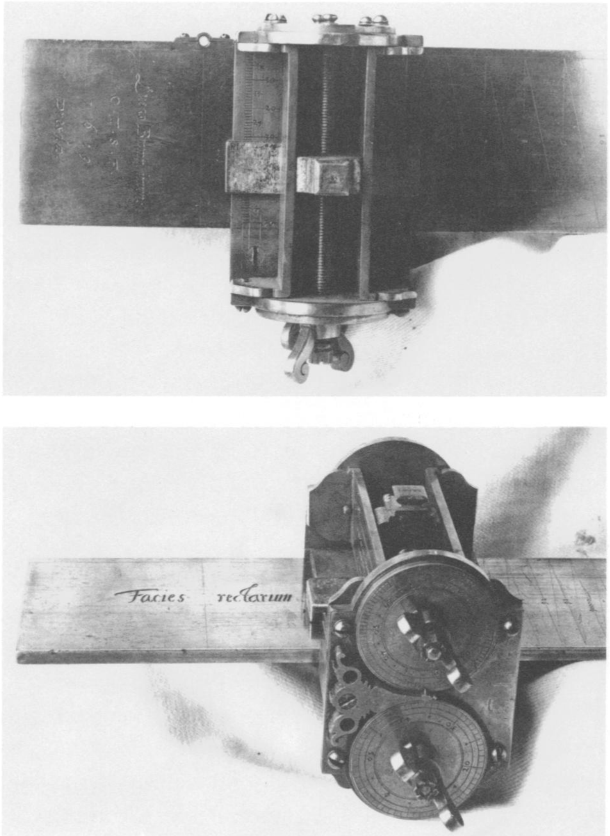
1609 instrument for taking geodetic measurements, Max Engelmann, who described Brunn's instrument in 1927, raised the question of whether the micrometer screws had not been added as the result of Brunn's practical experience with the instrument.[18] Whether they were part of the equipment originally made for use with the instrument in 1609 or additions to it made in 1619, these two devices have been cited as the earliest known examples of micrometer screws.[19]



6. The construction of Leonhard Zubler's "New Geometrical Instrument," *Novum Instrumentum Geometricum* (Basel, 1607) pl. 5 (photo: The New York Public Library, Science and Technology Division)

7. The use of Leonhard Zubler's instrument for military purposes, *Novum Instrumentum Geometricum* (Basel, 1607) pl. 9 (photo: The New York Public Library, Science and Technology Division)





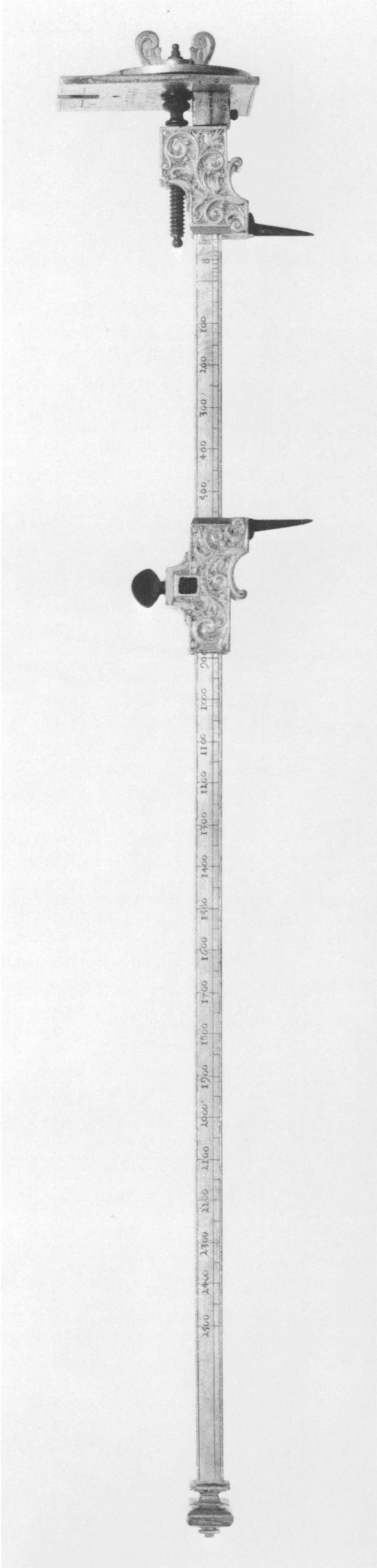
8. Details of the ruler made by Christoph Trechsler the Elder and Christoph Trechsler the Younger showing the slide with micrometer screw adjustments. The side pictured at the top was signed: Lucas Brunn inven./C.T.S.F./1619/Dresdae, but there was another inscription on the instrument, which has been recorded as: M.LUCAS.BRUNN.ANNAEB.INVENT. .C.T.M.F.D.1609..SOLI.DEO.GLORIA, German (Dresden), 1609 and 1619 (photo: Dresden, Mathematisch-Physikalischer Salon)

Although it was not discussed by Engelmann, a second question arises: Were the threaded micrometer screws the work of the elder instrument maker or were they added by his son? In all probability, the answer lies in the existence of two more instruments signed by Christoph Trechsler the Elder. Both are beam compasses with micrometer screw adjustments—one is in the collection of The Metropolitan Museum of Art (Figures 9, 10) and the other is in the Nationalmuseet in Copenhagen (Figure 11).[20] Both instruments are somewhat less than a foot in length, and they are similar in construction. A square-sectioned beam, or bar, made of gilded brass is fitted with cursors with sharp steel points that are adjusted by means of steel screws. The screw on the right side of the beam has a long, finely threaded shaft that passes through a rectangular plate with a slot at the top and is attached to a wing nut and a gilt-brass disk, which is engraved with a circular scale divided into one hundred parts. The screw can be turned by means of the wing nut, and it moves the right-hand cursor through one unit of the scale on the beam that is subdivided into ten portions (Figure 12). The disk on the end of the beam registers further subdivisions of the same unit of the scale, thus allowing the division of each turn of the screw and consequently each tenth of the basic unit of the scale into one hundred parts (Figure 13). In theory, therefore, the instrument is capable of measuring 1/1000th of a unit of measurement that equals 8 mm.

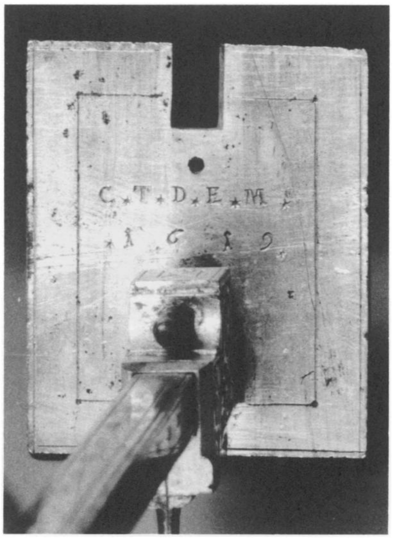
The remaining portions of one side and the top of the beam contain two scales, each divided into the same 8-mm. unit of measurement, but differently numbered. The scale on the side is marked 100 through 2,500 in steps of one hundred and reads from left to right, and the one on the top is marked 1,000 through 25,000 in steps of one thousand.[21] The larger units are read from right to left on the beam, while the ten subdivisions of the basic unit are read from left to right on the beam, and the subdivisions of the tenths are read from the revolving disk.

The primary use of the instrument is for constructing circles, and when the two cursors are set to the length of the radius desired, they can be used to construct very precise circles, or several circles with exactly proportional radii. Conversely, the instrument is capable of making accurate measurements of existing circles.

The basic construction of Trechsler's instrument



9.
Beam compass with a micrometer screw adjustment signed by Christoph Trechsler the Elder and dated 1619, German (Dresden). Gilded brass and steel, L. 11¼ in. (28.6 cm.). The Metropolitan Museum of Art, Bequest of W. Gedney Beatty, 1941, 41.160.721



10.
Detail of Figure 9 showing the initials used by Christoph Trechsler the Elder and the date 1619

11.
Beam compass with a micrometer screw adjustment signed by Christoph Trechsler the Elder and dated 1616, German (Dresden). Gilded brass and steel. Copenhagen, Nationalmuseet, inv. no. D-1507 (photo: Nationalmuseet)

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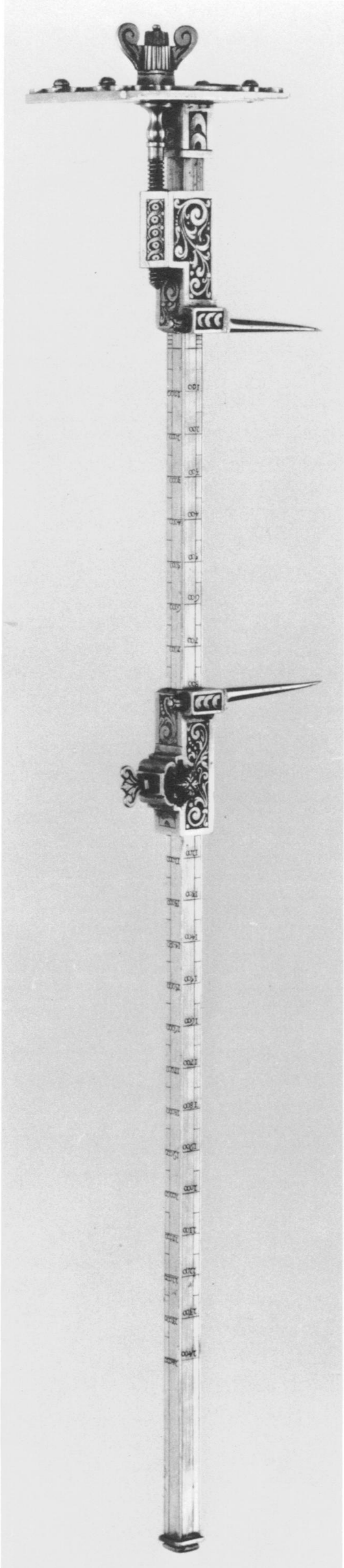
12.
Detail of Figure 9 showing the subdivisions of the basic unit of the measurement scale

13.
Detail of Figure 9 showing the micrometer scale that divides each tenth of the basic unit of the measurement scale into one hundred parts



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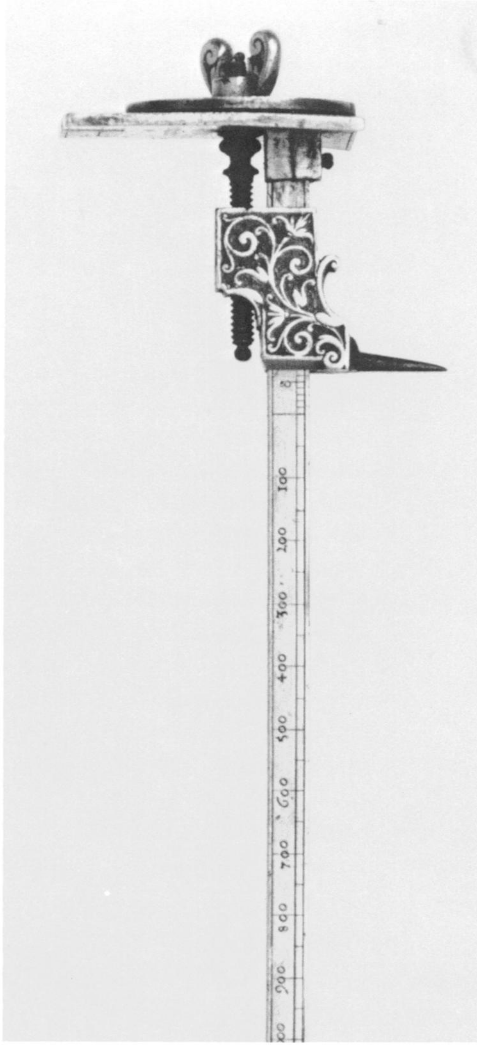

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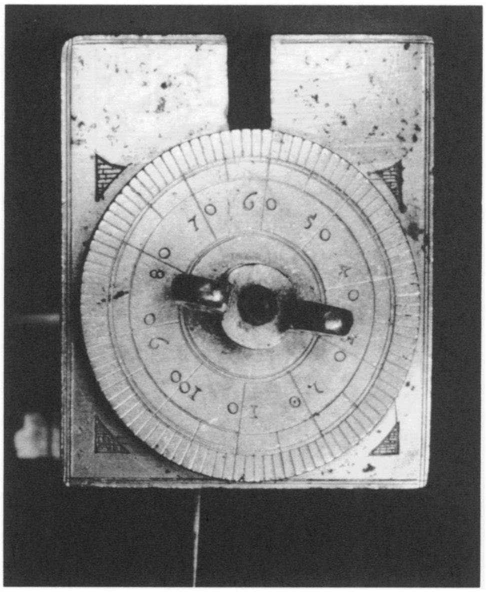

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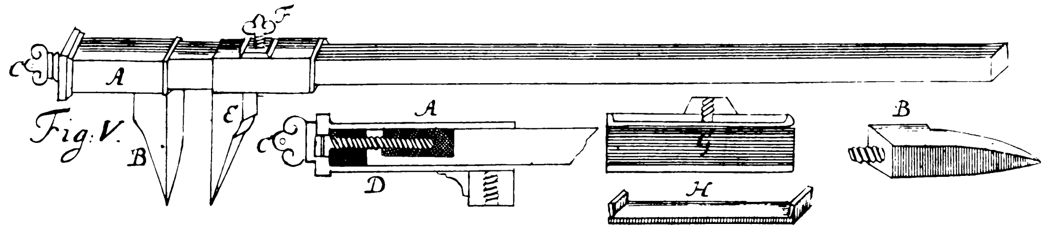
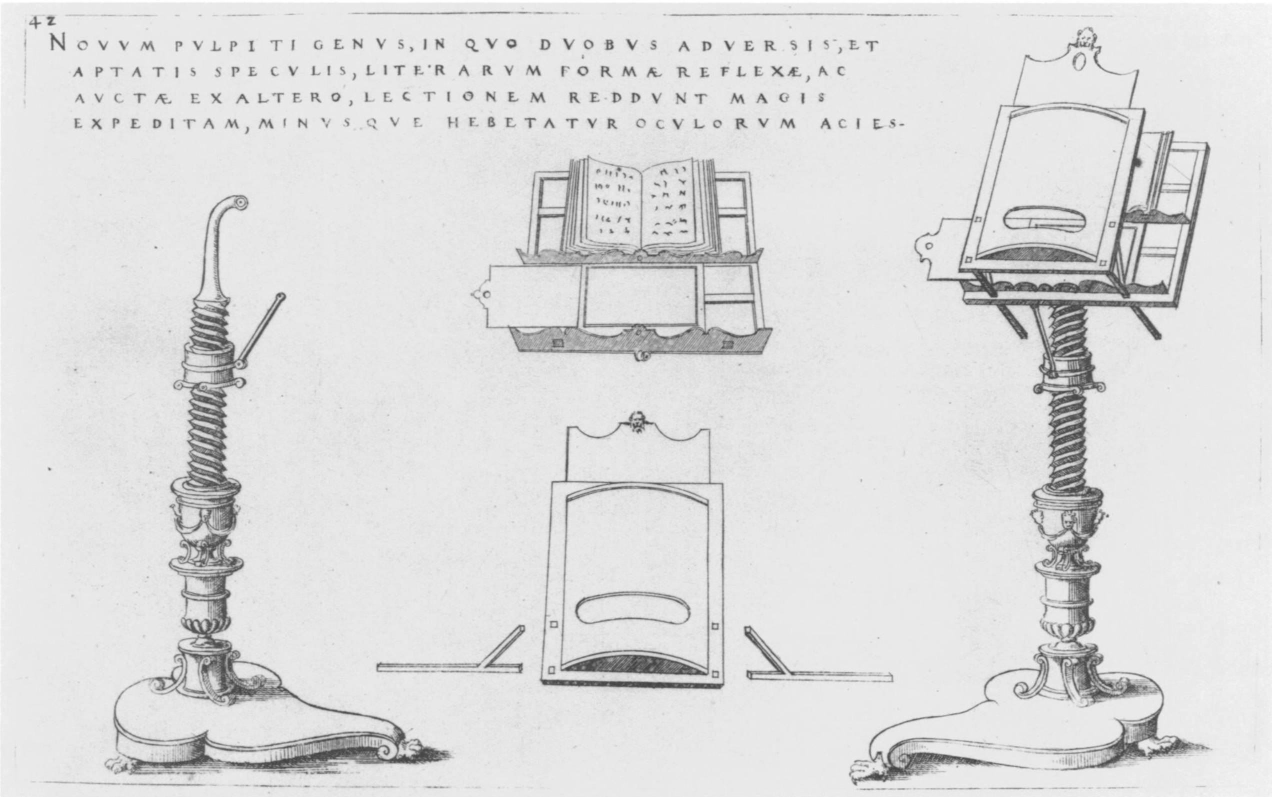


14. Detail of Plate XXB from Jacob Leupold's *Theatrum Arithmetico-Geometricum* (Leipzig, 1727) showing the construction of a beam compass with two screw-adjusted cursors (photo: The New York Public Library, Science and Technology Division)

can be seen more clearly in an illustration from a tome on the construction and use of mathematical instruments published in Leipzig more than one hundred years later by Jacob Leupold (Figure 14).[22] Leupold's beam compass not only lacked the decorative knop at the end of the beam and the luxuriantly scrolled ornament of Trechsler's cursors, but also lacked Trechsler's micrometer screw. The screw marked "c" in Leupold's design is an adjustment screw for the cursor, not a micrometer screw. Trechsler also used similar screw adjustments in many of his instruments, but even in his time they were hardly unique.[23]

The sixteenth century seems to have been a time of exuberant exploration of the possible applications of screws to various kinds of mechanical devices. Leonardo da Vinci's notebooks from the last years of the fifteenth century already contained a number of them, but more important to the widespread use of the screws were publications such as Jacques Besson's *Theatrum instrumentum et Machinarum*, first published

15. Lectern engraved by Jacques Androuet Ducerceau the Elder (ca. 1510–ca. 1584). Plate 42 from Jacques Besson's *Theatrum Instrumentum et Machinarum* (Lyons, 1578). The Metropolitan Museum of Art, Harris Brisbane Dick Fund, 1933, 33.103



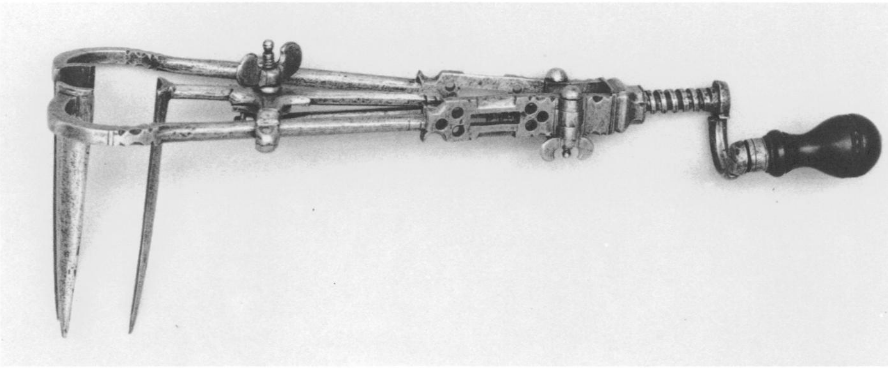
as the *Livre 1er des instruments mathématiques et mécaniques* in 1569, which contained splendid illustrations of applications of screws to various types of machines and devices such as mills, cranes, and presses.[24] An adjustable lectern was included (Figure 15).

Several rather typical examples of sixteenth-century screw devices can be found in the Metropolitan Museum's own collections. The clamp of an armorer's vise,[25] made in Italy and dated 1588 (Figure 16), is adjustable by means of a large screw that besides its functional purpose adds a wonderfully satisfying pattern to the surface of the lower end of its shaft. The maker of a small press (Figure 17), like the maker of the armorer's vise, made a virtue of the ornamental value of its robust screw.[26] Screw adjustments were applied to medical and scientific instruments as well. A gynaecologic speculum (Figure 18) with three blades manipulated by a screw is neither signed nor dated, but it was probably made in South Germany in the late sixteenth or early seventeenth century.[27]

A screw-adjusted gunner's level dated 1567 in the Mathematisch-Physikalischer Salon in Dresden[28] is

16. Armorer's vise signed by Jacopo da Ferrara and dated 1588, Italian. Iron, H. 10 9/16 in. (25.9 cm.). The Metropolitan Museum of Art, Harris Brisbane Dick Fund, 1958, 58.16.5

17. Screw press, probably Italian, second half of the 16th century. Iron, H. 7 3/16 in. (18.3 cm.). The Metropolitan Museum of Art, Rogers Fund, 1961, 61.194



18. Gynaecologic speculum, probably South German, last quarter of the 16th century or early 17th century. Iron, L. 11 7/8 in. (30.1 cm.). The Metropolitan Museum of Art, Gift of William H. Riggs, 1913, 14.25.1769

probably more directly the prototype of Trechsler's instruments. It was made by Christoph Schissler the Elder (1530/32–1609), the best of the instrument makers in sixteenth-century Augsburg. Schissler made a number of instruments for the Elector of Saxony, and Trechsler may perhaps have had first-hand knowledge of this one. Trechsler, himself, was making gunners' levels with screw adjustments only five years later (Figure 19),[29] and the gunner's level now in the Adler Planetarium in Chicago, although fragmentary, is one of his earliest surviving instruments.

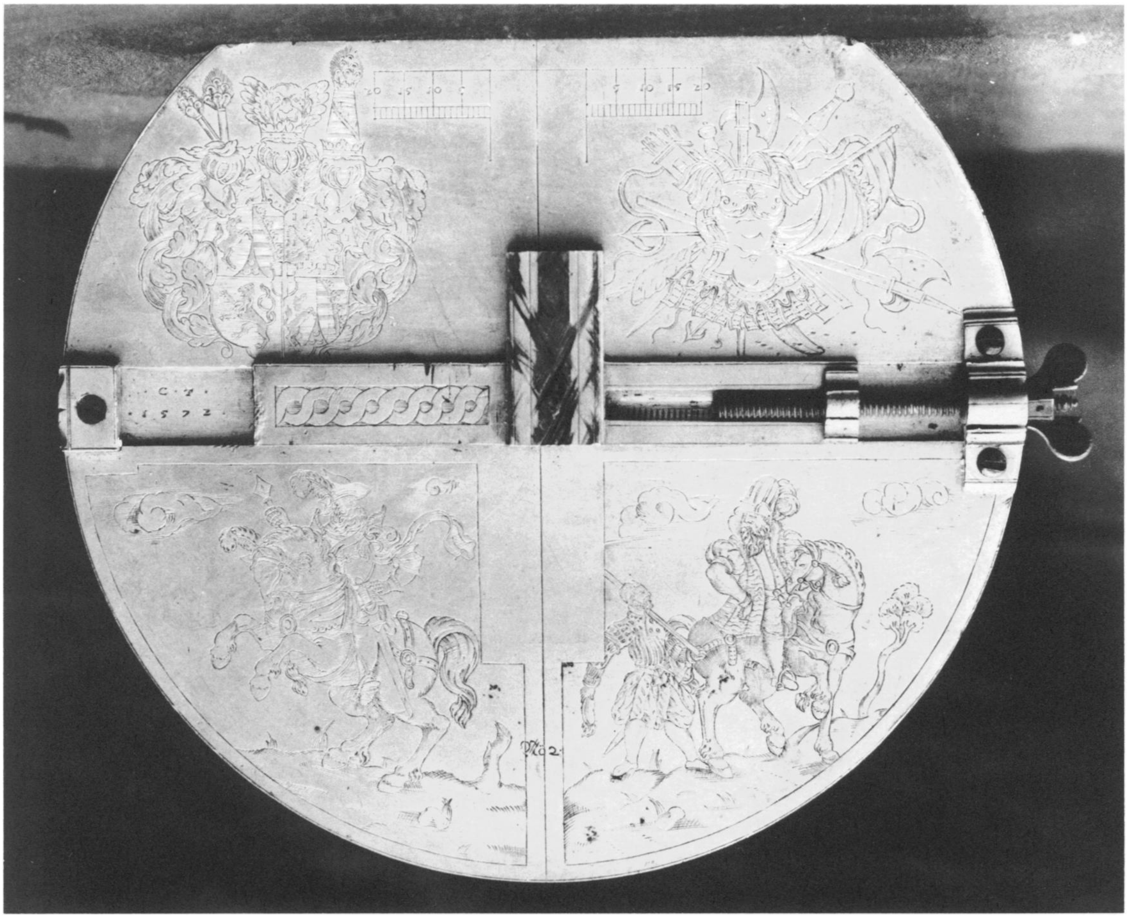
The third great instrument maker of Central Europe in the latter part of the sixteenth century was Erasmus Habermel (active probably about 1576–d. 1606), instrument maker to the Holy Roman Emperor Rudolf II (1552–1612) in Prague. Habermel may also have made screw adjusting instruments.[30]

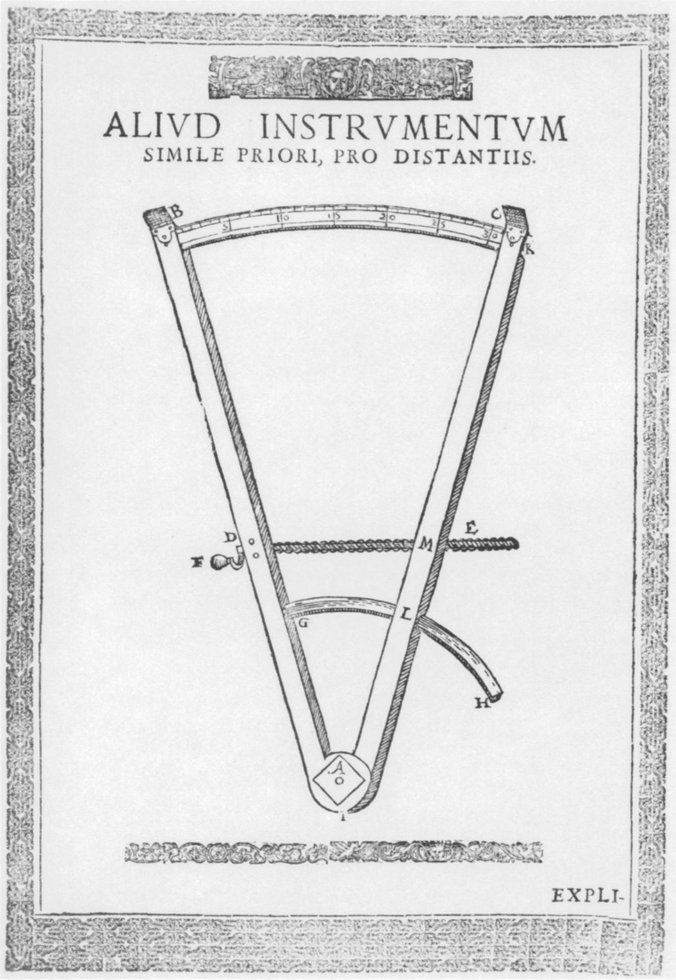
19. Fragment of a gunner's level signed by Christoph Trechsler the Elder and dated 1572, German (Dresden). Gilded brass, Diam. 9 7/16 in. (24 cm.). The arms are those of Emmanuel Philibert of Savoy (d. 1580). The banner with the military trophy bears the arms of Saxony. Chicago, The Adler Planetarium, inv. no. M-194 (photo: The Adler Planetarium)

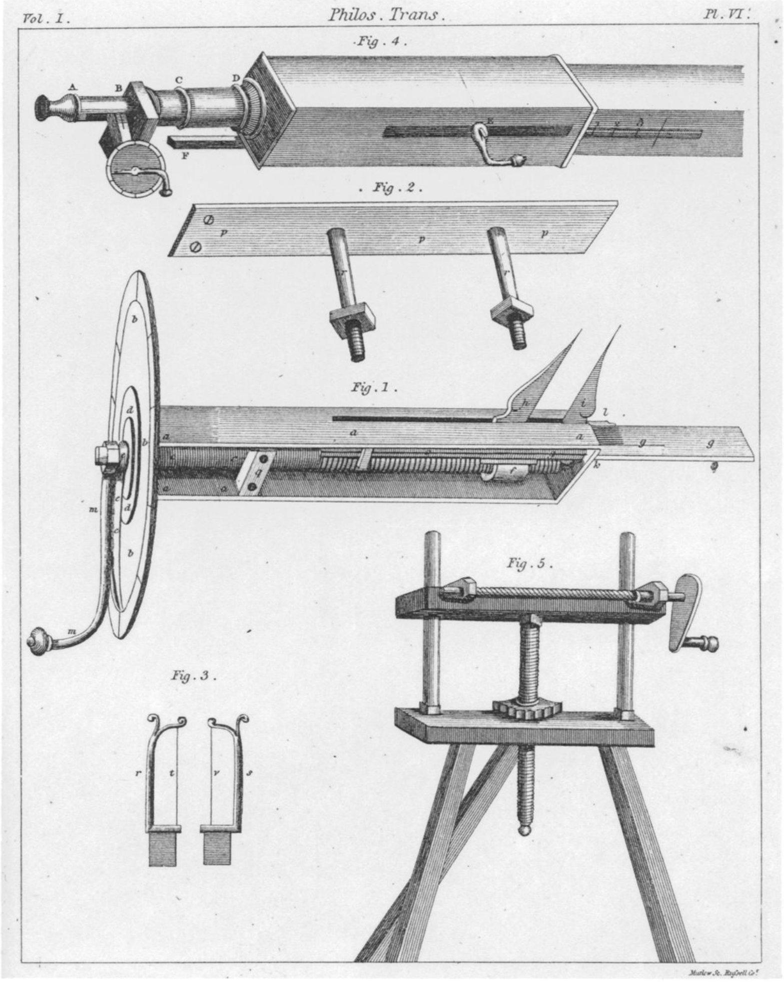
One of the best examples of a Prague instrument with a screw adjustment, however, is by Heinrich Stolle. Stolle learned clockmaking early in the seventeenth century as an assistant to the imperial clockmaker, Jost Bürgi (1552–1632), but he also produced some beautifully precise instruments. The gunner's level by Stolle in the collection of the Uměleckoprůmyslové Muzeum in Prague has a long, finely threaded screw adjustment similar to some of Trechsler's.[31]

The application of the screw adjustment to astronomical instruments would in the long run prove to be the most fruitful one for scientific investigation. Several astronomers' sextants with screw adjustments were among those used by the great Danish astronomer Tycho Brahe (1546–1601) and recorded in Brahe's *Astronomiae Instauratae Mechanica* (Figure 20).[32] These were among the instruments with which Brahe made the innumerable astronomical observations that served as the basis for Johannes Kepler's formulation of the laws of planetary motion, as well as for the planetary tables of the *Tabulae Rudolphinae Astronomicae* (Ulm, 1627). The Kepler tables were not supplanted by more accurate ones for nearly a century.

The sighting devices of Brahe's instruments would







20. Astronomer's sextant with screw adjustment illustrated in Tycho Brahe's *Astronomiae Instauratae Mechanica* (Wandesburg, 1598) n.p. (photo: The New York Public Library, Rare Book Division)

21. Plate VI of *Philosophical Transactions* I, Royal Society (London, 1803), showing William Gascoigne's form of the micrometer screw with improvements by Richard Towneley (fig. 1)

soon be superseded by telescopic sights; and the subsequent application of the micrometer screw to the telescopic sight permitted enormous advances in seventeenth-century observational astronomy. The invention of the micrometer is usually credited to an English astronomer, William Gascoigne (ca. 1612–44), who first applied a micrometer screw adjustment to the sight of a telescope about 1639–40. He evidently used this improvement for measuring the apparent diameters of planets and for measuring angular distances necessary in land surveying. The device was adopted by a small circle of English mathematicians and astronomers—William Oughtred (1574/5–1660) and Richard Towneley (1629–1707) were among the earliest—but other versions were also used by Christopher Wren (1632–1723), an astronomer and mathematician before he turned to architecture, and by Robert Hooke (1635–1703), the experimental philosopher who was curator of experiments for the Royal Society. It was not generally known, however, until about 1667, when a debate broke out about the priority of the invention after an account of a similar device—developed by the French astronomers Adrien Auzout (1622–91) and Jean Picard (1620–82)—was sent to the Royal Society in London.[33] Towneley's comments in the *Philosophical Transactions* of the Royal Society on the Auzout-Picard invention and the Gascoigne model were accompanied by a diagram of Gascoigne's invention (Figure 21)[34] that shows it to have been fairly close in principle to Trechsler's micrometers.

In the history of scientific instruments, Trechsler's micrometer screws must remain precocious and isolated examples. They were apparently unknown to any of the western European contenders claiming priority for the invention, and one can only speculate about why this might have been the case. Perhaps it was because Saxon court patronage in the seventeenth century, like that of the Bavarian court in Munich, turned away from scientific research owing to its rulers' lack of interest.[35] Of central importance, however, must have been the harmful effects of the Thirty Years' War, which broke out in nearby Prague in 1619, the very year that Lucas Brunn gave the Trechslers' universal measuring instrument to the Dresden Kunstkammer. The war proved to be particularly savage and devastating, and it finally succeeded in exhausting all of Germany. One of its evils was the blighting of what had been an inventive and flourishing scientific and technological community.

FREQUENTLY CITED SOURCES

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Wunderlich—Herbert Wunderlich, *Kursächsische Feldmesskunst, artilleristische Richtverfahren und Ballistik im 16. und 17. Jahrhundert* (Berlin, 1979)

Zinner—Ernst Zinner, *Deutsche und Niederländische Astronomische Instrumente des 11. bis 18. Jahrhunderts* (Munich, 1956)

NOTES

1. Joachim Menzhausen, "Five Centuries of Art Collecting in Dresden," *The Splendor of Dresden*, exh. cat., MMA (New York, 1978) p. 19. See also "Elector Augustus's *Kunstkammer*: An Analysis of the Inventory of 1587," *The Origins of Museums: The Cabinet of Curiosities in Sixteenth- and Seventeenth-Century Europe*, Oliver Impey and Arthur MacGregor, eds. (Oxford, 1985) p. 71, in which Menzhausen states that the tools and instruments listed in the inventory of the Kunstkammer made after the death of the elector "numbered 7,353, almost 75 per cent" of the collection. The large collections of instruments and scientific apparatus assembled elsewhere in Europe were to be made in the 17th and 18th centuries. For a summary discussion of these, see Gerard l'E. Turner, "The Cabinet of Experimental Philosophy" in Impey and MacGregor, pp. 214–222.

2. For some examples of the surviving instruments from Augustus's Kunstkammer, see Helmut Grötzsch and Jürgen Karpinski, *Dresden: Mathematisch-Physikalischer Salon* (Leipzig, 1978) pp. 11–12, 15–16, 20, 123, 126–127, and figs. 42–48, 113–115, and 137–139; see also Joachim Menzhausen, *Dresdener Kunstkammer und Grünes Gewölbe* (Leipzig, 1977) pp. 79–100, for other instruments and clocks that were in the late-16th- and early-17th-century collections of the Dresden Kunstkammer.

3. Wunderlich, pp. 198, 208.

4. Herbert Clark Hoover and Lou Henry Hoover, *Georgius Agricola, De Re Metallica, Translated from the First Latin Edition of 1556*, new ed. (New York, 1950) p. iv.

5. The date is usually given as about 1550, but it can be determined through an inscription on a gunner's level in the collection of the Observatoire at Paris: Inventor C.T.D.E.M. aetatis suae 68 (Made by Christoph Trechsler the Elder, Mechanic, aged 68 years); the level is dated 1614. See Henri Michel, *Scientific Instruments in Art and History*, R. E. W. Maddison and Francis R. Maddison, trans. (New York, 1967) p. 87, no. 23, fig. 23.

6. See Zinner, pp. 547–551, and Wunderlich, p. 198.

7. The majority of Trechsler's instruments are signed with initials, usually C.T. (Christoph Trechsler) or C.T.F. (Christoph Trechsler Fecit) in the years between 1572 and 1589. After 1595 various combinations appear, including C.T.D. (Christoph Trechsler Dresden), C.T.M.F. (Christoph Trechsler Mechanicus Fecit), C.T.M. (Christoph Trechsler Mechanicus), and C.T.M.D. (Christoph Trechsler Mechanicus Dresden). The younger Trechsler signed at least one of his instruments with the initials C.T.S.F. (Christoph Trechsler Sohn Fecit). C.T.S.M.F. (Christoph Trechsler Sohn Mechanicus Fecit) and C.T.S.M. (Christoph Trechsler Sohn Mechanicus) are other initials used by the younger instrument maker.

8. Inv. no. 81,714. The sector from this set is signed C.T.D.E.M., 1619. See Franz Adrian Dreier, *Winkelmessinstrumente vom 16. bis zum früher 19. Jahrhundert* (Berlin, 1979) pp. 110–111, no. 24; p. 110, fig. 24; and p. 111, fig. 24. Another set by Christoph Trechsler the Elder and Viktor Stark, dated 1622, was in the collection of the Mathematisch-Physikalischer Salon in Dresden until 1945. A photograph of the set appears in Wunderlich, p. 169.

9. Inv. no. K 9506. Signed and dated: C.T.. 1583. See Zinner, p. 548, and Klaus Pechstein, *Goldschmiedewerke der Renaissance* (Berlin, 1971) no. 28.

10. Inv. no. M–200. Signed and dated: C.T.M.D. 1609. See Max Engelmann, *Collection Ant. W. M. Mensing, Amsterdam: Old Scientific Instruments (1479–1800)* (Amsterdam, 1924) p. 30, no. 20, pl. I, and Zinner, p. 549.

11. Gen.-Inv. no. 1104. Signed and dated: Christof Treschler Mechani Anno 1599. Made for Johann Sigismund von Hohenzollern, later Elector of Brandenburg (r. 1608–19). See Zinner, p. 549, and Michel, *Scientific Instruments*, p. 87, no. 22, fig. 22.

12. Signed and dated: C. T. 1584. See Alfred Rohde, *Die Geschichte der Wissenschaftlichen Instrumente vom Beginn der Renaissance bis zum Ausgang des 18. Jahrhunderts* (Leipzig, 1923) p. 62 and p. 61, fig. 82; Wunderlich, pp. 60–62, fig. 16; and Grötzsch and Karpinski, *Dresden Salon*, pp. 126, 131, nos. 137–139, figs. 137–139.

13. Wunderlich, pp. 20–21, 130–131, 208–209; and Zinner, pp. 266–267.

14. Wunderlich, p. 135. The inventory of the Kunstkammer has the notation: "einkommen . . . Proportional Instrument—dies ist das Universal-Instrument—mit regula trigonometria." under the date May 13, 1620.

15. Wunderlich, pp. 130–143, figs. 44, 45. For a prewar description of the instrument, presumably made from first-hand observation, see Max Engelmann, "Schraubenmikrometer-Erstlinge," *Archiv für Geschichte der Mathematik, der Naturwissenschaften und der Technik*, 10, n.f. I (1927–28) pp. 295–297.

16. The 1607 edition published in Zurich illustrates its uses not only for gunners, but also for land surveying, for measuring heights of distant objects and depths of wells, etc.

17. J. A. Bennett, *The Divided Circle: A History of Instruments for Astronomy, Navigation, and Surveying* (Oxford, 1987) pp. 44–46.

18. Engelmann, "Schraubenmikrometer," p. 297.

19. See ibid., p. 295; Treue, pp. 112–114; and Zinner, p. 266.

20. MMA, acc. no. 41.160.721, and Nationalmuseet, inv. no. D–1507. The example in the Nationalmuseet is signed C.T.D.E.M. and dated 1616. Neither instrument was known to Zinner, but he did list (p. 551) two similar instruments that are unsigned and dated; they are in the collections of the Skokloster Schloss in Sweden and the Stuttgart Landesmuseum. The Metropolitan Museum's beam compass is listed in *The Triumph of Humanism: A Visual Survey of the Decorative Arts of the Renaissance*, exh. cat., Fine Arts Museum of San Francisco (1977) p. 88, cat. no. 157.

21. The unit of measurement is not a subdivision of the Saxon foot (28.3 cm.), which was variously divided into twelve parts (*Zolls*) and sixteen parts (*Fingers*), nor does it apparently correspond to units known to have been used in neighboring territories. It may have been an arbitrary choice, as the difference between the scale on the side of the beam and the one on the top seems to indicate that the use of the instrument is mainly for proportional measuring. The two sharp ends of the cursors can be placed on an ordinary ruler so that measurements in locally used units may also be obtained.

22. Jacob Leupold, *Theatrum Arithmetico-Geometricum, Das ist Schau-Platz der Rechen- und Mess Kunst* (Leipzig, 1727) pp. 130–131, pl. xx, fig. v. Leupold describes the inventions of a number of 17th-century instrument makers, but does not discuss the origin of the beam compass. A form of beam compass appears in one of the late-15th-century notebooks of Leonardo da Vinci (Paris, Bibliothèque de l'Institut de France, Manuscript B, 2173, fols. 57v and 58v). See Charles Ravaisson-Mollien, *Les Manuscrits de Léonard de Vinci: Les Manuscrits B&D de la Bibliothèque de l'Institut* (Paris, 1883) pp. 56–57, or Reale Commissione Vinciana, *Il Manoscritti e i disegni de Leonardo da Vinci* V (Rome, 1941) fols. 111v, 112r, 113v, and 114r. An engraving of a beam compass with two cursors, one of them adjustable by means of a screw at the top, appears on fol. 14r of the book titled "Della Specchio che Accende il Fuoco ad una Data Lontanza," included in Oronce Fine's *Opera* (Venice, 1587).

23. See Treue, pp. 31–34, 67–81; Leonardo da Vinci, *Facsimile Edition of Codex Madrid I, Original Spanish Title: Tratado de Estatica y Mechanica en Italiano, Library Number 8937* I (New York, 1974) fols. 4v, 14v–15r, 17v, 18r, 18v, 19r, 23v, 25r, 33v, 34r, 35r, 36r, 58r, 70r, and 86v; and Ladislao Reti, "Elements of Machines" in *The Unknown Leonardo* (New York/Toronto, 1974) pp. 275–280.

24. See Henry de Geymüller, *Les Du Cerceau, Leur Vie et leur Oeuvre* (Paris/London, 1887) p. 322; and Treue, pp. 81–90. Besson's book was translated into Latin, Italian, and Spanish. A German edition appeared in 1595, and as late as 1626 an edition in French was printed in Geneva.

25. Acc. no. 55.16.5. See Clare Vincent, "Precious Objects in Iron: Two Collections of European Smithing," *MMAB* 22 (April 1964) pp. 277, 280, fig. 10, and Fine Arts Museums of San Francisco, *Humanism*, p. 87, no. 128, fig. 80.

26. Acc. no. 61.194.

27. Acc. no. 14.25.1769. Formerly in the collection of the Musée Carnavalet in Paris. For a medical instrument with somewhat similar decorative treatment of the metal, see a brass and steel bullet extractor in the Germanisches Nationalmuseum in Nuremberg, illustrated by Elizabeth Bennion, *Antique Medical Instruments* (London, 1979) p. 156. See also Treue, p. 110.

28. See Maximilian Bobinger, *Christoph Schissler der Ältere und der Jüngere* (Augsburg/Basel, 1954) pp. 73, 135, fig. 21.

29. Chicago. Adler Planetarium, inv. no. M–194. Signed and dated: C. T. 1572. The arms are those of Savoy. See Engelmann, *Mensing*, p. 29, no. 194, pl. I; and Zinner, p. 548.

30. The late Wolfgang Eckhard once said that Habermel made instruments with similar screw adjustments, but I have been unable to locate an example of one. In any case, both Schissler and Trechsler were making gunners' levels with screw adjustments a decade before the earliest verified instrument by Habermel. For Habermel's early instruments see Wolfgang Eckhard, "Erasmus Habermel—Zur Biographie des Instrumentenmachers Kaiser Rudolfs II.," *Jahrbuch der Hamburger Kunstsammlungen* 21 (1976) pp. 59–60, and "Erasmus und Josua Habermel: Kunstgeschichtliche Anmerkungen zu den Werken der Beiden Instrumentmacher," *Jahrbuch der Hamburger Kunstsammlungen* 22 (1977) p. 23.

31. Inv. no. 6762. Signed Henricus Stolle Uhrm. prag (Heinrich Stolle Clockmaker Prague). See Jiří Lenfeld, "Sluneční Hodiny ze sbírek UPM v Praze," *Acta Uměleckoprůmyslové Muzeum v Praze* 16, D. Supplementa 4 (1984) p. 151, no. 44, pp. 152–153, figs. 44a, 44b.

32. Published by the author in Wandesburg in 1598, n.p. See also Det Kongelige Danske Videnskabernes Selskab, *Tycho Brahe's Description of His Instruments and Scientific Work as Given in Astronomiae Instauratae Mechanica (Wandesburgi, 1598)*, Hans Raeder, Elis Strömgren, and Bengt Strömgren, trans. and eds. (Copenhagen, 1946) pp. 80–83.

33. See A. Wolf, *A History of Science, Technology, and Philosophy in the 16th and 17th Centuries* (London, 1935) pp. 168–174. The debate is also summarized by Bennett, *Divided Circle*, pp. 63–65, and by Anthony Turner, *Early Scientific Instruments, Europe 1400–1800* (London, 1987) pp. 132–133. The Dutch mathematician Christiaan Huygens (1629–95) independently invented a form of micrometer, which he published in 1559. The essay on micrometers in Denis Diderot and Jean le Rond d'Alembert's *Encyclopédie* 10 (Paris, 1751) p. 488, credited Huygens with the first continental European application of the principle.

34. Richard Towneley, "On Mr. Gascoigne's Micrometer," *Philosophical Transactions* 2, Anno 1667 (London, 1803) p. 161.

35. See Lorenz Seelig, "The Munich Kunstkammer, 1568–1807" in Impey and MacGregor, p. 88.