income distribution, have none. The stagnation of wages has, to an extent, obscured these differences. But should wages begin to grow again, there is a danger that significant numbers of families will be left behind and inequality will correspondingly increase. Finding ways to better integrate these families into the mainstream economy will be a major priority of the period ahead.

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1. See, for example, R. Kuttner, "The declining middle" [*Atlantic Monthly* (no. 252) (July 1983), p. 60] and L. C. Thurow, "The disappearance of the middle class" (*New York Times*, 5 February 1984, sect. 3, p. 2).
2. Some authors have attributed this growing variance to the shift of men to service sector jobs as distinct from jobs in goods production (manufacturing, mining, and construction). The attribution is not correct. Among all male workers (16 years and older), the service sector has relatively large earnings inequality because of the large number of part-time workers in retail sales. But among men who work full time, earnings inequality in the service sector and in the goods-producing sector is relatively equal. Since 1979, earnings inequality in both sectors has increased significantly (*3*).
3. F. Levy, *Dollars and Dreams: The Changing American Income Distribution* (Russell Sage–Basic Books, New York, 1987), chap. 5.
4. On the concept of permanent income, see M. Friedman, *A Theory of the Consumption Function* (Princeton Univ. Press, Princeton, NJ, 1957).
5. For a discussion, see Levy (*3*, chap. 9).
6. At the same time, the growing number of people who live alone are not counted in the family income distribution but in a second distribution confined to unrelated individuals. Immediately after World War II, unrelated individuals contained disproportionate numbers of the elderly and the disabled. Since that time, a rising divorce rate and a post-1970 rise in the median age at first marriage have resulted in a growing number of prime-age individuals who also live as unrelated individuals.
7. National Conference of Catholic Bishops, Ad Hoc Committee on Catholic Social Teaching and the U.S. Economy, "First draft of pastoral letter on Catholic social teaching and the U.S. economy," *National Catholic Reporter*, 23 November 1984, pp. 9–31.
8. Young workers had the additional burden of belonging to the baby-boom cohorts who would have had slower-than-average wage growth because of their large numbers. Before 1973, a young man passing from age 25 to 35 could expect real income increase of about 110 percent. Young men who were 25 in 1973 saw their income during the next 10 years increase by 16 percent (*3*, chap. 7).
9. For summaries of productivity issues, see M. N. Baily, *Science* **234**, 443 (1986); E. F. Denison, *Trends in American Economic Growth, 1929–1982* (Brookings Institution, Washington, DC, 1985).
10. See Denison (*9*, chap. 3).
11. For example, high post-OPEC rates of inflation forced most Western governments to run their economies at rates well below full employment, and this further limited market growth.
12. Between 1970 and 1984 the median age of first marriage rose from 23.2 to 25.4 for men and 20.8 to 23.0 for women so that they were now as high as they had been in the early 1900s [Bureau of the Census, *Current Population Reports* (Series P-20, no. 399, Washington, DC, 1986).
13. Bureau of the Census, *Current Population Reports* (Series P-60, no. 97, Washington, DC, 1975), table 53; *ibid.*, no. 151 (1986), table 32.
14. See Bureau of the Census, *Current Population Reports* (Series P-60, no. 151, Washington, DC, 1986), table 16. The median income figure for black families headed by a woman under 65 years of age is the author's estimate based on data in this reference. The income figures for black husband wife families and all families nationwide are taken directly from this reference.
15. For a discussion, see Levy (*3*, chap. 8).
16. The data for Tables 1 and 2 come from the Bureau of the Census [*Current Population Reports* (Series P-60, Washington, DC, 1986), table 12].
17. The data for Table 3 come from the Bureau of the Census [*Current Population Reports* (Series P-60, no. 7, Washington, DC, 1951), table 17; *ibid.*, no. 35 (1961), table 23; *ibid.*, no. 75 (1970), table 45; and tables referenced in (*13*)]. In constructing Table 3, "income at 40" refers to the published statistic for median individual income for all men aged 45 to 54 (surveyed 10 years after the first observation).
18. The data for Table 4 come from the Department of Commerce [Bureau of Economic Analysis, *The National Income and Product Accounts of the United States, 1929–76* (Washington, DC, 1981), table 5.1; "National income and product accounts, 1982–85," in *Survey of Current Business* **66** (no. 3) (1982), table 5.1].

Phosphorus in Antique Iron Music Wire

MARTHA GOODWAY

Harpsichords and other wire-strung musical instruments were made with longer strings about the beginning of the 17th century. This change required stronger music wire. Although these changes coincided with the introduction of the first mass-produced steel (iron alloyed with carbon), carbon was not found in samples of antique iron harpsichord wire. The wire contained an amount of phosphorus sufficient to have impeded its conversion to steel, and may have been drawn from iron rejected for this purpose. The method used to select pig iron for wire drawing ensured the highest possible phosphorus content at a time when its presence in iron was unsuspected. Phosphorus as an alloying element has had the reputation for making steel brittle when worked cold. Nevertheless, in replicating the antique wire, it was found that low-carbon iron that contained 0.16 percent phosphorus was easily drawn to appropriate gauges and strengths for restringing antique harpsichords.

HISTORICAL INSTRUMENTS ARE BEING RESTORED TO PLAYing condition for the performance of baroque music in the original voices. In harpsichords the practical details of restoration include the choice of appropriate wire for each string. The first published data on wire strings occur in Mersenne's *Harmonie universelle* of 1636 (*1*), and, although most of the contemporary documents that relate to the historical harpsichord were compiled by Hubbard in *Three Centuries of Harpsichord Making* (*2*), there is little practical guidance in these documents for the choice of stringing material. The surviving instruments, however altered in the intervening centuries, remain a more reliable and comprehensive source.

A collection of the original materials for harpsichord construction and stringing was established at the Smithsonian Institution in 1966 by J. S. Odell. Although strings were routinely replaced during the active life of an instrument, fragments of earlier ephemeral parts overlooked in prior restoration or reconditioning of antique instruments have been discovered either by visual examination or by radiography. Wire has been found embedded in soft wood sound-

The author is at the Conservation Analytical Laboratory, Smithsonian Institution, Washington, DC 20560.

Table 1. The strength and hardness of antique iron music wire in relation to its diameter. The strength of the annealed sample represents the initial strength of the iron before drawing into wire. The diamond-pyramid hardness test was performed with a 100-g load.

Source	Diameter (mm)	Hardness (kg/mm^2)	Strength (MPa)	Phosphorus (% by weight)
1732 Vater, annealed*	0.33	190	552	0.1
1732 Vater	0.33	291	938	0.1
1782 Shudi	0.29	306	993	0.22
1733 Blanchet	0.23	322	1048	0.12

*Annealed at 860°C for 2 hours. The antique iron is nearly twice as strong before drawing as modern low-carbon steel (type 1008), which has an annealed hardness of about 100 kg/mm^2.

boards, under later string loops, covered by paint, or glued into joints.

Harpsichord wire was supplied in several gauges and three alloys, described as "red," "yellow," and "white" (*3, 4*). The red and yellow wire are brass of two distinct compositions (*5*). The white wire is a ferrous alloy but opinions vary as to its composition and properties. These properties were determined by the metallurgical examination and chemical analysis of antique wire, but, as is often the case with ancient materials, the results could not be interpreted entirely on the basis of modern practice. Two further sources of information were required: (i) contemporary documentation for details of early wire-drawing practice and (ii) the measurement of string lengths of 17th- and 18th-century harpsichords known to have survived in unaltered proportions, to estimate the strength required for the wire to stand to pitch.

Scale and Strength

In laying out the dimensions of his instrument the early harpsichord maker was limited by the materials he could buy (*6*). Among these dimensions was the string "scale," defined as the length of the string which sounds c′ (the C an octave above middle C) (*2*, p. 361). (The string length in this definition is understood to be the sounding length, the length of the vibrating section.) With these measurements the tension of each string when brought up to pitch can be estimated with the simple string equation ($S = 4000\ df^2l^2$, where S is stress in megapascals, d is the density of the wire in megagrams per cubic meter, f is the frequency in Hertz, and l is the sounding length of the string in meters). This equation ignores the relatively small effects of the stiffness of the wire and is independent of gauge size. This independence of gauge is fortunate, since many gauge standards were in use and it is not known how well the standards were met.

Music wire has always been highly drawn, so that its yield strength closely approaches its breaking strength. Antique music wire was chosen to be strung as taut as possible, to a pitch only a semitone below the breaking point (*7*). Most of the strength of the wire was due to work hardening. The wire became harder and stronger after each pass through the die; finer wire was stronger than coarser wire, so that in 1753 Corrette could advise replacing a string that broke repeatedly with one of a smaller gauge: "if the strings are too weak they give an ugly sound, and too thick they break . . ." (*4; 2*, p. 281).

The increase of tensile strength in the course of drawing required a drafting schedule that was uninterrupted by annealing of the wire, which softens it. In practice strength is limited by nonmetallic inclusions, which are not load bearing. By not being broken up and made smaller during drawing, nonmetallic inclusions account for a relatively larger part of the cross-sectional area with each pass through the die. "Overdrawing" occurs when the increase of strength in the metal, which is caused by work hardening, cannot overcome the loss in load-bearing area. Beyond this point attempts to draw wire only lead to weaker and more brittle wire, so that Corrette could remark of one of the finer gauges of wire that "as for No. 11, it is good only for the making of wigs" (*4*, p. 83).

There are several considerations in applying the string equation. Metal that is drawn decreases slightly in density; the amount of decrease depends on the degree of drawing. The 0.33-mm wire in Table 1 had a measured density of 7.69 Mg/m^3, compared with 7.87 Mg/m^3 for pure iron that is not drawn (*8*). Also, the strengths estimated from these calculations are subject to the practical necessity of bearing additional stresses when the wire is wrapped around the tuning pin or around itself to form the hitchpin loops; for modern music wire, which is stiffer than the antique wire, the estimated strength is increased by about 30%. The largest uncertainty in the string equation, however, is the level of pitch, or the "pitch standard" in use. The modern standard sets A above middle C at 440 Hz. The modern baroque revival has arrived at a general value of 415 Hz, a semitone lower; pitch standards as low as 390 Hz have

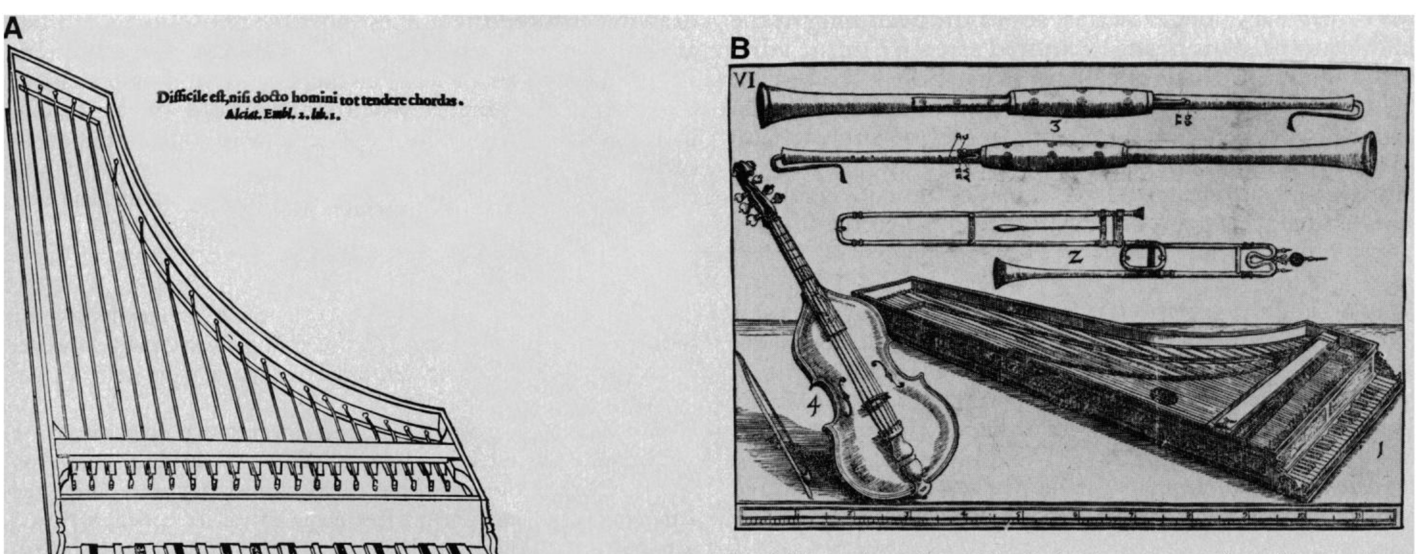

Fig. 1. Illustrations of harpsichords that show change of scale (*2*, plates 5 and 24): (**A**) 1558, from Gioseffo Zarlino, *Institutioni harmoniche*; (**B**) 1620, Michael Praetorius, *Theatrum instrumentorum*.

been suggested. A lower standard would require lower tensions. The measured sounding lengths of the unrestored 1733 Blanchet harpsichord (*9*) were used to calculate the sounding stresses on this instrument, by assuming a pitch standard of 415 Hz, a maximum sounding stress of 1050 MPa (on an iron string in the 4′ choir) was calculated.

Enlargement of Instrument Scale

Abbott and Segerman noted a change in the proportions of certain wire-strung instruments shortly before 1600 (*10, 11*). The instruments were made longer. The enlargement in scale can be seen by comparing illustrations of harpsichords published by Zarlino in 1558 and by Praetorius in 1620 (Fig. 1). Existing 16th-century harpsichords exhibit the same proportions as those in Zarlino's illustration. One of these, dated 1596, is in the Royal Ontario Museum and was built in Venice by Johannis Celestini (Fig. 2).

The enlarged scale and longer strings for the same frequencies indicated higher string stresses and thus the availability of stronger wire. Abbott and Segerman attributed the change to the introduction of steel wire, and suggested that iron wire had been converted to steel by case hardening (*10*). Karp held that "no steel strung instrument could have existed prior to the development of the techniques necessary for drawing steel wire" (*12*, p. 77) and that "techniques needed for drawing stronger steel wire were developed around the beginning of the 17th century" (*12*, p. 29). Lewis, however, identified these improvements as techniques for removing fire scale (iron oxide) from annealed wire (*13*). Documentary evidence also appears to support the identification of the stronger wire as steel: Biringuccio referred to music wire of steel (*acciaro*) (*14*); a 1621 letter by H. Schütz described "excellent steel (*Stahline*) instrument strings" (*12*, pp. 81–82; *15*), and Sauveur in 1713 mentioned "a white harpsichord string, that is to say of steel (*acier*)" (*16*, p. 326). However, "steel" was a term whose meanings differed with the period. Traditionally "steel" might simply mean iron that had been particularly well refined (*17*). After 1781 and T. Bergman's discovery of carbon in iron, steel came to mean iron that contained sufficient carbon to harden it.

About the same time that the scale of wire-strung musical instruments was enlarged, the first method for producing steel in large quantities was developed in Central Europe (*18*). The first detailed account of the process dates from 1601 in Nuremberg (*19*). The process, called cementation, introduced carbon into wrought iron by solid-state diffusion to form blister steel. Certain wrought iron bar would not cement well; steelmakers in England had this problem, which they solved by importing bar from Sweden. We now know that the difficulty was caused by phosphorus, and that Swedish bar iron could be cemented because it was low in phosphorus.

If the stronger wire had been drawn from blister steel, it should certainly contain carbon; the amount of carbon would depend on the grade of blister steel used. Arnold showed that the mean carbon content varied from 0.05% in No. 2 blister steel to 1.9% in glazed bar, the most highly carburized (*20*). Since bar iron from low-phosphorus ores was used for making steel, such wire should also contain very little phosphorus.

Antique Iron Wire

Strings on antique harpsichords were replaced often; wire found on an antique instrument may not date from the year the instrument was built, and in the absence of complete documentation may well date from a later restoration. Though samples of antique harpsichord wire tend to be small, few, and in poor condition, in practice it is the uncertainty as to the source and date of manufacture that remains a major problem in research on ancient materials. Because errors in provenience could be greater than those of the analytical method, the chemical analyses and estimates of strength reported here are for iron wire from three harpsichords, each of which has a known history from the time it was made (*21*). All are thought to have remained unaltered from the end of the 18th century to the present day. The dates associated with wire samples in Tables 1 and 2 are given solely as a means of identifying the harpsichords from which they came.

The chemical composition of samples from the 1732 Vater and the 1733 Blanchet reported in Table 2 were obtained by secondary ion mass spectroscopy. The carbon content was also analyzed with a field ion microscope atom probe. Iron wire from the 1782 Shudi was analyzed by microprobe and had a phosphorus content of 0.22%. The compositions in Table 2 show a number of features commonplace in old iron. Certain alloying elements (such as chromium, vanadium, or molybdenum), whose presence in modern steel is the result of recycling scrap, are absent. Sulfur is also absent; this indicates that wood charcoal, rather than coke, was the fuel used in smelting. However, the absence of sulfur does not establish an early date of manufacture; cold-blast, charcoal-smelted iron was preferred for wire drawing well into the 19th century (*22*). Slightly elevated levels of nitrogen and phosphorus are routinely encountered in analyses of old iron; the nitrogen content resulted from the use of an air blast. The nitrogen levels in the antique samples were well below those that would result from intentional nitriding of the iron for hardness, though this has been suggested (*10*, pp. 71–72).

Fig. 2. Harpsichord by Johannis Celestini of Venice dated 1596 in the R. S. Williams Collection of the Royal Ontario Museum, Toronto. [Photograph courtesy of the Royal Ontario Museum]

Table 2. Comparison of the chemical composition of antique iron music wire with that of modern piano wire. Carbon analyses were by field ion microscope atom probe, all other analyses by secondary ion mass spectrometry (*42*).

Source	Elements present (% by weight)										
	C	N	O	Al	Si	P	S	Mn	Cr	Ni	Cu
1732 Vater	<0.007	~0.015	~0.1	~0.01	<0.02	0.1		<0.02		<0.02	<0.02
1733 Blanchet	<0.007	~0.01	~0.12	~0.01	<0.02	~0.15		<0.02		<0.02	<0.02
Piano wire	0.91	0.005	0.004	0.04	0.22	0.016	0.03	0.45	0.03	0.01	0.02

The phosphorus content of the wire was high by modern standards. Other analysts (*23*) have found high levels of phosphorus in antique iron music wire.

The most surprising results were the carbon levels. The wires were not steel at all. Although it had been suggested that the iron of antique music wire had a lower carbon content than modern piano wire (*2*, p. 206; *24*), these samples contained no detectable amounts of carbon. Metallographic examination showed that the antique wire had fewer nonmetallic inclusions than wrought iron (Fig. 3). When the inclusions were analyzed by energy-dispersive x-ray emission, most were found to be iron oxide, or fire scale; others were either iron phosphide or slag. No iron carbide was observed. Moreover, phosphorus levels of 0.1 to 0.2% represented a substantial obstacle to the carburization necessary to cement steel. The increase in strength of music wire cannot have been due to the use of blister steel.

The samples were from strings, so they were strong enough to have been taken up to pitch. Their strengths could be closely estimated from diamond-pyramid hardness tests (Table 1), and fell in the inverse order of diameters. This means that the increase of tensile strength that resulted from drawing followed a similar curve for each wire; presumably each wire had been drawn down to its final size from annealed coarse wire of about the same diameter. The 0.23-mm-diameter wire from the 1733 Blanchet had a hardness that corresponded to a strength of about 1050 MPa, the maximum strength that had been previously calculated from the sounding lengths of this harpsichord, and showed that antique wire was as strong as these calculations suggested.

Much of this strength was the result of work hardening that occurred during drawing; the amount can be estimated by removing the effect of work hardening by annealing the metal to a larger grain size; the hardness and strength that remain are caused chiefly by alloying. The hardness and strength of the Vater wire after annealing at 860°C for 2 hours and furnace cooling (Table 1) were higher than those of, for example, annealed low-carbon steel. The greater strength of the annealed Vater wire can be attributed to alloying; the only alloying element present in significant quantities is phosphorus.

The Effect of Phosphorus in Iron

Iron that contains phosphorus has an established reputation for "cold shortness," that is, it is expected to be brittle when attempts are made to shape it without heating in the forge (*25*, p. 64). Since wire is drawn cold, these antique samples argue an exception to the rule; the exception is in the absence of carbon. If only a small amount of carbon is present, phosphorus strengthens iron without ill effect. In 1888 Bloxam and Huntington reported, "The amount of phosphorus which is admissible depends greatly upon the percentage of carbon" and that "phosphorus hardens iron to a greater extent than carbon, the ratio between them being at least as two to one" (*26*, p. 220). Hopkins and Tipler measured the relationship between phosphorus content in low-carbon (0.01%) iron and its increase in strength. They found that for each addition of 0.1% phosphorus (up to 0.3%) there was a linear increase of 48 MPa in the strength. The limit of the ductile range at room temperature was 0.22% phosphorus if the iron was air-quenched after annealing, and was beyond 0.3% phosphorus if the iron was furnace-cooled (*27*). Modern rephosphorized steels, which are low-carbon irons that contain 0.07 to 0.12% phosphorus, have compositions somewhat similar to that of the antique wire (*28*).

To test the strength that could be achieved with iron of the same general composition as the antique wire, a heat of low-carbon iron alloyed with 0.16% phosphorus was prepared and drawn by R. M. Fisher. This iron drew down to 0.27-mm diameter with no special adjustment of the drafting schedule, and broke in test at tensions greater than 1600 MPa.

The replication of antique wire demonstrated several things. It showed that despite the reputation for cold shortness, iron that contained phosphorus as the only alloying element is more easily drawn. This was an unexpected finding. Drawing the iron demanded no new or special techniques. Also, phosphorus as the sole alloying element was adequate to strengthen iron so that wire drawn from it would have the strength necessary for stringing instruments built to a longer scale. The use of carbon-containing steel was not necessary.

Although the presence of phosphorus is sufficient to explain the strengths achieved in drawing the antique iron wire, it remains to be shown that its presence was intentional. Because the presence of phosphorus in iron was only discovered in 1784 (*25, 29*), no document can provide us with direct evidence, but this can be inferred if the presence of phosphorus can be shown to have been an unavoidable result of traditional processing.

Early Wire Drawing

The traditional method of drawing iron wire required three steps: "straining," "ripping," and "drawing" (*30*). In straining, the iron bar stock was heated and then forged down to a small square cross section with a trip hammer. The forged bar was resoftened by annealing, and fire scale was removed after a prolonged soaking called "watering." The iron was then ripped by being drawn down through successively smaller die holes to coarse wire 2 to 3 mm in diameter. Several anneals, each followed by watering, were needed to soften the iron that had hardened during ripping, but, once the coarse wire had been softened for drawing, no further annealing was allowed. Beyond this point annealing would have caused an unwanted loss of strength.

Ripping was the most difficult of the three operations. Ripping by hand represented a bottleneck in production and waterpower was used, perhaps as early as the middle 1300s (*31*), in Nuremberg certainly no later than 1418 (*32*). Ripping with waterpower required iron of higher quality than did ripping by manpower. Too many nonmetallic inclusions weakened and embrittled the iron; unless a cleaner iron could be made, the wire broke. This necessity of substantially removing the inclusions resulted in the development of a method of fining applied only to iron for wire. This method I call

"Westphalian fining" from its likely place of origin (*33*).

Making iron for wire took two operations, smelting and fining. Iron smelted from the ore ran molten from the furnace as cast iron, high in carbon but far too brittle to be useful. In fining, the pig of cast iron was slowly remelted and decarburized in the open fire of the finery hearth as the excess carbon in the iron was oxidized. In the usual procedure the droplets of metal fell through a bath of molten slag and collected at the bottom of the hearth as wrought iron (*34*).

In the Westphalian process, however, the molten iron was not allowed to entrap slag as it fell; the droplets were collected on the tip of a long iron staff, somewhat like a gather of glass, and so were kept in the oxidizing zone of the fire for a longer period of time (*35*). The scale that formed on the iron along with any other dross was removed by repeatedly rinsing the surface of the ball of iron in a bath of molten slag. Very little slag was entrapped, and an acceptably clean iron for making wire was produced. This process also maximized the surface area of iron exposed to the oxidizing flame and so thoroughly decarburized it, as the analyses of Table 2 show.

The cast iron to be submitted to Westphalian fining was specially selected as well. Moxon in his *Mechanick Exercises* of 1677 noted that "There is another sort of Iron used for the making of *Wyer*, which of all Sorts is the soughtest and toughest: But this Sort is not peculiar to any Country, but is indifferently made where any Iron is made, though of the worst sort, for it is the first Iron that runs from the *Stone* when it is melting, and is only preserved from the making of *Wyer*" (*36*, p. 13). Because the material for iron wire was selected at the point of smelting and then subjected to special processing, information about antique wrought iron in general cannot be assumed to apply to antique iron wire.

Selection for Phosphorus

Moxon's "first Iron that runs from the *Stone*" had a lower melting point and a greater fluidity than cast iron that was tapped later from the furnace. The only element present in the analyses of the antique music wire that confers these specific properties on cast iron is phosphorus. According to Stead, "when alloys of iron, carbon, and phosphorus are heated to the point of incipient fusion, the phosphorus and carbon become concentrated in the part that first becomes liquid," and in fact the melting point of phosphoritic cast iron can fall below 1000°C (*37*); it also runs freely (*38*). The selection of the "first Iron" smelted to be fined for wire drawing was a specification that ensured that it contained as much phosphorus as possible.

Nearly all iron ore contains phosphorus, and it could also have entered the iron from the charcoal used as fuel (*39*). The analytical results in Table 2 show that though the carbon had been removed in Westphalian fining, phosphorus remained, and indeed, once introduced, phosphorus is very difficult to remove. Moxon's account, which emphasized that the iron could be "of the worst Sort" and that it was "only preserved from the making of *Wyer*" suggests the use of material rejected for steelmaking because of the presence of phosphorus.

Before blister steel was manufactured there had been no demand for large amounts of phosphorus-free bar and no procedures for choosing it. Iron unusable for steelmaking contained either sulfur or phosphorus or both. Sulfur announced its presence (by its odor during forging), as phosphorus did not. Cold shortness was not a reliable indicator that phosphorus was present in the bar because this effect is sensitive to the carbon content. The sorting of bar iron for manufacture into blister steel probably led to the discovery that the rejected iron made stronger wire if it did not contain sulfur and if it was fined by the Westphalian process. This selection appears to have become routine by the time of Moxon's account (1677).

The possible location of this discovery is limited to a place where fining was done by the Westphalian process, that is, where wire was drawn by waterpower, and also where blister steel was being made. There were few centers of wire production because of the skill required to draw wire; the product itself, having high value and low weight, could be shipped long distances with profit. The most prominent of these centers was Nuremberg, where the first factory in Western Europe for the production of blister steel was erected in 1601 (*19*). Thus it seems likely that this discovery took place in Nuremberg, especially in light of the 1621 letter of Schütz which identified Nuremberg as the source of "excellent steel strings" (*15*).

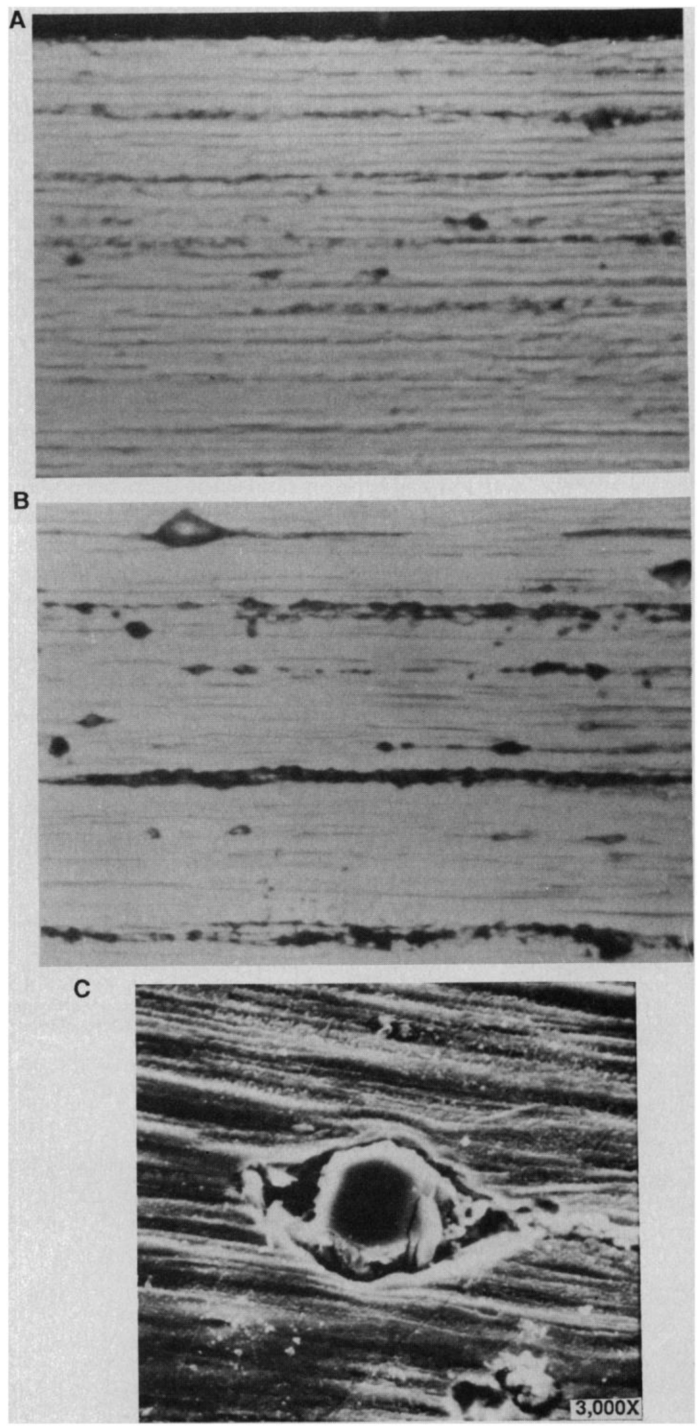

Fig. 3. Cross section of iron music wire from the 1732 Vater: (**A**) edge, magnification ×500; (**B**) inclusions, magnification ×1250; (**C**) inclusion, magnification ×3000.

Conclusion

The new iron music wire that influenced the design of harpsichords and other wire-strung musical instruments of the 17th and 18th centuries was stronger because it contained phosphorus, not carbon. The phosphorus was beneficial only because the iron had been thoroughly decarburized in a fining procedure unique to the making of iron wire that was intended only to clean it for successful ripping. A reliable date of introduction of this alloy as wire, about 1600, can be assigned on the basis of the changing dimensions of wire-strung musical instruments.

Replication of the antique wire demonstrated that low-carbon iron that contained phosphorus is easy to draw, and did not require new techniques; drawing the stronger wire of the 17th century may have been somewhat less exacting than drawing iron wire had been earlier.

The role of phosphorus as a beneficial element in ancient iron is beginning to be appreciated. Ehrenreich, for example, has reported that phosphorus concentration correlates with tool type in Iron Age sickles from Wessex (*40*). The role of phosphorus in iron music wire has been overlooked in the history of technology and of musical instruments. It could not have been considered by the wire drawer of the 17th century since its presence in iron was not suspected until the 1780s. It was during this same period, beginning about 1770, that the harpsichord was being superseded in popularity by the piano (*2*, p. 125).

With the shift in musical taste to the piano, the development of iron music wire took an entirely different direction. Modern piano wire is steel; in fact, it is the strongest steel available in any form. Early piano wire was low-carbon iron similar to harpsichord wire (*41*), but the new music wire technology that developed in the 19th century in response to changes in piano building exploited carbon instead of phosphorus as the strengthening element. Carbon permitted additional strengthening upon heating, quenching, and tempering, processing that is without effect with phosphorus.

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