Notes on the Construction of the Violin

By

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"O'r Masarn vo geir Miwsig."—Gruffydd ab Davydd ab Hywel.

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PREFACE

IT is one of the marvels of the age that for the last two centuries no improvement whatever has been found possible in the construction of the violin.

The apparent simplicity of its structure sometimes gives rise to the idea that there is almost a reproach to science in the fact that so little is known concerning the principles of the instrument; that there is in fact no theory of the violin worthy of the name.

Certain writers, indeed, profess to see in the works of the old masters a perfect compliance

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with the laws of acoustics, but we are left entirely in the dark as to what those particular laws are.

It seems, however, certain that the exact functions performed by the instrument in reinforcing the tones of the string are of an intensely complicated character, sufficiently so to almost forbid any attempt to analyse them, even in the roughest way.

In the case of a symmetrical and homogeneous body, such as a rod or plate, vibrating in its natural manner (for example, when lightly agitated with a bow), certain laws of vibration have been determined; they depend only on the form, dimensions and physical properties of the material of the plate; but if to these natural vibrations, whose rate for any given mode of vibration is independent of the manner in which they are generated, we add others of a compulsory order —such, for example, as those communicated by the violin string, and whose rate depends only on the rate of the string—the resultant vibrations may become extremely complicated.

Such appears to be the case with the violin. The vibration of the string, besides communicating to the instrument its own rate of vibration, also excites the natural vibrations of the various component parts of the instrument, and the two orders of vibrations

The tone of a violin evidently depends on one or more of the following qualifications:

1. The form or model.
2. The dimensions.
3. The workmanship.
4. The varnish.
5. The quality of the wood.

With regard to the first two of these qualifications, it is impossible to believe that, either singly or jointly, they can be made to account for the marked superiority of tone in the Italian and Tyrolese instruments. Amongst these instruments we find an

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ation of Savart's lectures in *The Violin*, by P. Davidson; London, 1881.

extraordinary variety of model and dimensions, with characteristic variations in the intensity or volume of tone; but what so clearly distinguishes them from the more modern violin is their remarkable *timbre (Klangfarbe)*, or, briefly, their "Italian tone."

In modern instruments again we find every conceivable variety of model and dimensions with a corresponding variation in volume of tone; but rarely, if ever, anything equal to the *timbre* of the early instruments.

With regard to the workmanship, it would seem sufficient to note that many of the finest Italian instruments are not conspicuous by any marked excellence in this respect.

As to the varnish, this may be removed and a substitute provided, without altogether destroying the "Italian tone"; and the same may be said of the neck, bass-bar and sound-post.

Coming now to the fifth qualification, it is not difficult to believe that quality of wood and quality of tone must be most intimately related. No two vibrating substances, even of the same species, yield precisely the same tone. In each there is a difference, either in the number or in the intensity of its overtones constituting its own peculiar *timbre*; a difference quite distinct from the pitch or intensity of the consonant note.

We have moreover strong evidence to show that the early makers attached great importance to the wood they employed, especially in the case of the pine: sufficient indeed to suggest its scarcity. It may therefore be of interest to inquire into the possible causes of a scarcity of such material and of its superiority.

Let us assume as a starting point, (1) that by some fortuitous circumstances a wood of exceptionally good sonorous qualities found its way to the workshop of one of the early makers, and that, by the migration of his pupils, the knowledge of the locality whence this wood was obtained spread to other parts of the country; and (2) that this wood was found only on comparatively small and scattered areas of forest which eventually became denuded of their timber.

The marked influence of geographical position, aspect of situation and nature of soil on the general properties of timber are well-known; and as regards the influence of the soil, the argument may perhaps be carried a little further than appears to have been hitherto done.

By way of analogy: it is a well-known fact that in some of the wine-growing districts of France (and no doubt in other countries) small areas of land—in some cases only a few acres—produce an exceptionally fine quality of wine as compared with the produce of other vineyards in the immediate locality. These small areas are often enclosed by a fence, and are known as the celebrated *clos* of their district. The wine from these *clos* is found to be sweet, mellow, etc., whilst the produce of the neighbouring vines—literally only a few yards off—may lack all the finer qualities of its distinguished neighbour.

This superiority in the quality of the wine from a very restricted area is without doubt chiefly, if not entirely, due to a difference in the soil; and without pushing the analogy too far, it seems admissible to suggest that a similar cause may account for the superior sonority of the wood from a small area of the same forest.

The Havana cigar offers an analogy of the same kind. It is made from tobacco grown in a certain district of the island of Cuba, known as the *Vuelta Abajo*; but the finest leaf is only found on isolated areas of this district. These areas, as in the case of the vineyards, are sometimes very small, and a distance of a hundred yards or so in any direction may make a difference of a hundred per cent or more in the market value of the leaf. A difference in the soil of these patches of land is often perceptible to the eye.

In no other part of Cuba is the true "Havana flavour" found; nor have the attempts that have been made to impart it artificially been more successful than the various means that have been tried for imparting, what one may perhaps be allowed to call, the "Italian flavour" to the tone of nineteenth-century fiddles.

The French vine and the Havana tobacco seed may be transferred to other lands; but the produce rapidly loses all its finer characteristics.

Fortunately the vine and the

tobacco plant admit of a succession of crops which do not require a century to mature; otherwise we should now be worse off for fine-flavoured claret and cigars than we are for fine-toned violins.

Importance is attached by violin-makers to the selection of wood that is "not too hard and not too soft"; "grown on a southern slope"; "cut from the south side of the tree," etc., etc.; some of which conditions, even to the sojourn in the "Swiss châlet," have a sort of *raison-d'être*; but the food which built up the cells of the tree would seem to be of at least equal importance.

The salt deposits of the Tyrol

have been suggested as a possible cause of the superiority of the wood from that country; and no doubt outcrops of other minerals would have a similar bearing on the question; whilst the scarcity of such outcrops might well explain the disappearance of a marked characteristic in the wood from a particular forest.

It may well be inferred that under the more simple conditions of trade of two centuries ago, the commercial relations between the violin-maker and the wood-cutter were of a much more direct kind than in these days of the "middleman." The maker was thus able to trace the origin of a log that was found to make a good-toned instrument; and in such case he would no doubt, according to his means, lay in a stock of the wood, almost regardless of its appearance.

This would account for the fact that the violins of certain makers, and from certain localities, show a preponderance of a wood of one particular pattern or "figure"; as well as certain minor variations in the quality of tone characteristic of the maker and of the birthplace of the instrument.

It seems regrettable that Savart should have attached so little importance to the origin of the wood in the Italian instruments. He might otherwise have been led to investigate this subject with a greater chance of throwing some light on the matter that could be hoped for nowadays. He strongly advocated the pine from the Vosges and the sycamore from the Ardennes, and considered the Tyrolese pine to be "of too uniform a density": yet this was the wood of the Italian makers.

Good wood is of course no panacea for defective dimensions; and there are reasons for believing that one of the chief merits of the old instruments lies in an accurate adjustment of the form and dimensions of the tables and sound-holes in accordance with the physical character of the wood. This at once suggests that the process of determining these dimensions was a tentative one; consisting in its final stage of a delicate working down of the tables and widening of the sound-holes *after the instrument had been put together*, the tables and sound-holes being previously cut as closely to their final dimensions as the experience of a former instrument (made of the same wood) would indicate; a process analogous, for example, to the filing down the metal of a bell for the purpose of flattening its tierce.

If, as here suggested, the Italian maker possessed a wood singularly capable of responding to the slender cuttings that constituted his finishing touches to the instrument, there is no cause for surprise in the failure of the copyist who stops short at a mathematically exact copy, especially if he is using a wood that the Italian maker might very possibly have rejected as unfit for violin-making; a wood perhaps physically incapable of reinforcing the full series of over-tones that go to build up the *timbre* of the "Italian tone."

A violin-maker of high repute recently showed the writer an exceedingly well made and well varnished violin of his own make. The price asked for this instrument was almost exactly its weight in gold! On inquiring as to the tone of the instrument, the reply was that it had "never had a string on it." Was the maker sure that the tone of this instrument would justify his expectations? "Yes; unless there is something radically wrong with it!"

Is it after all possible that the finishing touches to the "king of instruments" may be of a less tentative kind than those bestowed, for example, on the salmon-rod, the lens, and that humble contrivance the fiddle bow?*

* Vuillaume has endeavoured to show that the profile of the fiddle-stick should

A noted authority on the violin has remarked on the wonderful simplicity of the instrument. "It seems to scorn complication in its structure, and successfully holds its own in its simplicity." *

This is true only in the sense in which the horse is "an animal with a head at one end, a tail at the other, and a leg at each

be a logarithmic curve. We may perhaps be thankful that François Tourte and John Dodd were unfettered by any knowledge of such a curve. The "continuous beam" and the "solid of equal resistance" are also fine ideal conceptions, but nature refuses to supply the perfectly homogeneous material.

* *The Violin.* By G. Hart. London, 1887.

corner." From the mechanical point of view the violin is a highly complex structure. When tuned to concert pitch it is subject to statically indeterminate stresses of considerable intensity which are quite beyond the reach of mathematical analysis, and which no doubt affect the transverse vibrations of the tables in a very intricate manner. It is also obvious that the results of experiments made with simple and symmetrical test pieces, for the purpose of determining the general laws of vibration and sound, are not immediately applicable to the violin as a whole.

The *timbre* of the violin, like that of the human voice, is developed by the vibration of constant use; and of all the means that have been proposed for promoting this development, none is more rational than that of Otto, which may be described as "vibration by machinery." Whether this is an advisable proceeding, is another question; and the owner of a good violin would do well to consider the experiments of Wöhler and Spangenberg on the "fatigue" due to often-repeated stresses of small intensity, before submitting his instrument to any severe treatment of this kind. It is doubtful whether any solid is perfectly elastic, and it would seem that certain intervals of rest are required to allow of recovery after strain. Carried sufficiently far, it would be theoretically possible by this means to "shake a violin to pieces."

Savart has undoubtedly contributed more than anyone to our knowledge of the principles of the violin; the modern treatise on the subject contains in fact little more than a *réchauffé* of the conclusions arrived at by that industrious experimenter. Unfortunately he set himself the gigantic task of improving on the model of the Italian makers before attempting to solve the problem of why it was that he could not make an equally good instrument on the same model; and all his work shows him to have been keenly intent on the laws of quantity rather than quality of sound. His investigations yielded some instructive results with respect to the principles of construction which govern the volume of tone, but they can hardly be said to throw much light on the more subtle question of *timbre*; and there is great need of further experimental research on this interesting, and to all admirers of the violin and its music, important subject.

Amongst the many experiments recorded by Savart there is one of special interest, as it seems to form the basis of the idea that the modern violin-maker is more scientific in his methods than the early Italian makers.

Fétis, in his *Notice of Anthony Stradivari*,* relates the following experiments made conjointly by Savart and the celebrated violin-maker, Jean Baptiste Vuillaume, by whom Fétis was personally supplied with the details of the experiments.

From some fragments of violins made by Stradivari, rectangular rods were cut 200 millimètres long, twenty millimètres wide, and five millimètres thick. These rods (presumably cut with their lengths in the direction of the axis of the tree) were supported

* English translation by John Bishop, London, 1864.

at points about one-fourth of their length from each end, and made to vibrate transversely so as to emit their fundamental notes for that method of vibration. The following were the results obtained:

Three rods of deal (pine, no doubt) from instruments dated respectively 1690, 1724 and 1730, yielded the same note F=682 vibrations; and two rods of maple (? sycamore), dated 1708 and 1717, gave the note A sharp=450 vibrations.

In the ordinary course of things the record of these experiments would be open to a certain amount of suspicion, for it is in the highest degree anomalous.

that three rods of pine and two rods of maple should in both cases give exactly the same note. The experiments of Chevandier and Wertheim * show that this perfect coincidence is very rarely found even in test pieces from the same tree; and then only when cut from the same annual rings, and at the same height above the ground.

However this may be, the following experiment, recently made by the writer, would seem to show that the record given of Savart's experiments is probably substantially correct.

A piece of Swiss pine and a

* *Mémoire sur les Propriétés mécaniques du Bois.* Paris, 1848.

piece of sycamore, of the usual form sold for violin-making, were taken at random from the stock of a London dealer. From each piece of wood a rod was cut (with its length in the direction of the axis of the tree) of the same length and width as Savart's rods, but ten millimètres thick. On vibrating these rods in the manner just described (by striking them sharply at the centre), the pine rod gave the note corresponding to 1338 vibrations, and the sycamore the note corresponding to 1024 vibrations.

Since these rods are twice as thick as Savart's rods, the vibration numbers must be halved to make the comparison ; thus giving for the pine 669 vibrations and for the sycamore 512 vibrations. The note of the pine is only about a semi-tone below; but the note of the sycamore is considerably higher than the corresponding notes in Savart's rods.

The sycamore used in this experiment has a wide "curl" (about seventeen curls in the length of the rod); but on repeating the experiment with a piece of sycamore obtained from another dealer, and having a narrow curl (about forty-five curls in the length of the rod), it gave the note equal to 856 vibrations; or, reduced to the dimensions of Savart's rods, 428 vibrations; or about a semi-tone below the note given by Savart's rods.

These rods were made thicker than Savart's rods for two reasons; first because a thick rod gives a much more distinct note; and secondly, because any little error in gauging the thickness is of less importance in a thick rod than in a thin one. Savart's rods were, of course, as thick as the tables of the violin admitted.*

* It may perhaps be useful to note that it is not necessary to make test rods of exactly the same dimensions; and it is often more convenient to reduce the vibrations to those of a standard rod by calculation. Thus if L is the length and T the thickness of the standard rod: *l* the length, *t* the thickness, and *n* the number of vibrations of another rod of

Having established the fact of a remarkable similarity in the woods used by the chief of all violin-makers, Savart deduced therefrom many interesting con-

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proportionately the same width; then if this rod were reduced to the same length and thickness as the standard rod, the number of its vibrations would be

$$N = n \frac{T l^2}{t L^2}$$

Theoretically the value of the note is independent of the width of the rod; but for practical reasons the width should be comparatively small in relation to the length; and one-tenth is a good proportion. If the thickness is one-half of the width, the rod when struck on the edge should give very approximately the octave above the note emitted when struck on the flat.

clusions. Amongst others he formulated the theory that, of two pieces of pine of the same dimensions, that which yields the highest note is the best for violin making.

(It is only right to say that few, if any, violin-makers of repute admit the utility of this test.)

Chladni had already pointed out* that rods of steel, glass and pine of the same dimensions yield the same note; and apparently on the strength of this statement (which of course is practically correct) Savart was led to the extraordinary conclusion that the reason why deal (pine) is pre-

* *Traité d'Acoustique.* Paris, 1809.

ferred to all other woods for the table of the violin, is because of its small density, its elasticity, and "because its resistance to flexion is greater than that of any other wood, and also than a great number of other substances even metallic; *it is equal to that of glass and steel!*" *

There is evidently some confusion here. It is a great mistake to suppose that because a rod of pine and a rod of steel of the same dimensions yield the same note (and consequently that the velocity of sound is the same in the two substances), that these rods are therefore equal as re-

* *Vide* Davidson, also Fétis, *loc. cit.*

gards elasticity and resistance to flexure. The velocity of sound in any substance is directly proportional to the square root of its coefficient of elasticity, and inversely proportional to the square root of its density; consequently the equality of the pitch of the notes yielded by rods of different substances (or rods of different specimens of the same wood), merely indicates that the ratio

$$\frac{\text{coefficient of elasticity}}{\text{density}}$$

is the same in both cases. The absolute values of the coefficient of elasticity (which is directly proportional to the resistance to flexure), and the density, may be—and indeed in the case of pine and steel actually are—very different.

As the writer has proved (curiously enough on a first trial) it is easy to find a piece of pine possessing very nearly the same conductivity of sound along its "fibres"* as that employed by Stradivari; and yet, for all we know, that distinguished maker would have used this wood to heat his glue-pot, simply because,

* The pitch of the note obtained by the transverse vibration of the rod having its length in the direction of the "fibres," is that due to the *longitudinal* elasticity. Transverse *vibration* must not be confounded with transverse *elasticity* referred to further on.

not having the proper absolute values of coefficient of elasticity and density, it will not yield the "Cremona tone." Glass, yielding the same note as pine, will not make an equally good violin; there would be something radically wrong with its *timbre.*

Pitch alone is evidently insufficient as a criterion of the quality of wood required, and we must seek for some further test.

The following table, compiled from the records of experiments made by Chevandier and Wertheim,* contains the average values of the velocity of sound along the three "axes of elasticity" in fourteen different kinds

* *Loc. cit.*

of wood, the unit being the the velocity of sound in air.

Name of wood	Velocity along the fibres	Velocity across the annual rings	Velocity along the annual rings
Aspen	15·30	4·86	2·74
Acacia	14·19	4·44	4·07
Ash	14·05	4·19	3·80
Alder	13·95	4·12	3·14
Beech	10·06	5·53	4·26
Birch	13·32	3·23*	4·57
Elm	12·40	4·28	3·05
Hornbeam	11·80	5·14	3·60
Oak	11·58	4·62	3·88
Poplar	12·89	4·22	3·16
Maple	12·36	4·63	3·12
Sycamore	13·43	4·51	3·42
Fir	13·96	4·02	2·36
Pine	10·00	4·23	2·39

* One experiment only.

(It is necessary to observe that, owing to the limited number of trees experimented with—ninety-four in all, and in some cases only one of each species—and to the fact that the trees were all cut in one particular country, these experiments, admirable as they are, can only be regarded as exhibiting the general tendency of the qualities indicated for each wood.)

On comparing the figures in this table, it is seen that, as regards the velocity of sound along the fibres, *i.e.*, in the direction of the axis of the tree, pine stands at the bottom of the list, whilst fir *(sapin)* is amongst the highest. On examining the complete tables published by Chevandier and Wertheim, it is found that the highest and lowest values recorded for these two woods are respectively 17·80 and 10·07 for fir, and 12·53 and 7·56 for pine. It must be observed, however, that the wide difference between the high and low values is chiefly due to the variation of moisture in the test pieces.

By a process of experiment and calculation, which need not be described here, the writer finds that the velocity of sound along the fibres of Stradivari's pine is sixteen times the velocity of sound in air,* and comparing this with

* The velocity of sound "along the fibres" of the rod may also be obtained directly from its transverse

the values given by Chevandier and Wertheim, it will be seen to be a relatively high velocity, corresponding to the fir rather than the pine *(Pinus Sylvestris)* used by those experimenters.

A possible explanation of this apparent anomaly is that, physically, the line of demarcation between fir and pine is not very clearly defined, and the terms are often used in a loose sense; but, without going further into this question, it will be sufficient

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vibrations. Thus, if l is the length, t the thickness, and n the number of vibrations, then, for a rectangular rod vibrating in the manner described above, the velocity of sound along its axis is

$$v = \cdot 973 \frac{l^2 n}{t}$$

for the present purpose to consider the wood under its position as a conifer.

In the absence of more complete data, we may perhaps assume, on the evidence of Stradivari's pine, that one of the properties of the wood used for the upper table or "belly" of the violin should be a high conductivity of sound along its fibres; that is to say, a high value of the ratio $\frac{E}{d}$ (where E is the coefficient of longitudinal elasticity, and *d* the density of the wood); but as Savart does not appear to have recorded the value of *d* in Stradivari's wood, it is impossible to say whether the high value of the ratio is due to a high value of E or a low value of *d*.

There are no doubt practical limits to these values. A high value of E indicates a stiff or inelastic wood, whilst a high or a low value of *d* indicates respectively a hard or a soft wood; all of which extremes are known to be objectionable.* The skilled

* The experiments of Chevandier and Wertheim show that in wood from the same tree an increase of density—except when due to moisture—is generally accompanied by an approximately proportional increase in the coefficient of elasticity; but it would not be safe to assume that this is always the case.

In the two pieces of sycamore experimented with by the writer, the densities are very nearly the same, namely, ·547 eye and hand may no doubt be able to roughly interpret the specification of the text-book, which says that the wood must be "not too hard, and not too soft"; but the *timbre* of the violin is far too delicate a matter to come under the common rules of carpentry.

As to the velocity of sound across the annual rings, *i.e.*,

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and ·554; so that the difference in the velocity of sound (pitch of the notes) is here almost entirely due to a difference of elasticity.

In another experiment, two rods of Swiss pine, whose densities are ·420 and ·468, gave almost exactly the same note. In this case the greater density is accompanied by a proportionally higher coefficient of elasticity.

along a diameter of the tree, there is nothing very noteworthy in the figures recorded in the above table; and the tendency would seem to be that all woods are approximately equal in this respect.

Coming to the velocity "along the rings," *i.e.*, tangentially to the annual rings, it is seen that pine and its relative, fir, are in this case practically equal, but lower in the scale than all the other woods.

Now, the experience of more than two centuries has proved beyond doubt that one of these two conifers is, of all woods, the best for the belly of the violin, whilst experiment seems to show that this wood is, as regards sonority, chiefly conspicuous amongst other woods by a very low conductivity of sound along its rings, which implies a low coefficient of elasticity, and consequently great elasticity,* along that "axis."

This being so, it may perhaps be inferred that the same property which marks the suitability of the wood amongst others of different genera should also be

* Some writers speak of the velocity of sound as being directly proportional to the square root of the "elasticity," instead of "coefficient of elasticity." Chladni very correctly uses the word "*rigidité*" (stiffness), which is the inverse of elasticity (extensibility or flexibility).

the guide in selecting the most suitable wood from different specimens of the same genus (or species); or possibly that a low conductivity along the rings, coupled with a high conductivity along the fibres (or some particular ratio of the two) should be the resultant index of the quality to be sought for.*

Unfortunately the writer is unable to go beyond the sugges-

* It would appear from the above table that, as regards conductivity of sound, the aspen corresponds very nearly to the conifers. It is, however, a differently-constituted wood, in having the true *vessels*, which are not found in the pines and firs, and this perhaps accounts for the wood not being suitable for the tables of the violin.

tion; for, owing to the form in which violin wood is supplied to the market, it is impossible to cut test-rods of sufficient length to determine the velocity of sound along the "tangential axis." The co-operation of the wood-cutter is here required, and experiments with such rods could hardly fail to supply results of great interest, if not something more in the shape of a "missing-link" in the "lignology" of the violin; and it would certainly be well to connect the experiments with the character of the soil at the spot where the tree was felled.

What rules the old makers may have had to guide them in the selection of their wood we shall probably never know. They evidently knew a good wood when they got it, and up to the middle of the eighteenth century they also knew—perhaps to a few yards—where to go for more when they wanted it. There was thus a continuity in the supply, of great assistance to them in perfecting their instruments. Any little change of form or dimensions found to be advantageous could be repeated with something like a certainty of obtaining the same result, because the wood was the same.

They were therefore placed at a great advantage over the modern maker, who knows little or nothing of the origin of his wood—no more in fact than the "middleman" who supplies it to him.

When Alessandro Gagliano went to Naples he must have taken with him something more than his mere knowledge of the handicraft of violin-making. He did not use the wood of the *Azzeruolo* (Neapolitan medlar-tree), nor even *Epicea* (? Pitch Pine),*

* It is curious that these woods should have been suggested as an explanation of the excellence of the old Italian instruments; but the solution of an enigma of this kind is often sought for in most unlikely quarters. The writer was once present at a conversation between an Englishman and a boot-maker in a continental town, when the former was praising the greater durability of the

and the consequence is that his instruments and those of his sons possess some of the beauty and "carrying power" of the "Cremona tone."

Thanks to Helmholtz, we know why a rod of pine, yielding the same *note* as a rod of glass, does not yield the same *tone;* but we have yet to learn the wherefore of the fact that the wood of the modern violin does not reinforce the same "demonstrable crowd of overtones" as the wood of the old Italian and Tyrolese instruments.

English boot. "C'est très vrai, monsieur," was the reply, "et je vous dirai pourquoi"; then in a half-whisper, "c'est parceque les anglais emploient du cuir *d'hippopotame*"!

In the meantime it would be a mistake to rest satisfied with the belief that the violin-making of to-day is more scientific than the violin-making of the seventeenth and eighteenth centuries. The whole doctrine of the existing theory of the violin, so far as concerns the practical construction of the instrument, may be very briefly paraphrased, "Copy the Italian makers; we do not know precisely why, but copy them as closely as you can." Very sound advice; and the first step is to discover the equivalent of their wood, especially the pine; though there is perhaps something more than meets the eye in the quaint remark made four centuries ago by Gruffydd ab Davydd ab Hywel, when describing the Welsh *Crŵth*, that "music is to be got out of the sycamore," and it seems safe to say that if any improvement is to be made in the modern violin, it will only be as the result of carefully recorded experiments on the properties of the two principal woods employed in the construction of the instrument.

There is another "rule" formulated by Savart, to the effect that in a properly-proportioned violin the back and belly when vibrated separately should give notes of different pitch.

There are two somewhat conflicting accounts of the experiments from which this rule is derived: one, contained in the report of the lectures delivered by Savart at the College of France in 1838-9, and published in *L'Institut* in 1840; and the other as given by Fétis in the book already mentioned.

Both accounts agree in stating that Savart detached the backs and bellies from several violins of Stradivari and Guarneri, and that on clamping them in a vice and vibrating them with a bow it was found that there was always a difference in the pitch of the notes emitted respectively by the back and belly of each instrument.

According to the account in

L'Institut,* the note given by the bellies of these instruments varied between C sharp and D, whilst the note of the backs varied between D and D sharp, so that the note given by the back might be anything from *o* to one tone *higher* than the note of the belly, but never lower.

Fétis, on the other hand, says that the back was always found to give a note exactly one tone *lower* than the belly.

This discrepancy has been keenly discussed, but there is nothing to show what Savart himself would have said on the matter, as he died before com-

* *Vide* Davidson's translation of Savart's lectures, *loc. cit.*

pleting the publication of the records of his experiments.

Mr Heron-Allen * adopts the version given in *L'Institut*, and holds that the back should give a note about a tone *higher* than the belly; stating that this opinion will be confirmed by the experience of any one who will make a fiddle; whilst Mr Bishop in his translation of Otto's book † maintains the version given by Fétis, arguing that Vuillaume, who assisted Savart in making the experiments in question, would have corrected

* *Loc. cit.*

† *A Treatise on the Structure and Preservation of the Violin.* Third Edition. London, 1875.

Fétis if his account had been incorrect. It certainly tells against the probability of the version given by Fétis, that the difference between the notes found in the instruments of two independent makers should be stated to have always been *exactly* the same.

However this may be, and whichever version be adopted, these experiments cannot be held to indicate any "scientific rule" for determining the relative dimensions of the tables of the violin. It is curious that in the report given by *L'Institut* we are told that besides this difference of note in the back and belly, the dimensions must be the same as in the instruments of Stradivari. Suppose then that we make a back and belly strictly to the dimensions of a Stradivari violin, it is obvious that they may or may not give the difference of notes we are told they should; and they certainly will not unless the two ratios $\frac{E}{d}$ are the same, or in the same proportion as in the woods of the instrument that is copied; but this would be a rare coincidence. Moreover, we cannot expect in this way to reproduce the qualities of Stradivari's instrument, unless we have the equivalent of his wood; but this we do not know, because, as already explained, we do not know what are the particular values of E* and *d* in that wood.

If, as is practically certain, we are working with two woods having different values to those of Stradivari's woods, there is nothing to warrant the conclusion that the same difference between the notes will also in this case give us the proper relative thicknesses of the two tables; and,

* It may be noted that the value of E in the present case is not the same as in the experiments with the rods. The mode of vibration of a thin, wide, and unsymmetrical plate is not so simple as that of a narrow rod; and the value of E (and consequently the pitch of the note) would depend on a combination of the two elasticities "along the fibres" and "across the rings."

moreover, this rule tells us nothing as to the *absolute* thicknesses, a matter of great importance.

There is one more rule laid down by Savart which deserves notice ; *viz.*, that the volume of air contained by the violin should be such that, when set in vibration by blowing in at one of the sound-holes, it should emit the note C of 512 vibrations (256 double vibrations). Savart states that this is always the case with the best instruments of Stradivari and Guarneri, and that any violin of the same size which does not comply with this condition is certain to be defective in tone.

But we are further told that the pitch of the note emitted depends on (1) the thickness of the tables, (2) the pressure exerted by the sound-post, (3) the height of the sides, and (4) the dimensions of the sound-holes.

There are consequently many ways in which an instrument may be adjusted, so as to make it give the required note, by ringing the changes in varying degrees with the four conditions mentioned.

Savart indeed recognizes the indeterminate character of these conditions, but says that "they are so related to each other that *one* being determined it is easy to determine the others." This of course is not so; and we cannot be sure that the solution arrived at will be the proper one.

At the same time there may perhaps be something more than mere coincidence in the results recorded by Savart; but if we have here any indication of a principle actually practised by the Italian makers, we have yet to discover the particular method by which they effected the adjustment of the pitch of the note.

We must however remember that many of the finest instruments have been fitted with new and stronger bass-bars, an alteration which would change the relation between the notes of the back and belly, as well as the pitch of the note emitted by the vibration of the contained air; and according to Savart the in-

The relative dimensions adopted for the violin and other instruments of the same tribe would appear to indicate that this should not be so.

It is impossible therefore to admit Savart's claim that these theories "determine the rôle of each part of the violin, and indicate the means of constructing excellent instruments resembling in *everything* the most perfect ones of Stradivari;" neither do they afford sufficient grounds for the opinion that the modern violin is "more scientific in its thicknesses" than the instruments of Giuseppe Guarneri del Gesù; an opinion not, of course, generally accepted, but on the contrary said to be "very difficult to hammer into the heads of amateurs and others."

The practical question is whether by varying the model, relative and absolute thicknesses of the tables, shape and position of the sound-holes, etc., we can compensate for the difference in the values of E and *d* possessed by the wood of the modern violin-maker. The innumerable trials of a century and a half seem to tell us that we cannot; and if by chance a violin-maker is fortunate enough to succeed in producing an instrument at all comparable with the old Italian masterpieces, he can give no explanation of the causes of his success; nor can he, unless pro-

vided with a further supply of the same wood, repeat his work with any certainty.

It is of course quite impossible to suggest anything like an exact course to be followed in the investigation of this question, but, in principle, what seems to be required is that the wood used in violin-making should be tested by experiments similar to those of Chevandier and Wertheim, and the properties of the wood carefully recorded. This would probably soon make it possible to form a tolerably exact idea as to why two woods, in appearance equally good but of such widely different densities as are now to be found in the market, are not equally suitable for violin-making; and though further progress might be slow, we should at least be on the way towards a more rational method of selecting the woods of the instrument.

APPENDIX

THE following are some of the general conclusions arrived at by Chevandier and Wertheim with respect to the variations observed in the mechanical properties (conductivity of sound, coefficient of elasticity, etc.) of the woods experimented with. They are of interest in connection with the present subject, and have a certain bearing on some of the conditions which are held to mark the suitability of wood for the violin:

(1) Rods cut from the same annual rings, and at the same height in the tree, but from parts exposed respec-

tively to the four cardinal points, present certain differences in their mechanical properties, without however indicating any relation between the variations observed and the position of the rod in the tree with reference to the cardinal points. The *maxima* and *minima* are found sometimes in one and sometimes in another of those parts of the tree.

The notion that there is some particular merit in wood "cut from the south side of the tree" is very possibly a survival of the theory suggested by Musschenbroek in 1726, to the effect that the colder temperature on the north side of the tree checks the development of the wood. This theory was founded on very insufficient data.

(2) In fir, pine, hornbeam, maple, sycamore, aspen, birch, and to some extent in acacia, the mechanical properties increase in value in a constant manner from the centre towards the circumference; though there is somesometimes a slight falling off in the values for wood cut near the bark. This increase from the centre towards the circumference is especially marked in the resinous woods, and seems independent of the age of the tree. In large trees the coefficient of elasticity in the outer rings is often double, and sometimes more than double, that found in wood from the centre of the tree. Oak and birch are exceptions to this rule, and in these two woods the highest coefficient of elasticity is generally found at about one-third of the radius from the centre of the tree.

(3) The mechanical properties are generally found to decrease in value in proportion to the height in the tree.

(4) The season in which the tree is felled does not appear to have any influence on the mechanical properties of the wood.

In the ordinary treatment of timber it is no doubt better that the tree should be cut when the sap is down, as the wood is then less liable to warp, split, etc.; but there is not sufficient knowledge of this subject to enable one to say whether cutting the wood with the sap in is detrimental, or otherwise, to the particular properties of the wood which constitute its merits in violin-making.

(5) The coefficient of elasticity seems, in a general way, to diminish

with the age of the tree; but there is no uniformity in this respect.

(6) The relative thickness of the annual rings cannot be considered the cause of the variations observed in the properties of the wood from different parts of the same tree, nor in woods from different trees; though narrow rings generally indicate a high coefficient of elasticity. In fir there is often a gradual narrowing of the rings from the centre towards the circumference, but even in a contrary case there is still an appreciable increase in the coefficient of elasticity, as noted above.

The common rule in this matter is that the rings should be "not too wide and not too narrow"; and Maugin in his *Manuel du Luthier* recommends two millimetres as about the best width;

but it seems very doubtful whether any rule can be laid down in this matter.

(7) Woods grown in situations exposed to the north, and in dry ground, always possess a comparatively high coefficient of elasticity; and all the higher when these two conditions occur together; whilst woods grown in marshy land have low coefficients of elasticity.

The popular rules that wood for violin-making should be "grown on a southern slope" and at the same time possess a high conductivity of sound may therefore be antagonistic.

(8) In the same tree the variations in the mechanical properties nearly

always accompany each other in the same direction. For instance, the densest part of the tree generally possesses the highest conductivity of sound, and consequently the highest coefficient of elasticity; but this relation, which is not constant in the same tree, rarely holds good in different woods of the same species; and disappears altogether in woods of different natural orders.

Though the examination of woods other than those employed in violin-making might not have any direct bearing on the subject, there would still appear to be scope for the research of points of difference between such woods and those known to be suitable for the construction of the instrument. There is always the chance that any peculiarity found in the physical or mechanical properties of the pines (or firs) and the sycamores, may prove a clue to the discovery of the particular qualities that should be sought for in their highest degree in those two woods themselves; and which make them *par excellence* the proper materials for the violin.

Knowing the velocity V of the sound pulse along a rod (see foot-note p. 43-44), and the density d of the wood, the coefficient of elasticity is given by the relation

$$E = \frac{V^2 d}{g}$$

Taking as units: for dimensions, the millimetre; for weight, the kilogramme; for the velocity of sound, its velocity in air (say 332226 millimetres = 1090 feet per sec.); for density, the specific weight of water ($\frac{1}{1000000}$ kilo. per cubic millimetre); then with $g = 9810$ millimetres (= 32·2 feet) per second, the above equation may be written:

$$\log E = 2 \log V + \log d + 1{\cdot}05119$$

It is of course still possible to determine the density, and consequently the coefficients of elasticity "along the fibres," and perhaps "across the rings," (though not "along the rings") of the woods in old violins; but it would be impossible to say to what extent they have been affected by the varnish.

It seems practically certain that age increases the ratio $\frac{E}{d}$ (and consequently the pitch of the note emitted by the wood), since *d* must diminish owing to the evaporation of volatile matter; and there may possibly be an increase in the value of E due to the vibration of the instrument, for, up to a certain limit, strain is sometimes found to raise the coefficient of elasticity.