CLASSICS OF SCIENCE:

Helmholtz on Harmonizing Music

"The series of tones which... combine with a given fundamental tone, is perfectly determinate. They are tones which perform twice, thrice, four times, etc., as much vibrations in a second as the fundamental tone. They are called the upper partials, or harmonic overtones, of the fundamental tone. If this last be c, the series may be written (as above) in musical notation (it being understood, on account of the temperament of a piano, these are not precisely the fundamental tones of the corresponding strings on that instrument, and that in particular the upper partial, b, is necessarily much farther than the fundamental tone of the corresponding note on the piano)."—Helmholtz.

Marchese Corti discovered some very remarkable formations in the middle section. They consist of innumerable plates, microscopically small, and arranged orderly side by side, like the keys of a piano. They are connected at one end with the fibres of the auditory nerve, and at the other with the stretched membrane. . .

In the so-called vestibulum, also, where the nerves expand upon little membranous bags swimming in water, elastic appendages, similar to stiff hairs, have been lately discovered at the ends of the nerves. The anatomical arrangement of these appendages leaves scarcely any room to doubt that they are set into sympathetic vibration by the waves of sound which are conducted through the ear. Now if we venture to conjecture—it is at present only a conjecture, but after careful consideration I am led to think it very probable—that every such appendage is tuned to a certain tone like the strings of a piano, then the recent experiment with a piano shows you that when (and only when) that tone is sounded the corresponding hair-like appendage may vibrate, and the corresponding nerve-fibre experience a sensation, so that the presence of each single such tone in the midst of a whole confusion of tones must be indicated by the corresponding sensation.

Experience then shows us that the ear really possesses the power of analysing waves of air into their elementary forms.

By compound motions of the air, we have hitherto meant such as have been caused by the simultaneous vibration of several elastic bodies. Now, since the forms of the waves of sound of different musical instruments are different, there is room to suppose that the kind of vi-
Harmony—Continued

ibration excited in the passages of the ear by one such tone will be exactly the same as the kind of vibration which in another case is there excited by two or more instruments sounded together. If the ear analyses the motion into its elements in the latter case, it cannot well avoid doing so in the former, where the tone is due to a single source. And this is found to be really the case.

I have previously mentioned the form of wave with gently rounded crests and hollows, and termed it simple or pure. In reference to this form the French mathematician Fourier has established a celebrated and important theorem which may be translated from mathematical into ordinary language, thus: Any form of wave whatever can be compounded of a number of simple waves of different lengths. The longest of these simple waves has the same length as that of the given form of wave, the others have lengths one-half, one-third, one-fourth, &c. as great.

By the different modes of uniting the crests and hollows of these simple waves, an endless multiplicity of wave-forms may be produced. . . .

Ear Analyzes Waves

Not only strings, but almost all kinds of musical instruments, produce waves of sound which are more or less different from those of simple tones, and are therefore capable of being compounded out of a greater or less number of simple waves. The ear analyses them all by means of Fourier’s theorem better than the best mathematician, and on paying sufficient attention can distinguish the separate simple tones due to the corresponding simple waves. This corresponds precisely to our theory of the sympathetic vibration of the organs described by Corti. Experiments with the piano, as well as the mathematical theory of sympathetic vibrations, show that any upper partials which may be present will also produce sympathetic vibrations.

It follows, therefore, that in the cochlea of the ear, every external tone will set in sympathetic vibration, not merely the little plates with their accompanying nerve-fibres, corresponding to its fundamental tone, but also those corresponding to all the upper partials, and that consequently the latter must be heard as well as the former.

Hence a simple tone is one excited by a succession of simple wave-forms. All other wave-forms, such as those produced by the greater number of musical instruments, excite sensations of a variety of simple tones.

Consequently, all the tones of musical instruments must in strict language, so far as the sensation of musical tone is concerned, be regarded as chords with a predominant fundamental tone.

The whole of this theory of upper partials or harmonic overtones will perhaps seem new and singular. Probably few or none of those present, however frequently they may have heard or performed music, and however fine their musical ear, have hitherto perceived the existence of any such tones, although, according to my representations, they must always be present and continuously present. In fact, a peculiar act of attention is required to hear them, and unless we know how to perform this act, the tones remain concealed. As you are aware, no perceptions obtained by the senses are merely sensations impressed on our nervous systems. A peculiar intellectual activity is required to pass from a nervous sensation to the conception of an external object, which the sensation has aroused. The sensations of our nerves of sense are mere symbols indicating certain external objects, and it is usually only after considerable practice that we acquire the power of drawing correct conclusions from our sensations respecting the corresponding objects. Now it is a universal law of the perceptions obtained through the senses, that we pay only so much attention to the sensations actually experienced, as is sufficient for us to recognise external objects. In this respect we are very one-sided and insconsiderate in our practical utility; far more so indeed than we suspect. All sensations which have no direct reference to external objects, we are accustomed, as a matter of course, entirely to ignore, and we do not become aware of them till we make a scientific investigation of the action of the senses, or have our attention directed by illness to the phenomena of our own bodies. Thus we often find patients, when suffering under a slight inflammation of the eyes, become for the first time aware of those beads and fibres knows as mouches volantes swimming about within the vitreous humour of the eye, and then they often hyppochondriacally imagine all sorts of coming evils, because they fancy that these appearances are new, whereas they have generally existed all their lives. . . .

To this class of phenomena belong the upper partial tones. It is not enough for the auditory nerve to have a sensation. The intellect must reflect upon it. Hence my former distinction of a material and a spiritual ear.

We always hear the tone of a string accompanied by a certain combination of upper partial tones. A different combination of such tones belongs to the tone of a flute, or of the human voices, or of a dog’s howl. Whether a violin or a flute, a man or a dog is close by us is a matter of interest for us to know, and our ear takes care to distinguish the peculiarities of their tones with accuracy. The means by which we can distinguish them, however, is a matter of perfect indifference.

Whether the cry of the dog contains the higher octave or the twelfth of the fundamental tone, has no practical interest for us, and never occupies our attention. The upper partials are consequently thrown into that unanalysed mass of peculiarities of a tone which we call its quality. Now as the existence of upper partial tones depends on the wave form, we see, as I was able to state previously, that the quality of tone corresponds to the types of waves.

Hermann Ludwig Ferdinand von Helmholtz was born August 31, 1821, at Potsdam, near Berlin, and died in Berlin September 8, 1894. He was trained as a surgeon in the Prussian army, and most of his early discoveries were in the field of physiology. At the age of 21, his first scientific paper announced the presence of nerve-cells in ganglia. The field of physics, however, soon claimed his attention, and five years later, in 1847, he read before the Physical Society of Berlin a paper on the Conservation of Force which was one of the foundation stones of that doctrine. In 1849 Helmholtz became professor of physiology at Königsberg, and in later years filled the same position at Bonn and Heidelberg. In 1851 he invented the ophthalmoscope, by which one may see the interior of the living eye. It is one of the greatest instruments of medical science. His studies on the eye appeared in 1856-66 as the Physiological Optics. A corresponding work on the ear, Sensations of Tone, appeared in 1862. Studies on electricity interested him next, and in 1871 he found that the speed of electromagnetic induction is about 314,000 miles per second. In the same year Helmholtz became professor of physics in the University of Berlin. He was then 50 years old. The remainder of his life was devoted to physical rather than physiological researches.

Science News-Letter, March 31, 1938

One pair of twins occurs in about 100 births.

Some of the most beautiful garnets come from Arizona.