Baltimore in December last. At the January meeting of the Seminary, he read a paper "On Two Cases of the Quadric Transformation between two Planes," and has subsequently read other papers, and been a contributor to the *Journal*. But the result of his visit has been the delivery of "a systematic and highly original course of lectures upon Algebraical Geometry, in connection with the Abelian and Theta Functions."

These lectures, we hope, will be given, in book form, to a more extended audience. Besides the ordinary class lectures, given by the able staff of assistant professors, some of whom are well known to mathematicians here, short courses of lectures have been delivered by Mr. C. S. Peirce (who has recently annotated and published in the *American Journal* his father's fine work on "Linear Associative Algebra"), on the Logic of Relatives, by Dr. Story; on the Clebsch-Gordan invariantive theory; and by Dr. Craig, on the Construction and Direction of a Riemann's surface (how these two last courses recall to our minds a departed master.)

Leibnitz somewhere says "Les mathématiques sont l'honneur de l'esprit humain;" if this be so, then the University has done well in assigning so great a part of its time and resources to the study of the higher branches of this department of knowledge. But indeed Johns Hopkins is a true university, for it is catholic in its sympathies, and enfolds in its wide embrace all branches of culture and learning.

In No. 13 is an abstract of a lecture before the students by Dr. James Bryce, M.P., on our English universities.

R. T.

KŒNIG'S EXPERIMENTS IN ACOUSTICS

I.

IN the volume mentioned below[1] Dr. Kœnig has collected the valuable series of researches in experimental acoustics that have been published by him chiefly in the *Annalen* of Poggendorff and of Wiedemann during the past twenty years. Many of these researches are well known in England, having attained to "classic" importance, and their main results are to be found embodied in all the best text-books of acoustics. Other researches of more recent date are yet known only to the few, but will doubtless win their way to general knowledge before long. The most novel points in the book are the late researches of its author with the ingenious instrument known as the wave-siren. This invention Dr. Kœnig has applied to support his views upon the origin of the beats of imperfect consonances, and also to investigate the influence of differences of phase upon the quality of tones. The general nature of the wave-siren has already been explained in the pages of NATURE, but in the sequel we will attempt to describe fully its most recent forms, as applied in the last investigation. In addition to these deeply interesting matters of recent research, there is a mine of wealth contained in the volume. The first chapter deals with the application of the graphic method in acoustics; an equally interesting chapter on manometric flames and their applications occur a little further on. Dr. Kœnig's researches on the standard tuning-fork or "*diapason normal*" are too well known to need comment. The reader will find the whole series of papers collected in Chapter XIII. He will also find notices of an adjustible tuning-fork capable of giving a variety of tones, of a curious tuning-fork clock, of new stethoscopes, of instruments for producing continuous beats audible to a large company of persons, together with researches on the phase of vibration of two associated telephones, on the fixed notes charcteristic of the different vowel sounds, and on several other matters of great importance. He must not, indeed, expect to find deep mathematical insight nor folios of analytical equations. But he will find a perspicuous and fascinating record of experiments planned with rare ingenuity, carried out with honesty, patience, and consummate skill, by the man whose exceptional abilities as experimentalist and constructor have done more than those of any other physicist to make the science of experimental acoustics what it is to day.

In the present article we shall refer in some detail to Dr. Kœnig's researches on the influence of phase upon the quality of sound.

It has long been an accepted doctrine of acoustics that every continuous sound possesses three recognizable characteristics, viz., *pitch*, *intensity* and *quality*, and that these three characteristics depend respectively upon the frequency, the amplitude, and the degree of complexity of the sonorous vibrations. The third of these characteristics, the *quality* of a sound, has also been denominated "*timbre*" or "*clang-tint*" by those who affect Gallic or Teutonic proclivities in scientific nomenclature. Everyone now knows that, by whatever name this third characteristic is called, it constitutes the almost indefinable yet perfectly recognizable difference which exists between a note as played on one musical instrument and the same note as played upon another. The notes may be the same in pitch and in intensity, but there is a residual difference in quality that the dullest ear cannot mistake.

It was by one of the finest pieces of scientific research by Germany's greatest living physicist, that the true cause of this mysterious "quality" was established. Helmholtz's great work on *The Sensations of Tone* takes for its basis the fact that with every fundamental "tone" or perfectly simple sound there co-exists a whole series of "partial tones," which together with the fundamental make up the mass of sound that we usually call a "note." All our musical instruments yield us complex sounds in which every fundamental is accompanied by a variety of upper partial tones (sometimes called by mistranslation "overtones"; and also, by a far more serious mistake, "harmonics), the number of such upper partials and their relative intensity being a consequence of the conditions of vibration in the instrument. Hence instruments having different kinds of vibrating parts—strings in one, reeds in another, columns of air in another—will emit tones that vary in number and intensity of accompanying partial tones; and the ear taking the mass of complex vibration as a whole will pronounce that there is a difference *in quality*. Helmholtz's theory, in short, asserts that the quality of a tone depends on the following points: firstly, whether there were any upper partials present; secondly, what those upper partials were; thirdly, what their relative intensity toward one another and toward the fundamental note might be. Thus, for example, the thin quality of the notes of wide, stopped organ-pipes, which contrasts both with the full rich quality of the pianoforte notes, and with the harsh, strident, irrepressible notes of the harmonium, becomes intelligible when it is rendered plain that in the first case there is an almost complete absence of upper partials, that in the second the partials, though numerous, are loud only for such partial tones as are concordant with the fundamental, while in the third discordant partials, loud and shrill mingle with the fundamental.

But there is a negative proviso in Helmholtz's theory of a very important kind, namely, that differences in quality of tone depend "*in no respect on the differences in phase under which these partial tones enter into composition*."[1]

This negative law, which Helmholtz has sought to confirm by various experimental proofs, is a consequence of the hypothesis that the ear unconsciously analyzes complex sounds into their simple elements—the partial tones—each simple (partial) tone actuating a separate part of the nerve-structures of the ear. Before Helm-

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[1] "Quelques Expériences d'Acoustique." Par Rudolf Kœnig. (Paris: R. Kœnig, 27, Quai d'Anjou, 1882.)

[1] *Helmholtz*. Sensations of Tone (Ellis's Translation) p. 186.

holtz's time, the theory had been propounded that quality depended on the *form* of the vibrations of the wave of sound; but since differences of phase greatly affect the form of the vibration, Helmholtz was forced either to abandon the new hypothesis that the ear thus decomposes complex tones into simple ones, or else to establish by experiment that no difference of phase affected the perception of quality by the ear.

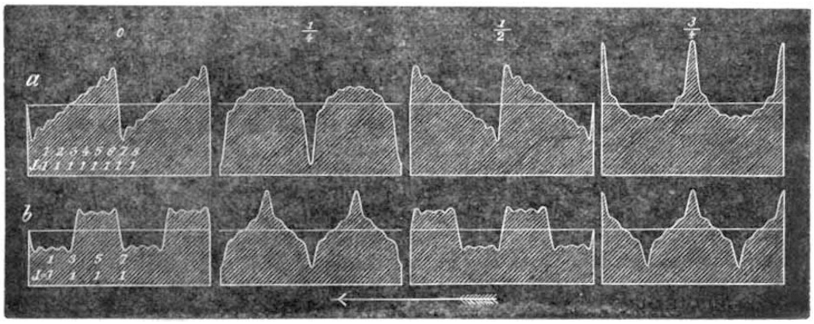

FIG. 1.—Resultant curves formed by compounding together the wave-forms of a harmonic series of simple tones of equal intensity but differing in phase.

The difference of form introduced into a complex vibration by a difference of phase between its components is already known; but Kœnig has brought forward some very striking examples. Fig. 1*a*, for example, gives the curves which result from compounding together the wave-forms of a note and its first eight upper partials, each of the nine tones being of equal intensity. Of the four curves ranged in line the first corresponds to the resultant when the components start at similar phases, each component beginning from zero with descending ordinates. In the second of the row, each of the separate component waves begins with a negative ordinate of maximum amplitude, or differing in phase by one quarter from the first case. In the third the difference is half a wave-length, and in the fourth case three-quarters of a wave-length. It will be noticed how very different these curves are to the eye, though compounded of the same elements. It will also be observed that the curves for

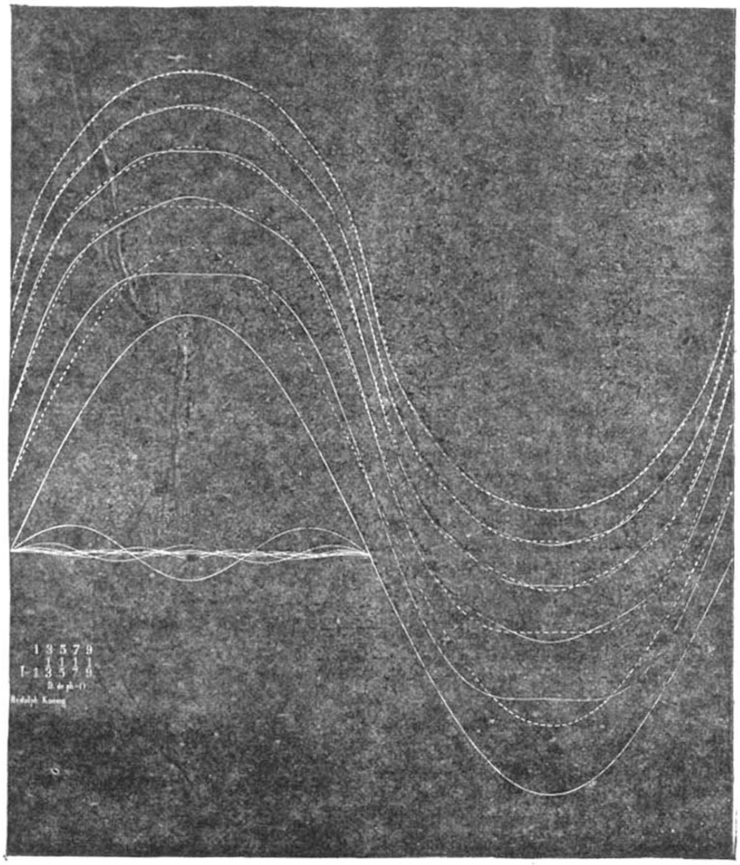

FIG. 2.—Resultant wave-form for odd members of series of upper partial tones when there is no difference of phase.

difference of phase = $\frac{1}{2}$ is a reversed copy of that for which the difference of phase = 0; while the curves for phase-difference $\frac{1}{4}$ and $\frac{3}{4}$ are reversed copies of one another. Now, according to Helmholtz's theory, all these forms of vibration should yield identical sounds in the ear. Kœnig finds, on the contrary, the startling result that the sounds are perceptibly different in quality. His proof is extremely simple. The curve, calculated graphically with great care, is set off upon the circumference of a cylindrical band of thin metal, the edge being then cut away leaving the shaded portion, the curve being repeated half a dozen times, and meeting itself after passing round the circumference. For convenience the four curves to be compared are set out upon separate rims of metal, all of which are mounted upon one axis to which a rapid motion of rotation can be imparted. Against the indented edges of these rims wind can be blown through an appropriate slit; the whole combination forming a variety of the Wave-Siren described a few months ago in the columns of NATURE (p. 358, vol. xxiv.). It will be obvious that as these indented curves pass in front of the slit the maximum condensation will result when the slit is least covered, or when the point of greatest depression of the curve crosses the front of the slit. The negative ordinates of the curves correspond therefore to condensations, the positive ordinates to rarefactions. Now, according to Kœnig's experiment, the sound is louder and more forcible, with a difference of phase of $\frac{1}{4}$, than in any other case, that with $\frac{3}{4}$ difference being the most gentle and soft in tone; whilst the curves of phase 0 and $\frac{1}{2}$ yield intermediate qualities of tone. Kœnig also finds that by combining simply a note and its octave, the loudest resultant sound occurs when the phase of combination is $\frac{1}{4}$, a difference of phase of $\frac{3}{4}$ again yielding the feeblest resultant. In Fig. 1, *b*, four curves are shown corresponding to the combination of the odd members, 1, 3, 5, 7, 9, of the harmonic series, taken as before as of equal intensity. In this case the form of the waves is identical for the phases 0 and $\frac{1}{2}$ and also for the phases $\frac{1}{4}$ and $\frac{3}{4}$. The latter yield a loud and strident tone as com-

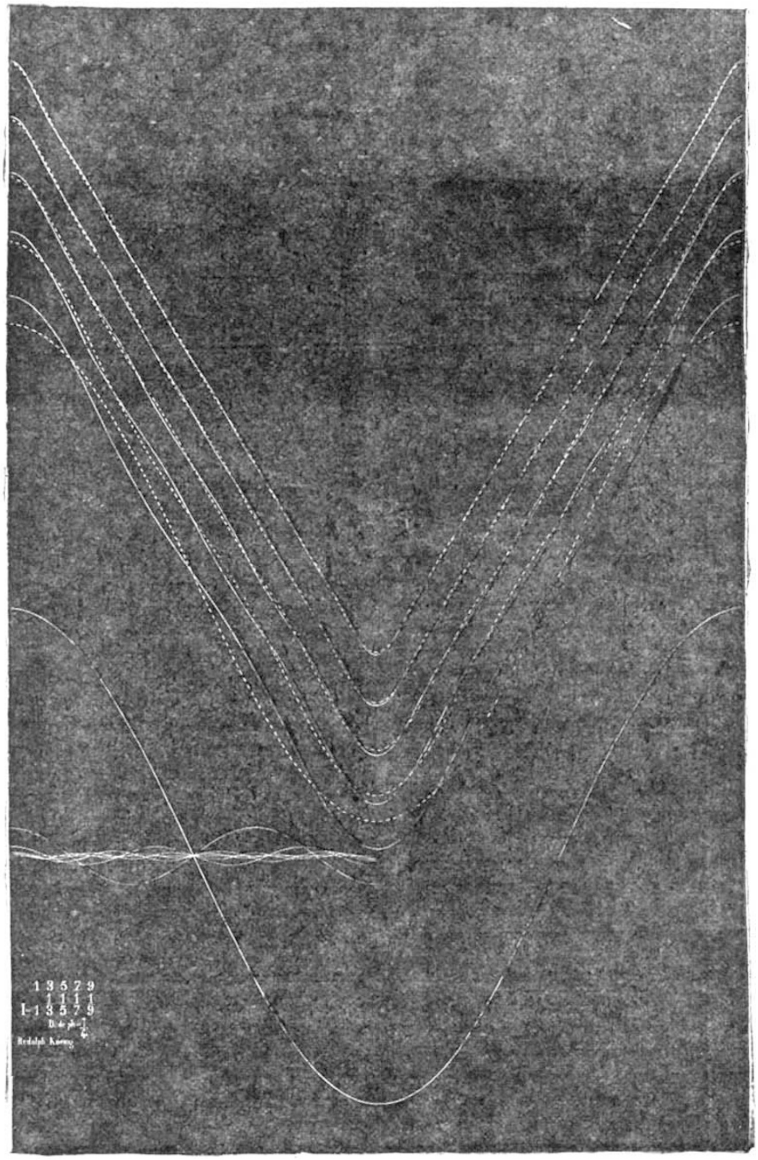

FIG. 3.—Resultant wave-form for odd members of series of upper partial tones when the difference of phase is a $\frac{1}{4}$.

pared with the former, though according to Helmholtz's theory their tones should be alike. It may be objected to these illustrations that in all natural sources of tone one never finds a whole series of partial tones every member of which is equally loud as the fundamental tone. It is more nearly true for most musical instruments that the higher up one goes in the series of partial tones the feebler are they in comparison with the fundamental tone.

Accordingly, Kœnig has combined, as in Fig. 2, a series of partial tones corresponding to the respective frequencies 1, 3, 5, 7, 9, making the amplitude of each partial tone inversely proportional to its frequency. The separate curves are shown in Fig. 2, both grouped about a horizontal line, and also as successively superposed upon the fundamental. The uppermost of the set of curves exhibits the final resultant; which, in this case, where the difference of phase is taken as *nil*, and all the components rise from zero together, is seen to consist of bold, well-rounded sinuosities. In Fig. 3, curves identical in wave-length and amplitude, but differing in phase by $\frac{1}{4}$, are compounded together; but the final resultant shows a wave-form that is practically a zig-zag. Now if these bold sinuosities and zig-zags be cut out in thin metal and curled up into circumferences so as to adapt them to use as wave-sirens in the manner before-mentioned, it is again found that the zig-zags corresponding to differences of phase $\frac{1}{4}$ and $\frac{3}{4}$ yield always harsher and louder tones than the rounded sinuosities that correspond to 0 and $\frac{1}{2}$.

These observations are very remarkable, and have important bearings that must be left for discussion in the next article on Kœnig's work.

For the present we will conclude by observing that more than once it has been pointed out that a certain perception of difference of phase did exist. Sir W. Thomson has suggested that there is evidence of this in the phenomenon of slow beats which by a curious acoustic illusion almost always suggest the idea of something revolving. The writer of this notice had also previously pointed out that in certain cases where a compound sound was led separately to the two ears a difference of phase between the components could be detected.

It may not be generally known that Dr. Kœnig has quite recently republished under the title of "*Quelques Expériences d'Acoustique*" the most important of his recent researches, including those on the Wave-Siren and on the Beats of Imperfect Consonances. The figures herewith presented, and those which will accompany the continuation of this notice, are taken by Dr. Kœnig's courteous permission from this his very valuable contribution to experimental acoustics. S. P. T.

THE RAINFALL OF THE GLOBE

PROF. LOOMIS has recently contributed a paper on this subject to the *American Journal of Science* of no small interest and value. The paper gives the mean annual rainfall at 713 places in all parts of the globe, and the results are graphically represented on a map of the world as closely as can be done by five tints of one colour. These tints represent respectively annual amounts of rain under 10 inches, from 10 to 25 inches, 25 to 50 inches, 50 to 75 inches, and above 75 inches. It is stated that the map is merely a provisional one, it being Prof. Loomis's expressed intention to publish a list of additional observations with a revised edition of the map; and in the meantime he invites the assistance and criticism of meteorologists in furtherance of the work.

The map shows unquestionably the broad features of the geographical distribution of the rainfall of the globe, so that any changes that will be made in a future issue, however interesting and important these may be locally, will only be rectifications of the iso-hyetal lines in some of their subordinate details.

Leaving out of consideration all exceptionally heavy rainfalls confined to limited spots, such as those of Cherapunji, in Assam, which amounts to 492 inches annually, and the Stye, in Cumberland, which is about 190 inches, the heaviest rainfall is met with in the rain-belt, which surrounds nearly the whole globe lying between the north-east and south-east trade-winds. Absolutely the largest rainfalls over large regions are to be found where the trade-winds, after having traversed a great breadth of ocean, are forced against and over a breadth of land, of some elevation and extent which lie across their path. Of these the best examples are the highlands of Java, Sumatra, and Assam, in the Old World, and parts of the north of South America, and of the steep slopes of Mexico facing the Gulf of Mexico in the New World, over which the trades or monsoons discharge their moisture so copiously as to raise the rainfall over large tracts up to, and in cases considerably above 200 inches annually. The influence of height is well illustrated by the rainfall of Mauritius; thus, while at the observatory it is 46 inches, it amounts at Cluny to 149 inches on a mean of the same 19 years. Similarly in St. Helena, while near the sea-level it is only 5 inches, at a height of 1764 feet it is 48 inches. In Ascension, no part of which rises to any considerable height, the annual rainfall is only 3 inches, and the whole island is little else than a burned-up desert.

The rainfall is particularly large in mountainous regions in both hemispheres above lat 40°, situated on the eastern shores of the great oceans, and consequently in the full sweep of the strong westerly winds of these high latitudes. Thus large portions of Scotland north of the Clyde, one or two small patches in England, a few spots in Ireland, large tracts between California and Alaska, the south of Chile, and the west coast of the south island of New Zealand have an annual rainfall exceeding 80 inches. Nay, even at Bergen, lat. 60° 23′ N., bathed in the warm, moist, westerly winds of the Atlantic, the rainfall is 73 inches annually, which is the largest rainfall yet observed anywhere at so high a latitude. Those headlands, even though of comparatively small height, which ran out into the sea, meeting the moist oceanic winds, have rainfalls very considerably above the average—owing doubtless largely to the greater friction of land than water on the winds, thus partially arresting their progress, and inducing a more copious precipitation.

As causes of deficient rainfall, Prof. Loomis enumerates five, viz.: (1) a uniform direction of the winds during the year, such as prevails within the regions of the trades, illustrated by the rainfall of Ascension, Sahara, and South California; (2) the prevailing wind having crossed a mountain range, thence descends on the leeside, illustrated by desert of Gobi, Chili, and large tracts in Spain; (3) ranges of mountains so high as to obstruct the free movement of the surface-winds towards the interior, as parts of Central Asia and California; (4) remoteness from the ocean measured in the direction from which the wind proceeds, illustrated by the gradual diminution of the rainfall on advancing eastward into Europe; and (5) high latitudes, since beyond lat. 60°, at a little distance from the ocean, it seldom exceeds 10 inches, and there are apparently large tracts in North America and Asia, where the rainfall is less than 10 inches. As regards this last statement, observation scarcely bears it out, since in Europeo-Asiatic continent, only two stations in latitude the above 60°, viz. Kola in Russian Finland, on the Arctic Sea, and Yakutsk, show rainfalls less than 10 inches, and these are doubtful owing to the short periods over which the observations extend.

The truth is there are other causes powerfully influencing the distribution of the rainfall than these, which an examination of the rainfall of the individual months, notably January and July, best discloses. These causes have their explanation in the systems of low and high pressures, which appear and disappear with season. Of these the most