A short history of bad acoustics

M. C. M. Wright[a)]
Institute of Sound and Vibration Research, University of Southampton, Southampton SO17 1BJ, United Kingdom

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Every branch of science attracts its share of cranks and pseudoscientists, and acoustics has been no exception. A brief survey of those who touched on acoustics is given with quotations from the more interesting or egregious examples. A contrast is drawn between the nineteenth century contrarian's quarrel with particular theories and the modern new age wholesale rejection of theory. This world-view is traced back to the later scientific writings of Goethe. Examples of pseudoscience applied to biomedical acoustics, architectural acoustics, and audio reproduction are given. © *2006 Acoustical Society of America.* [DOI: 10.1121/1.2336746]

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I. INTRODUCTION

"Bad acoustics" is not the same as "wrong acoustics." Acoustical science has progressed to its present, well-attested status by continuous debate, and it would be quite wrong to fault those who, for honest reasons, found themselves on the losing side of an argument. After all, as pointed out by Jeng,[1] when Laplace calculated his correction to Newton's famous underprediction of sound speed he made two errors that luckily canceled each other out.

Nor is "bad acoustics" the same as "odd acoustics." The story of Darwin playing the bassoon to worms is often given as an example of scientific eccentricity. In fact it was part of an entirely sensible test to ascertain whether they could hear, or sense vibrations directly through their bodies (he also tried the piano and a metal whistle[2]).

There is, however, a distinct strand of acoustical pseudoscience, which has produced some particularly strange and, in some cases, remarkable publications, and it is these that will be reviewed in this article.

II. DOWN WITH WAVES!

A. Alexander Wilford Hall (1819–1902)

In 1877 a Methodist clergyman from New York named A. Wilford Hall published a book called "The Problem of Human Life: Here and Hereafter," [3] Its second edition was issued in 1883 and is available for purchase today in a print-on-demand facsimile edition. His aim was to present scientific arguments against Darwinian evolution which he felt to be incompatible with religion. He was neither the first nor the last to do so, and if that were all he did his book would be of little interest to us. What is of interest is this promise from the preface:

> Prior, however, to undertaking the task of breaking through the entrenched works of the evolutionist, and in order to prepare the reader for placing the proper estimate upon these so-called scientific theories which assume to overthrow religion […] I resolved, as an example of what might be expected in the future, to attempt the overthrow of one of the universally accepted theories of science […] namely, the Wave-Theory of Sound, out of which has been developed the Undulatory Theory of Light and the more recently constructed theory of Heat as a Mode of Motion.

Wilford Hall's claim that he will take on the wave theory of acoustics as a sort of warm-up lap before overthrowing evolution is disingenuous. His true motive is shortly revealed:

> In this seemingly preposterous and hazardous attempt I was necessarily compelled to undertake the additional task of reviewing no less an authority than Professor Tyndall (the ablest and most popular exponent of the sound-theory now living), and of thus demonstrating the complete unreliability and defenselessness of the scientific opinions and statements of one of the most aggressive advocates of modern evolution, even when treating on the simple facts of science and making the most ordinary philosophical deductions.

Tyndall's book "Sound" had, by this time, become a recognized classic of popular science.[4] In his introduction to the third edition of 1875 Tyndall notes with satisfaction that it had been translated into German in an edition supervised by no less an authority than Helmholtz, and also into Chinese. Acoustics was just one of Tyndall's many scientific interests and in his time he was renowned as a passionate scientific educator and proponent of evolution, and it is this last fact that surely roused Wilford Hall. Another reason to attack Tyndall, as opposed to other acousticians, is that his book was eminently readable by those without higher scientific education when compared to that of, say, Rayleigh. Indeed, Wilford Hall gives no sign that he is even aware of Rayleigh's existence. His relish for the assault on Tyndall, as well as his misunderstanding of acoustics can be seen in the following extract (emphasis in the original):

> Whether two unison forks, or other instruments, if sounded half a wave-length apart, with the ear stationed in line, can be heard the same as in any other position, must absolutely settle the whole undula-

a)Electronic mail: mcmw@isvr.soton.ac.uk

> tory problem, now and forever. *If they can be heard the same in that as in any other position, which the whole world knows to be a fact, then the wave-theory falls to pieces, and with it falls Professor Tyndall as a scientist!*

In fact, by being sure to attack Tyndall on every possible point he did manage to score one hit. In "Heat: a Mode of Motion" [5] Tyndall uses the concept of the luminiferous ether to describe the transmission of light, memorably pointing out that

> Here your conceptions must be perfectly clear. It is just as easy to picture a vibrating atom as to picture a vibrating cannonball; and there is no more difficulty in conceiving of this *ether*, as it is called, which fills all space, than in imagining all space filled with jelly.

The fact that Wilford Hall was right to disagree with this is only marginally to his credit; as the saying goes even a broken clock will be right twice a day.

Wilford Hall's style of writing, taken in small doses, has a preacher's eloquence to it; when comparing Christian theists with the free-thinkers Underwood and Ingersoll in his first chapter he rhapsodizes that:

> The one represents the glorious eagle which is never so proud and happy as when facing the sun and soaring toward heaven, while the other is a fit symbol of the buzzard, whose glory is in its shame and whose fondest felicity is in feasting on filth.

His arguments, however, are long-winded in the extreme and he often puts words in his adversary's mouths, in one case going so far as to stage-manage an imaginary debate:

> I wish I could have the opportunity of saying to Mr. Comte, Sir: Your impression of the tree's existence is not a reality at all […] Should he admit this, as he would be forced to do by his own logic, I would then take him a step further […] Thus I might keep him going with this house-that-Jack-built logic […] till he would be totally lost in the labyrinths of his own metaphysical confusion, and be obliged to admit […]

and so on.

So what was his argument with acoustics? He described his own philosophy as Substantialism, and held that all things are material substances. He applied this principle theologically to human souls, and physically to sound waves, which he believes to be corpuscular. Naturally, he shows supreme confidence in his theory:

> Should any physicist a hundred years hence happen to be so illy informed and so far behind the age as to believe in and advocate the preposterous position involved in the current wave-theory of sound, the educated scientist of that epoch in attempting to set him right will then feel about the same indefinable sensation of pity mingled with disgust that the astronomer of to-day feels when hearing some scientific lunatic urge, as is sometimes the case, that the earth can not revolve on its axis, because if it did so it would overturn the water-bucket; or that the writer of this review is compelled to feel while trying to convince Professors Tyndall, Helmholtz, and Mayer that a locust can not, by moving its legs, throw four cubic miles of air into condensations and rarefactions, and thus exert a mechanical pressure of thousands of millions of tons!

He repeatedly returns to the example of a locust or a cricket, which can be heard from a great distance. He calculates the volume of air that would have to be set in motion for this to happen by waves, and then, fatally, assumes this body of air to be moving in unison, that is to say in solid body motion. He then divides the force necessary to achieve this by the area of a locust's leg to achieve his value of pressure. His preferred explanation is that anything that emits sound exudes particles and that sound works like smell. He was prepared for the counterargument that the locust would have to fill four cubic miles with sound particles, pointing out that some substances can be smelled over comparable distances without losing appreciable mass.

He was also unsatisfied that something as small as the human eardrum can respond to sound whose wavelengths in air can be meters long. Never one to leave a point unlabored he scripts the following imaginary exchange between Helmholtz and Steinway.

> HELMHOLTZ. Good morning, Mr Steinway. What in the world are you making there, in which you seem to be so deeply absorbed?
>
> STEINWAY. A grand piano, sir;—an improvement that is going to revolutionize the business, based on late acoustical discoveries which do away with the necessity of such enormous size and expense in construction. I am building, sir, a vest-pocket piano,—one that a musician can carry with him, where he goes, as easily as he can carry his watch. There are millions in it!
>
> HELMHOLTZ. What length, Mr. Steinway, do you propose to have the strings?
>
> STEINWAY. The longest string, or those producing the lowest notes of the bass, according to my improved scale, which I have just completed, will be exactly one inch in length, while, for the highest notes, seven octaves above, the strings will be just half that length.
>
> HELMHOLTZ. Mr. Steinway, you are a practical joker. But come, now, be serious. We Germans do not deal in jokes when we come to mechanical improvements, involving, as yours does, the established laws of acoustics […]

This script continues over three large pages.

All the quotes so far are taken from the second edition, the preface of which contains the following tantalizing information about its predecessor:

> Since the early edition of the book was published, partly in meter, the author has had an abundant reason to become satisfied that the metrical form of the argument was a mistake, so far, at least, as the general reading public is concerned.

Sure enough, the considerably scarcer first edition was largely written in nonrhyming verse, with copious prose footnotes to amplify concepts that did not easily fit within

the scansion. Typical examples of the metrical form of argument are:

> Sound I now proclaim as substance
> Real as the ear which hears it
> Or the objects which produce it,
> Notwithstanding all the reasons
> And phenomena so numerous
> Drawn from vibratory motion
> Which appear to contradict it,
> Which the reader will remember,
> As I have distinctly hinted,
> Are in harmony completely
> With the view as here foreshadowed,
> When we come to analyze them;
> And so infinitely simple,
> When compared to explanations
> Given by the current doctrine,
> That the mind at once accepts them
> As the only true solutions.

and

> And though I may speak of sound-waves
> In the course of this discussion,
> I shall do so under protest,
> With this frank asseveration
> That sonorous undulations
> Are a work of pure invention,
> Brilliantly imaginary,
> Having not the least foundation
> Either in the laws of nature
> Or the principles of science.

As a final curious footnote it turns out that in 1879 a US Patent was awarded to one A. Wilford Hall of New York for an improvement to Edison's phonograph,[6] although I have not been able to establish that this is definitely the same person.

B. Joseph Battell (1839–1915)

Colonel Joseph Battell was a wealthy Vermont landowner who donated over 30 000 acres of land to the state on condition that it be kept as a public wilderness, an action that has rightly made him something of a hero to the environmental movement. He was also a Republican member of the Vermont Legislature eight times (once in the Senate) and wrote a book about the breed of horse known as the Morgan. In 1901 he also wrote and published a book called "Ellen or Whisperings of an Old Pine,"[7] initially in one volume, though a second and a third were added in subsequent editions. It is lavishly produced with gold embossed lettering on the cover (see Fig. 1) and a profusion of photographs of Vermont scenery. It is summed up by Martin Gardner, in his classic study of pseudoscience "Fads and Fallacies,"[8] as follows:

> Few odder works than Ellen have appeared in the United States. All three volumes are in the form of a Platonic dialogue between a sixteen-year-old girl named Ellen and the narrator who happens to be an old Vermont Pine tree.

Ellen and the Pine (who is the nominal narrator) refer to each other and themselves in the third person throughout, which lends the prose a particular sluggishness. Neither expresses any surprise at the situation they find themselves in. Indeed at one point Ellen admonishes the Pine to remember when he first learned algebra, although no explanation of when or why these lessons were conducted is given. The relationship between the two principal characters is highly dysfunctional. The Pine is pathetically grateful for Ellen's attention, which she is constantly threatening to withdraw, often in favor of other trees. Although they pretend to engage in free philosophical discussions Ellen soon makes it clear who decides whether a particular topic is legitimate (the quotes are from the second edition):

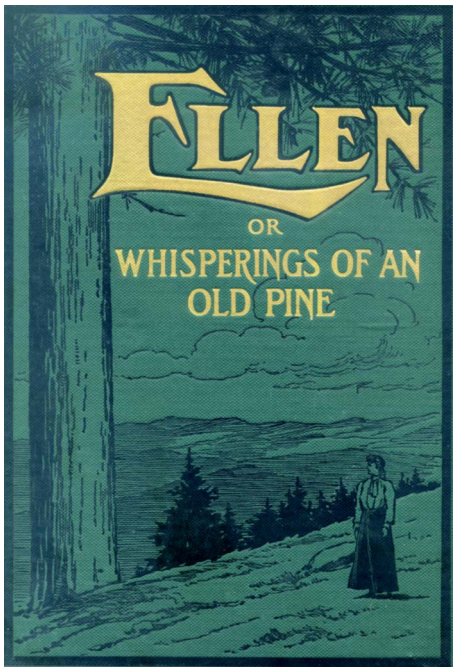

FIG. 1. (Color online) The cover of "Ellen" (second edition)—Ref. 7.

> "[…] does the old Pine suppose that the intelligence which he suggests comes from life lives after the life is gone?" […]
> "The old Pine doesn't think at all," I said. "He is only asking questions, and letting Ellen do all the thinking."
> "And Ellen thinks he is getting crazy," she replied, "with such foolish questions."
> "But the scientists ask such questions," I said, "as though they could not be answered, and they are very great men."
> "Very ignorant men," she said […]
> "Well," I said, "the old Pine was striving to get the facts."
> "Asked Ellen lots of foolish questions," she said. "Ellen got awfully scared about him. Afraid he was losing his wits."
> "But, Ellen, the old Pine doesn't know of any way to get at the truth but by trying. It is the bold mariner only who makes discoveries."
> "And doesn't the old Pine know," she said, "that there are no discoveries possible about things which

> are self-evident? The old Pine was awfully crazy and Ellen was dreadfully frightened; afraid he would never get out of it. He talked just like a scientist."

Ellen takes the Pine through theology, botany, algebra, and trigonometry, in all cases ridiculing experts while defending any weaknesses in her own theories by vehement assertions that they are self-evident and need no proof. Whole chapters are taken up by Ellen quoting learned works, from Plato to Newton to the Edinburgh Philosophical Journal, all seemingly off by heart. By Volume II they have got around to the subject of sound, and Ellen favors (or rather insists upon) a corpuscular theory like Wilford Hall's and has a similar loathing for Tyndall. Among her reasons for dismissing the wave theory is her contention that superposition would be impossible (again this is claimed as self-evident) so that multiple sound waves passing through the same space would be affected by one another. She makes much of Newton's famous mistake of assuming isothermal rather than adiabatic change in sound waves and thus underpredicting the speed of sound. As for Laplace's correction mentioned earlier she has this to say:

> By this hypothesis of Laplace one-half of the air is constantly overheated, and one-half underheated, and this couldn't help being noticeable if it meant any perceptible amount of difference of temperature, even though the two halves should constantly interchange conditions. For the old Pine will remember that some of the hypothetical sound waves are quite long, that of the lower C 28 feet, having 14 feet of condensation and 14 of rarefaction. And this increase of heat which, not in the ordinary way but in some inexplicable manner, is said to add 176 feet per second to the speed of sound, must take place with every sound, even the slightest. […] It makes Ellen pretty sick to discus seriously such intolerable nonsense.

She also harps on the point that the recently invented telephone can still be faintly heard when its diaphragm is removed. This could be explained as magnetostriction in the coils causing a small force on the housing which acts as an inefficient radiator. To Ellen, however, it is proof of nothing less than the complete failure of wave theory.

III. INTO THE NEW AGE

A. John Ernst Worrel Keely (1837–1898)

John Keely claimed to have invented a perpetual motion machine, which he called a "vibratory generator with a hydro-pneumatic pulsating generator," and insisted that sympathetic vibrations were essential to the functioning of his device. The story is taken up in John Sladek's "The New Apocrypha:" [9]

> From time to time investors in the Keely Motor Company began to wonder if they were wasting their money. Keely always persuaded them to waste a bit more. Demonstrations always took place in Keely's home, where the motor tore ropes apart and twisted iron bars, while its gauges showed enormous pressures—all from a pint of water. Committees of scientists and engineers were invited to see his demonstrations, but not to inspect the motor. They did so, however, after his death in 1898, and found in the cellar the compressed-air equipment that really ran it.

In fact, one person invited to witness a demonstration of Keely's motor was none other than the Reverend Dr A. Wilford Hall, who, apparently, was not particularly impressed.

Some, however, have not been shaken by such revelations. The 1996 book "The Physics of Love: The Ultimate Universal Laws" [10] is credited to Dale Pond, Edgar Cayce, John Keely, Rudolf Steiner, and Nikola Tesla, though only the first author was alive at the time of writing. In it, Keely's secrets are supposedly revealed. A brief sample is enough to get the flavor:

> The Law of One: Everything that is in the universe is included in it. Therefore all that is may be considered as one yet each discrete thing is individualized. The common mechanical connection between them all is what they have in common-vibratory motions. Every thing in the universe vibrates according to the laws of harmony. The connecting link between all these seemingly separate things is sympathetic vibrations. When the numbers of the vibrations are the same there is greater action/reaction or commoness [*sic*] of experience […]

Note the contrast between the earlier attacks on establishment science by Wilford Hall and Battell, in which an accepted theory is attacked and evidence (however spurious or badly interpreted) is offered to convince the reader, and the new age mystical literature in which anything can be conjectured and whether or not it agrees with scientific theory or observation is not even considered relevant.

B. Hans Jenny (1904–1972)

The transition between the old and new styles can be detected in the writings of Hans Jenny, a friend and follower of the occultist Rudolf Steiner (1861–1925). A proper survey of Steiner's beliefs and activities would be beyond the scope of this article. Briefly, he broke away from Madame Blavatsky's Theosophy cult to found his own Anthroposophy movement. Today he is best-known for the foundation of Waldorf or Steiner schools, some of which are still in controversial existence. Jenny, a medical doctor by profession, became fascinated with visual manifestations of vibration such as Chladni plates and Lissajous figures and set about studying them. The way he did so emphasizes the difference between the scientific method and Steiner's approach to the world. Jenny coined the term "Cymatics" to mean the study of waves and in 1967 published a book of that name, followed by a second volume in 1972.[11] It contains many photographs, some of them remarkable and beautiful, of powders, liquids, and pastes on vibrating plates, such as those shown in Fig. 2, taken from Chapter 8 of the first volume. These show a suspension of kaolin placed on a vibrating membrane. In some of the pictures the suspension is cooling and solidifying, in others it is a viscous mixture. It is inter-

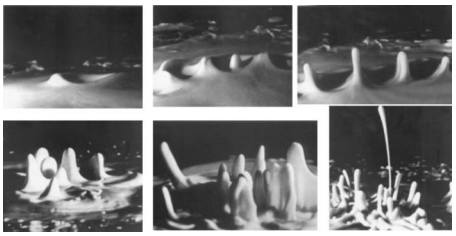

FIG. 2. A montage of pictures of kaolin paste on a vibrating membrane from Jenny's "Cymatics" (Ref. 11). The figures do not appear in this order there, and the properties of the paste are not constant over all figures. © MACROmedia publishing, used by permission.

esting to compare these to Fig. 3, which shows the delocalization of a hole in vertically vibrated cornstarch suspension reported by Merkt *et al.* in 2004.[12] This could be taken to suggest that a self-taught amateur working alone had preempted the work of a number of experts at a world-class research center. But the differences between the reports are as revealing as the similarities. Merkt *et al.* are able to map how the qualitative behavior of the system depends on amplitude and frequency of vibration. In order to do this they take considerable trouble to make sure that the properties of the suspension are fixed, uniform, and repeatable. They are then able to discuss the observed behavior in the context of the shear-thickening property of the cornstarch suspension they used. And, crucially, they were able to observe persistent holes, which Jenny missed.

Jenny, in contrast, gives no frequencies or amplitudes, nor any of the properties of his mixtures. All of this might be forgivable in an amateur investigator who might not possess, for example, the means to measure viscosity, although he makes no reference to the shear-thickening property of kaolin suspensions, which are readily apparent to anyone who tries to stir them. It soon becomes apparent, however, that Jenny didn't just neglect to categorize his results systematically, he actively avoided doing so:

> What it all boils down to is this, we must keep on asking ourselves as Goethe did: "Is it you or is it the object which is speaking here?" If we were to establish rigid definitions and split up the various manifestations into sections, we should be artificially dismembering the phenomenon by applying the analytical instrument of the intellect. If the phenomenon is to remain vital, its spectrum must be grasped as a fluctuating entity. True, there are significant forms there; but what we have to evolve is the concept of moving form and formative movement.

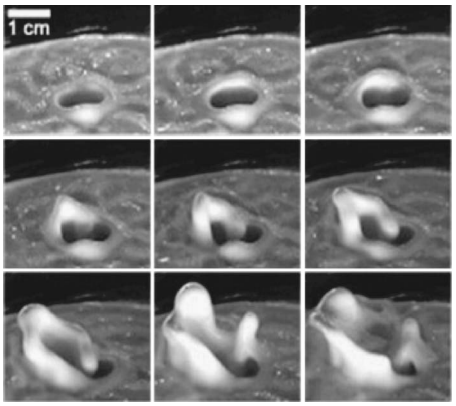

FIG. 3. A persistent hole in a cornstarch suspension being vibrated at 80 Hz at a peak acceleration of 25 g. Photos are taken every 0.9 s. Reprinted figure with permission from F. S. Merkt *et al.*, Phys. Rev. Lett. Vol. 92, 184501, 2004. Copyright 2004 by the American Physical Society.

This avoidance of any attempt at categorization or systematic investigation in favor of what would now be called a holistic approach is made explicit in the opening chapter of the second volume:

> Here again methods have been employed in which the phenomenon is treated as a whole and not dissected. Why is this? When we observe a phenomenon, it is natural to concentrate on one single factor and make it the focus of our attention. Now, if such a factor is abstracted from its context and allowed to dictate our procedure, the investigation tends to become biased and other characteristics of the object under study are easily missed. This is clearly reflected in the history of science in the way interest has alternated between opposed theories.
>
> […]
>
> A very special feature of the study of vibrations is the way in which the observer penetrates to the genetic element. Before our eyes we have the creative and the created, the vibrating and the sounding, and also what is produced by vibration and sound. Now none of this can be simply and harmlessly dissected for our examination. The events of the wave sequence transpire under complex conditions, in interferences, resonances, turbulences, in harmony, consonance, in disharmony, in dissonance, in frequency spectra, amplitude relations, etc. It is in this sphere of multiple creation that the investigator must carry out his observations. He must find out whether amidst all this tumultuous activity there are basic or ultimate phenomena in term of which "everything else" can be comprehended. It happens often enough that we have the parts in our hands but unfortunately lack the "mental ribbon" (Goethe) with which to bind them together. What is the status of the parts, the details, the single pieces, the fragments? In the vibrational field it can be shown that every part is, in the true sense, implicated in the whole.

The result is, for any physicist, a series of missed opportunities. Strange and rich behaviors, which would provide several interesting challenges to model, rub shoulders with Lissajous figures created with sine wave generators and an oscilloscope, which can be completely explained with high school physics; both are treated with the same mystic wonder:

> We have, among other things, been able to generate the formal vocabulary of Gothic tracery. It would therefore be correct to say that these architectural forms actually embody intervals as figures, thus verifying Geothe's dictum that "architecture is frozen music."

Unfortunately, although extensive examples and photographs are given through the book, none are given that show this architectural correspondence. We are, however, shown the result of speaking vowels into his "tonoscope," a stretched membrane with powder, sand, or liquid used to show the resulting nodal pattern, and of playing the music of Bach and Mozart into an electroacoustic version.

C. Johann Wolfgang von Goethe (1749–1832)

Jenny's reference to Goethe (there are several throughout the book) is apposite; the author of Faust had a parallel career as an amateur scientist and wrote "Zur Farbenlehre," [13] a large volume on the theory of color, which he regarded as his most important work; as Gardner[8] puts it:

> Since Goethe had no understanding of experimental methods, and even less of mathematics, his attack proved one of the most irrelevant in the history of physics.[14]

Although it diverts us from acoustics to optics it is worth noting the responses to Goethe of two eminent acousticians. Helmholtz, in an 1853 lecture to the German society of Königsberg[15] considered both his useful contributions to osteology (he discovered evidence for the presence of the intermaxillary bone in the human jaw) and to optics. He describes how Goethe looked at a white wall through a borrowed prism expecting (thanks to a misreading of Newton) to see colors. When he saw them only at edges, such as the boundary of a black figure on a white background he leapt to the conclusion that Newton's theory could only be utterly wrong. Helmholtz continues

> It is evident that at the first moment Goethe did not recollect Newton's theory well enough to be able to find out the physical explanation of the facts I have just glanced at. It was afterward laid before him again and again, and that in a thoroughly intelligible form, for he speaks about it several times in terms that show he understood it quite correctly. But he is still so dissatisfied with it that he persists in his assertion that the facts just cited are of a nature to convince any one who observes them of the absolute incorrectness of Newton's theory. Neither here nor in his later controversial writings does he ever clearly state in what he conceives the insufficiency of the explanation to consist. He merely repeats again and again that it is quite absurd.

He also points out Goethe's disdain for experiment, which Jenny inherited:

> […] in his attack on Newton he often sneers at spectra, tortured through a number of narrow slits and glasses, and commends the experiments that can be made in the open air under a bright sun, not merely as particularly easy and particularly enchanting, but also as particularly convincing!

Goethe's later writings also prefigured Wilford Hall in his attacks on his opponent. Helmholtz again:

> To give some idea of the passionate way in which Goethe, usually so temperate and even courtier-like, attacks Newton, I quote from a few pages of the controversial part of his work the following expressions, which he applied to the propositions of this consummate thinker in physical and astronomical science—'incredibly impudent'; 'mere twaddle'; 'ludicrous explanation'; 'admirable for schoolchildren in a go-cart'; 'but I see nothing will do but lying, and plenty of it.'
> […]
> Thus in the theory of colour, Goethe remains faithful to his principle, that Nature must reveal her secrets of her own free will; that she is but the transparent representation of the ideal world.

Of course Newton was equally irascible but generally preferred to use his position to suppress his opponents work rather than to attack them in print.

John Tyndall, in a Friday Evening Discourse at the Royal Institution of 1880,[16] makes similar points, but draws an analogy that modesty would have forbidden Helmholtz to make:

> We frequently hear protests made against the cold mechanical mode of dealing with aesthetic phenomena employed by scientific men. The dissection by Newton of the light to which the world owes all its visible splendour seemed to Goethe a desecration. We find, even in our own day, the endeavour of Helmholtz to arrive at the principles of harmony and discord in music resented as an intrusion of the scientific intellect into a region which ought to be sacred to the human heart. But all this opposition and antagonism has for its essential cause the incompleteness of those with whom it originates. […] There is no fear that the man of science can ever destroy the glory of the lilies of the field; there is no hope that the poet can ever successfully contend against our right to examine, in accordance with scientific method, the agent to which the lily owes its glory.

D. Pyramidology and beyond

The Egyptian Pyramids seem to act as a magnet to unconventional theories. There has apparently been a longstanding debate about how the stones were moved, to which surely the least convincing answer must be that given in "Gods of Eden" (1998) by Andrew Collins,[17] which is that they were moved by acoustic levitation. Of course acoustic levitation is a scientifically recognized phenomenon, described and explained in the pages of this journal among others. The radiation forces emitted by sound waves can only lift small particles, though more substantial weights can be lifted through nonlinear effects.[18] None of this technology is mentioned by Collins, who bases his belief on the 1961 book "Försvunnen Teknik" by Henri Kjellson,[19] which reports the experiences of a Swedish doctor known only as Jarl who claimed, on a journey through Tibet some time in the two decades before the second world war, to have witnessed monks using drums and trumpets to levitate large stone blocks.

In "The Giza Power Plant" [20] (1998) Christopher Dunn

suggests that the pyramids were, in fact, built to generate energy, possibly for a highly advanced civilization. He also claims that artifacts found in the pyramids could only have been machined with ultrasonic tools.

John Reid, in experiments described in "Egyptian Sonics," [21] apparently sought to emulate Jenny's tonoscope by stretching a membrane over the sarcophagus in the King's chamber of the Great Pyramid and insonifying it to apparently reveal hieroglyphics in the resulting vibration patterns.

Pyramids are not mentioned in "Healing Codes for the Biological Apocalypse" by Dr. Leonard G. Horowitz and Dr. Joseph S. Puleo,[22] but almost everything else is. As the dust jacket puts it:

> This book […] offers the greatest hope for humanity to spiritually evolve, and reveals the divine musical notes destined to be sung by the gathering critical mass of "144,000" people required to establish 1,000 years of world peace. Let the singing and the greatest healing of all time begin!

Mad cow disease, freemasonry, Bible codes, numerology, and so forth are brought up in dizzying sequence. As for the secret frequencies (emphasis in the original):

> *These previously secret sound frequencies, or electromagnetic vibrations, are likely the primary ones associated with the matrix of creation and destruction. That is, they were likely the frequencies used by God to form the cosmos in six days, as well as the tones required to shatter Jericho's great wall in six days*. Additional evidence for this assertion come from the fact that the third note Mi for Miracles, or 528 is the exact frequency used by genetic engineers throughout the world to repair the blueprint of life, DNA, the healthy core of which is six-sided crystal hexagonal clustered water.

Readers may also be interested to learn that

> Beethoven, like his Masonic mentors, most likely created his masterpieces transposing the mathematics encoded in the Bible, and elsewhere, into musical scores.

IV. SOUND POWER

A. Health and human factors

Orthodox medical science has found great benefit in sending sound waves into the human body (for purposes such as therapeutic ultrasound, lithotripsy, or excising tumors depending on the wave form and intensity), monitoring the sounds that come from it (heartbeats, otoacoustic emissions, etc.), or doing both at the same time (ultrasound imaging). A "cargo cult" version of this process seems to have developed among some alternative practitioners, variously known as vibration retraining, vibrational medicine, or sound therapy. As Sharry Edwards of Sound Health Inc. explains on her website[23]

> Each person possesses unique harmonics of frequency that can be expressed through the voice. However, when these complex frequencies of the body become unbalanced, the voice primarily reflects this altered state, and the body manifests it as dis-stress or dis-ease at the structural and biochemical levels.
>
> In reality, there are no solids. We exist in a universe that consists entirely of energy. Einstein proved this. Frequency defines it. Frequency, as vibrational medicine, is at the heart of the world of wellness as we know it.

The details of this therapy vary somewhat among practitioners but the principle appears to be that diseases can be diagnosed by spectral analysis of the voice, and then cured by playing back the necessary sounds. The same website says:

> Experiments have been repeated that show that introducing a person to the frequency formula for niacin, a nutritive substance, can cause a niacin-like skin flushing; the same as if the person actually ingested the nutrient.

This is a claim which, if confirmed by a double blind, randomized, placebo-controlled clinical study would be a significant challenge to explain. So far, however, none have been reported in any reputable peer-reviewed journal. Another sound therapist, whom I had the interesting experience of interviewing, informed me that playing the correct sounds through a domestic loudspeaker to a test-tube of blood could change the level of uric acid in it to a measurable extent.

It can be difficult for legitimate scientists to know how to respond to such grandiose but ridiculous claims. To test every such claim would be an unconscionable drain on time and resources, and would in many cases unjustly dignify the claimant's position, but to deny the claim without testing it is open to mischaracterization as closed-mindedness or fear of new ideas. Fortunately there is a third way: the magician[24] and skeptic James Randi's Educational Foundation offers a one million dollar prize for a demonstration under an agreed protocol of any such paranormal power. The progress of applicants can be followed through the foundation's website.[25] Any scientist faced with an unreasonable but in principle testable claim can suggest that they win the million dollar challenge, thus impressing scientists the world over, instead of having to convince them one at a time. Of course, many excuses for not taking the challenge are offered; as one wag put it "if it ducks like a quack, it probably is a quack." Strangely, no practitioner of vibrational healing or any of its variants has been successful, and to the best of my knowledge none have ever applied.

One amusing effect of the prevalence of such ideas can be seen in the warning added to the website of one supplier of scientific tuning forks:[26]

> These tuning forks are intended for science and engineering applications; we cannot guarantee their performance for any other uses or for metaphysical expectations.

B. Snake oil for the ears

The fact that the human auditory system is connected to the human brain makes it a marvellous subject for study, but it also means that we are capable of being fooled about what we are listening to. This, among other factors, has made

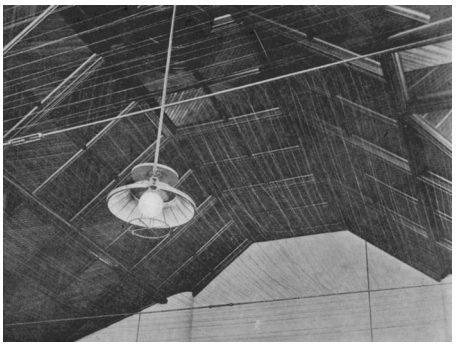

FIG. 4. Stretched wires in the ceiling of a church in San Jose, CA (Ref. 27).

objective assessment of subjective listening experiences very difficult, and easily swayed by suggestion, a fact that is exploited by many purveyors of devices that purport to improve sound.

Architectural acoustics was prey to a form of this delusion as recorded by Sabine:[27]

> The stretching of wires is a method [for remedying acoustical difficulties] which has long been employed, and its disfiguring relics in many churches and court rooms proclaim a difficulty which they are powerless to relieve. Like many other traditions, it has been abandoned but slowly. The fact that it was wholly without either foundation of reason or defense of argument made it difficult to answer or to meet. The device, devoid on the one hand of scientific foundation, and on the other of successful experience, has taken varied forms in its application. Apparently it is a matter of no moment where the wires are stretched or in what amount. There are theatres and churches in Boston and New York in which four or five wires are stretched across the middle of the room; in other auditoriums miles on miles of wire have been stretched; in both it is equally without effect. In no case can one obtain more than a qualified approval, and the most earnest negatives come where the wires have been used in the largest amount. Occasionally the response to inquiries is that "the wires may have done some good but certainly not much," and in general when even that qualified approval is given the installation of the wires was accompanied by some other changes of form or occupancy to which the credit should be given.

A photograph of such an installation, taken from Sabine's collected papers, is shown in Fig. 4.

Many readers will know of the long debate over the importance of Stradivari's varnish to the sound of his violins. Consider, then, the claims made by luthier Dieter Ennemoser for his C37 varnish:[28]

> All attempts by science to explain the secrets of the character of sound have so far been unsuccessful. […] The imperative selection of the right materials (wood and varnish quality) raised the question about the existence of a reference property. I eventually discovered that human bones and tissue to possess similar qualities. A more detailed analysis showed that carbon is the decisive element in sound quality, and since the sound is also coloured by body temperature, I chose to call this property the C37 structure. (Where C=Carbon and 37=body temperature in degrees Centigrade). Further analysis showed that C37 frequencies lie very close together (at least 10 frequencies per octave) and this structure reoccurs in each octave.

This apparently miraculous (but, naturally, expensive) substance apparently improves the sound of anything it is applied to, not just violins but loudspeaker cones and even Hi-Fi volume controls.

Once the sound has left the loudspeaker it still needs to survive transmission through the room.[29]

> Brilliant Pebbles is a unique room & system tuning device for audio systems and satellite TV. Original (Large) Brilliant Pebbles is a 3-inch clear glass bottle containing various minerals/stones. A number of highly-specialized, proprietary techniques are used for preparation/assembly. Brilliant Pebbles acts as both a vibration "node damper" and EMI/RFI absorber via various atomic mechanisms in the crystal structures. On the floor in room corners, Large Brilliant Pebbles reduces comb filter effects caused by very high sound pressure levels that occur in the corners when music is playing. Large Brilliant Pebbles is also effective on tube and solid state amps, on speaker cabinets, on armboards of turntables and on tube traps and Room Lenses.

The doyen of this field is Peter Belt, whose products have a small but devoted band of followers who seem to be convinced beyond doubt that their listening experience has been enhanced by the use of his products. And how could they not, after all:[30]

> Any series of identical species of living objects are linked by Nature irrespective of their location within the world. This applies equally to inanimate objects such as identical Compact Discs, vinyl records, printed objects etc. The energy pattern emanating from such man made objects has similarities to those same living objects to which our senses evolved. The man made objects have, however, some energy patterns which are dissimilar from those emanating from living objects. Placing a strip of the new type 'Real' Foil on these man made objects within the listening room interjects a changed energy pattern which allows the senses to respond as though the man made object had the same energy pattern as a living object.

If the actual effects of these foil strips, jars of stones and varnish might seem negligible the prices charged for them are certainly not; readers are invited to guess what they might be before investigating for themselves.

Of course, the actual value of any such device can be separated from the psychological effect of its presence (and price) on the listener by careful double-blind testing. Sadly this is strongly resisted by a significant proportion of the audiophile community. Until it becomes commonplace it will

be hard for those who seek to improve Hi-Fi systems by legitimate means to distinguish themselves from those who just sell false hope. As a last psychosociological note it is worth pointing out that such devices are given short shrift in the world of professional audio systems, where the audience neither knows nor cares what has been done to the equipment, and is therefore immunized to the power of suggestion.

V. CONCLUSIONS

We are unlikely to see another Wilford Hall or Battell arguing that the fundamental theories of acoustics are mistaken, because acoustics is no longer sufficiently novel. Contrarians have long since moved on the denying the validity of relativity, quantum physics, and cosmology. But fantastical powers are still regularly ascribed to acoustic and vibratory phenomena that can be understood with elementary physics. Furthermore, the language of acoustics forms a significant part of the new-age lexicon, replete as it is with resonance, harmony, vibration, waves (all good), and rays (usually bad). Without evidence I can only offer the conjecture that this is because this mindset saw a great growth in popularity in the 1960s and 1970s, when supersonic flight was front page news—if the TV series Dr Who were starting today I do not think its hero would depend on a sonic screwdriver. In the present day a key goal of scientists and educators is clear: to ensure that our students (in the broadest sense of the word) are equipped with the critical thinking skills necessary to avoid falling into any of the traps listed here, or becoming ensnared in others of their own making.

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[1]M. Jeng, "A selected history of expectation bias in physics," Am. J. Phys. **74**, 578–583 (2006).
[2]C. Darwin, *Formation of Vegetable Mould Through the Action of Worms With Observations of Their Habits* (Murray, London, 1904).
[3]A. W. Hall, *The Problem of Human Life: Here and Hereafter*, 2nd ed. (Hall, New York, 1883), 1st ed. published anonymously 1877, facsimile 2nd ed. published by Kessinger, Whitefish, MT.
[4]J. Tyndall, *On Sound*, 3rd ed. (Longmans, Green, London, 1875).
[5]J. Tyndall, *Heat, a Mode of Motion*, 6th ed. (Longmans, Green, London, 1904).
[6]A. W. Hall, "Improvement in phonographs," US Patent 219,939, 23 September 1879.
[7]J. Battell, *Ellen, or Whisperings of an Old Pine*, 2nd ed. (The American Publishing Company, Middlebury, VT, 1901).
[8]M. Gardner, *Fads and Fallacies: In the Name of Science* (Dover, New York, 1957).
[9]J. Sladek, *The New Apocrypha*, 3rd ed. (Panther, London, 1978).
[10]D. Pond *et al.*, *The Physics of Love; The Ultimate Universal Laws* (Message, Santa Fe, NM, 1996).
[11]H. Jenny, *Cymatics* (MACROmedia, Newmarket, NH, 2001), first published Vol. **1**, 1967, Vol. **2**, 1972.
[12]F. S. Merkt, R. D. Deegan, D. I. Goldman, E. C. Rericha, and H. L. Swinney, "Persistent holes in a fluid," Phys. Rev. Lett. **92**, 184501 (2004).
[13]J. W. von Goethe, *Theory of Colours* (MIT, Cambridge, 1969), first published 1810.
[14]This view has recently been contested. (Ref. 31).
[15]H. von Helmholtz, "On Goethe's scientific researches," in *Popular Lectures on Scientific Subjects* (Longmans, Green, London, 1898).
[16]J. Tyndall, "Goethe's 'Farbenlehre,' " in *New Fragments* (Appleton, New York, 1897).
[17]A. Collins, *Gods of Eden* (Bear, Rochester, VT, 1998).
[18]V. Vandaele, P. Lambert, and A. Delchambre, "Non-contact handling in microassembly: Acoustical levitation," Precision Engineering—Journal of the International Societies for Precision Engineering and Nanotechnology **29**, 491–505 (2005).
[19]H. Kjellson, *Forsvunden Teknik* (Nihil, Copenhagen, 1974). (Danish translation, First published in Swedish as *Försvunnen Teknik*, 1961).
[20]C. Dunn, *The Giza Power Plant* (Bear, Rochester, VT, 1998).
[21]J. Reid, *Egyptian Sonics* (Sonic Age, Northumberland, 2001).
[22]L. G. Horowitz and J. S. Puleo, *Healing Codes for the Biological Apocalypse* (Tetrahedron, Sandpoint, ID, 1999).
[23]S. Edwards, "Sound Health Inc.," 2001, URL http://www.sharryedwards.com.
[24]Interestingly the suggestion that magicians, as well as scientists, should be employed to examine supernatural claims was apparently first made by another acoustician, Sir Charles Wheatstone (Ref. 32).
[25]J. Randi, "James Randi Educational Foundation," URL http://www.randi.org.
[26]URL http://www.indigo.com/tuning/scientific-tuning-forks.html.
[27]W. C. Sabine, "Acoustical difficulties," in *Collected Papers on Acoustics* (Dover, New York, 1964), Chap. 6, pp. 132–133, first published in The Architectural Quarterly of Harvard University, March 1912.
[28]D. Ennemoser, "C37 acoustics," URL http://www.ennemoser.com.
[29]"Machina Dynamica Advanced Audio Concepts," URL http://www.machinadynamica.com.
[30]"P.W.B. 'Real' Foil—the entry point into the Real World," URL http://www.belt.demon.co.uk/product/realfoil/realfoil.html.
[31]N. Ribe and F. Steinile, "Exploratory experimentation: Goethe, Land, and color theory," Phys. Today **55**, 43–49 (2002).
[32]B. Bowers, *Sir Charles Wheatstone FRS 1802–1875* (HMSO, London, 1975).