Acústica en la Enciclopedia Británica de 1797

Conferencia dictada en el 25º Congreso Internacional Mexicano de Acústica

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Resumen:
En esta conferencia de carácter didáctico-cultural se revisa el contenido de la entrada sobre el término *Acoustics* en la *Encyclopædia Britannica* en su 3ª Edición de 1797. Primeramente se presenta el desarrollo de la Enciclopedia Británica desde su primera edición y su impacto a nivel internacional. Posteriormente se contextualiza y describe la 3ª edición, para luego revisar la estructura de contenido para el término "acústica". También se incluye y discute la hoja con los grabados correspondientes al tema.

Palabras clave: acústica, historia, Enciclopedia Británica, 3ª edición, 1797.

Abstract:
This didactic-cultural conference examines the contents of the entry about "Acoustics" in the *Encyclopædia Britannica* in its 3rd Edition of 1797. The development of the *Britannica* since its first edition and their impact at the international level is presented. Subsequently it contextualizes and describes the 3rd Edition, to then review the structure of content for the term "acoustic". It also includes and discussed the etched sheet corresponding to the theme.

Key words: acoustics, history, Encyclopædia Britannica, 3rd Edition, 1797.

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[1] Revista ECOS agradece al Prof. Sergio Beristáin por autorizar su reproducción.

1. INTRODUCCIÓN

A hacerse una búsqueda en internet para la compra de libros de acústica, apareció en subasta la sección de acústica de la *Encyclopædia Britannica* de 1797.[1] Esta fue adquirida y estudiada en conjunto por miembros del Cuerpo Académico de Acústica y Vibraciones, de la Facultad de Ingeniería Mecánica y Eléctrica de la Universidad Autónoma de Nuevo León.

A partir de esta actividad se consideró, para incrementar la cultura científica de los acústicos, el compartir esta experiencia, y el texto completo de la sección de acústica en dicha enciclopedia, la cual se incluye como anexo a esta ponencia.

2. *ENCYCLOPÆDIA BRITANNICA*

Siendo la enciclopedia de conocimiento general en inglés más antigua todavía en edición, la *Encyclopædia Britannica* se publica en su primera edición entre 1768 y 1771, en Edimburgo, Escocia, y rápidamente obtuvo gran popularidad y crecimiento en su tamaño [2].

Las primeras ediciones de la Enciclopedia Británica fueron publicadas e impresas en Edimburgo por el grabador Andrew Bell y el impresor Colin Macfarquhar por "*una sociedad de caballeros en Escocia*". El 10 de diciembre de 1768, el *Caledonian Mercury* y el *Edinburgh Evening Courant* publicaron un anuncio informando: "*Hoy se publica*" la primera parte de la Enciclopedia Británica, comprometiéndose a que la enciclopedia proporcionaría "*DEFINICIONES Y EXPLICACIONES PRECIOSAS, de todos los Términos… en el Orden del Alfabeto*" [3].

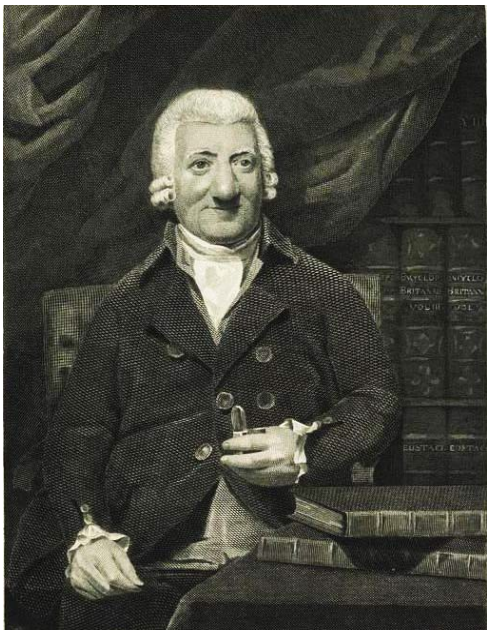
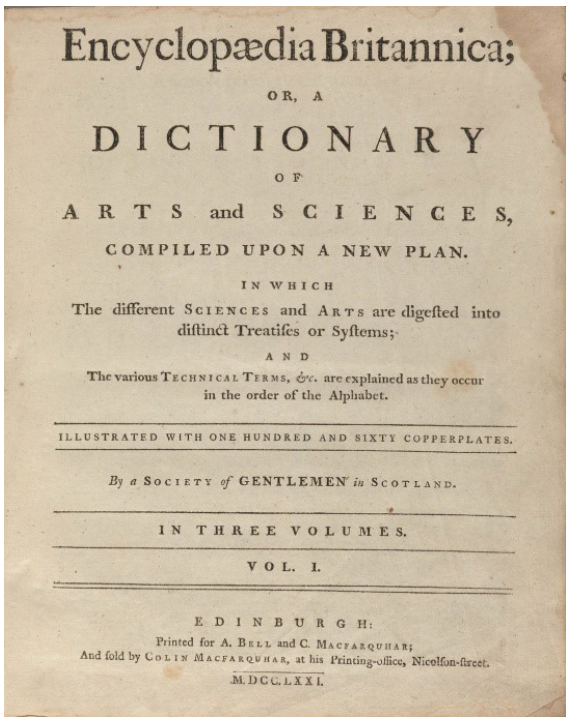


Figura 1 y 2. El grabador Andrew Bell [4] y el impresor Colin Macfarquhar [5], fundadores de la *Encyclopædia Britannica.*

La primera edición de la obra fue publicada en partes desde 1768 a 1771 con páginas de doble columna. Las aproximadamente 2,500 páginas estaban encuadernadas en tres grandes volúmenes, con 160 grabados en cobre de Bell. La portada, ver Figura 3, comienza de la siguiente manera: "*Encyclopædia Britannica; O, UN DICCIONARIO DE ARTES Y CIENCIAS, COMPILADO EN UN NUEVO PLAN.*" [6] La obra no podía competir a granel con los 68 volúmenes del Lexicón Universal de Johann Heinrich Zedler, ni con la Enciclopedia Francesa cuyos 17 volúmenes de texto se habían completado en esa época. Pero sí desafió la comparación con todos los diccionarios anteriores de artes y ciencias, grandes o pequeños, debido a su nuevo estilo editorial y plan de evolución [3].



Encyclopædia Britannica;

OR, A

DICTIONARY

OF

ARTS and SCIENCES,

COMPILED UPON A NEW PLAN.

IN WHICH

The different SCIENCES and ARTS are digested into distinct Treatises or Systems;

AND

The various TECHNICAL TERMS, &c. are explained as they occur in the order of the Alphabet.

ILLUSTRATED WITH ONE HUNDRED AND SIXTY COPPERPLATES.

By a SOCIETY *of* GENTLEMEN *in* SCOTLAND.

IN THREE VOLUMES.

VOL. I.

EDINBURGH:

Printed for A. BELL and C. MACFARQUHAR;

And fold by COLIN MACFARQUHAR, at his Printing-office, Nicolfon-ftreet.

M.DCC.LXXI.

Figura 3. Frontispicio de la primera edición de la *Encyclopædia Britannica.* [6]

El tamaño de la enciclopedia ha variado en las diferentes ediciones, por un lado creciendo en busca de competir con las diferentes enciclopedias que se desarrollaban en el mundo y por otro reduciendo el tamaño de las entradas por la tendencia a lo compacto que la modernidad ha generado. En la Tabla 1 se presenta un resumen histórico de las características y tamaño de la británica a lo largo de sus ediciones [2].

Tabla 1. Ediciones de la *Encyclopædia Britannica* [2]

Edición	Año publicación	Tamaño	Notas
1ª	1768–1771	3 vol., 2.670 pp. 160 láminas	Principalmente elaborada por un solo editor, Smellie. 30 de los artículos tienen más de tres páginas de largo.
2ª	1777–1784	10 vol., 8.595 pp. 340 láminas	150 artículos largos. Muchos errores de paginación. Todos los mapas se encontraban dentro del artículo "Geografía".
3ª	1788–1797	18 vol., 14.579 pp. 542 láminas	Obtuvo una ganancia de £42,000 con la venta de 10.000 copias. Se da introducción a los Símbolos químicos. Contiene la primera dedicación al monarca
Suplemento de 3ª edición	1801	2 vol., 1,624 pp. 50 láminas	Thomas Bonar obtiene los derechos.
4ª	1801–1809	20 vol., 16.033 pp. 581 láminas	Por primera vez los autores mantienen el copyright de sus contribuciones.
5ª	1817	20 vol., 16.017 pp. 582 laminas	Pérdidas para los herederos de Millar y Andrew Bell; los derechos de la enciclopedia son vendidos a Archibald Constable.
Suplemento de 5ª edición	1816–1824	6 vol., 4.933 pp. 125 láminas	Se reclutan contribuidores tales como Sir Humphry Davy, Sir Walter Scott y Malthus
6ª	1820–1823	20 vol.	Constable cae en bancarrota el 19 de enero de 1826; Adam Black recuperará los derechos de la Britannica.
7ª	1830–1842	21 vol., 17.101 pp., 506 láminas, índice de 187 pp.	Se amplía la red de contribuidores famosos, tales como Sir David Brewster, Thomas de Quincey, Antonio Panizzi.
8ª	1853–1860	21 vol., 17.957 pp., 402 láminas; índice de 239 pp.por separado, publicado en 1861.	Varios artículos extensos fueron copiados de la 7ª edición; 344 contribuidores incluyendo William Thomson.
9ª	1875–1889	24 vol., más un vol., de índice	Alguno artículos traídos de la 8ª edición, pero en su mayoría un trabajo nuevo; muy académica; pirateado de forma extensa en EE.UU.
10ª, suplemento de 9ª	1902–1903	11 vol., más 24 vol., de la 9.	Una sociedad americana compró los derechos el 9 de mayo de 1901; aplica métodos de venta agresivos.
11ª	1910–1911	28 vol., más un vol., de índice	Otro alto nivel académico y de escritura; más artículos que la 9ª, pero más simples y cortos; el propietario Horace Everett Hooper tiene dificultades académicas; los derechos de la Britannica se venden a Sears Roebuck en 1920.
12ª, suplemento de 11ª	1921–1922	3 vol., más los 28 vol., de la 11ª	Resumía el estado del mundo durante, antes y después de la Primera Guerra Mundial.
13ª, suplemento de 11ª	1926	3 vol., más los 28 vol., de la 11ª	Sustituyó a los volúmenes de la 12ª; mejor perspectiva de los eventos de 1910–1926.
14ª	1929–1933	24 vol.	Publicada antes de la Gran Depresión, fue una catástrofe financiera.
14ª revisada	1933–1973	24 vol.	La revisión continua empezó en 1936: cada artículo es revisado al menos dos veces cada década.
15ª	1974–1984	30 vol.	Introdujo la estructura en tres partes: Micropædia y Macropædia con artículos; Propædia como Esquema de Conocimiento; se elimina el índice separado.
	1985–2010	32 vol.	Vuelve índice de dos volúmenes; combina artículos de Micropædia y Macropædia; nuevas versiones cada pocos años

En el transcurso de su historia, la *Britannica* ha tenido dificultades para cosechar beneficios económicos, un problema común entre muchas enciclopedias. Algunos artículos de ediciones pasadas han sido criticados por inexactitud, parcialidad, o por haber sido redactados por contribuyentes no suficientemente cualificados. Así mismo, la precisión de algunas partes de algunas ediciones vigentes ha sido cuestionadas en sus diferentes ediciones; sin embargo, esas críticas han sido rechazadas por la administración de la enciclopedia [2].

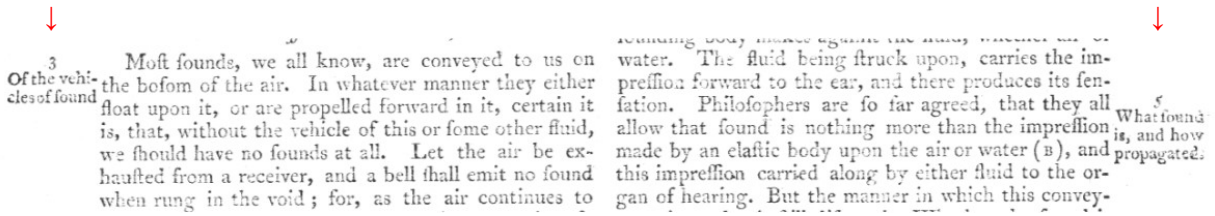
La primera edición en CD-ROM se lanzó en 1994. En ese momento se ofreció también una versión online mediante suscripción, pero el 13 de marzo de 2012, los editores de la Enciclopedia Británica anunciaron que dejarían de imprimirse en papel y que se centrarían en la edición web [2].

LA TERCERA EDICIÓN DE LA BRITÁNICA

La tercera edición de la Británica en su versión de 1797, sobre la que se basa esta ponencia, por supuesto está desarrollada de acuerdo a los criterios editoriales de la época, esto implica que está escrita en inglés de la época, con sus diferencias lingüísticas y tipográficas, por ejemplo para las s se usaba ſ como en sonido, *sound*,

ſounds.

Tipográficamente, como era moda en libros de estudio y consulta, se dejaban columnas laterales para indicar el inicio del tratamiento de algún tema específico.

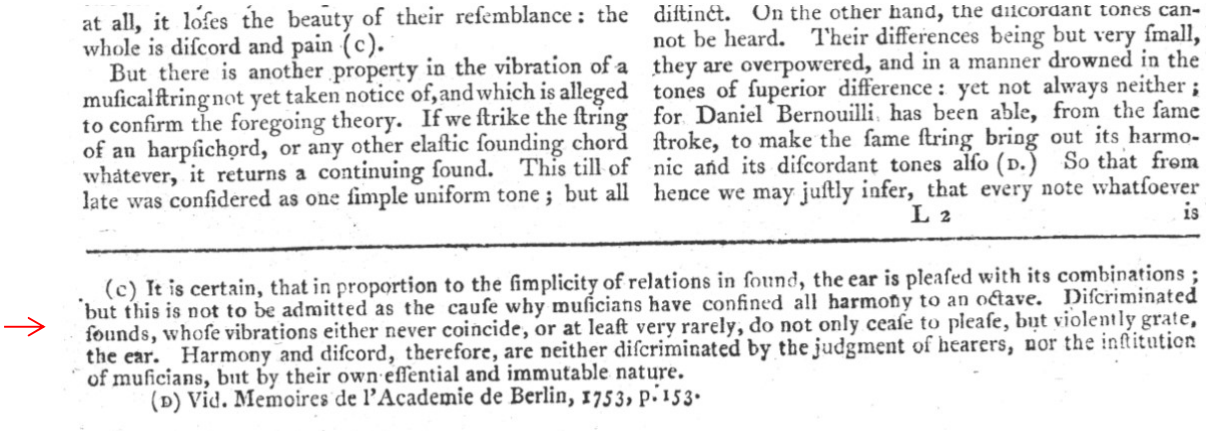


3 Of the vehicles of ſound. Moſt ſounds, we all know, are conveyed to us on the boſom of the air. In whatever manner they either float upon it, or are propelled forward in it, certain it is, that, without the vehicle of this or ſome other fluid, we ſhould have no ſounds at all. Let the air be exhauſted from a receiver, and a bell ſhall emit no ſound when rung in the void; for, as the air continues to

water. The fluid being ſtruck upon, carries the impreſſion forward to the ear, and there produces its ſenſation. Philoſophers are ſo far agreed, that they all allow that ſound is nothing more than the impreſſion made by an elaſtic body upon the air or water (B), and this impreſſion carried along by either fluid to the organ of hearing. But the manner in which this convey-

5 What ſound is, and how propagated.

También se usaban notas de pie de página, ampliamente usadas hasta mitad de siglo pasado cuando empiezan a ser puestas a fin de capitulo o en un apartado al final de cuerpo principal.



at all, it loſes the beauty of their reſemblance: the whole is diſcord and pain (C).

But there is another property in the vibration of a muſical ſtring not yet taken notice of, and which is alleged to confirm the foregoing theory. If we ſtrike the ſtring of an harpſichord, or any other elaſtic ſounding chord whatever, it returns a continuing ſound. This till of late was conſidered as one ſimple uniform tone; but all diſtinct. On the other hand, the diſcordant tones cannot be heard. Their differences being but very ſmall, they are overpowered, and in a manner drowned in the tones of ſuperior difference: yet not always neither; for Daniel Bernouilli has been able, from the ſame ſtroke, to make the ſame ſtring bring out its harmonic and its diſcordant tones alſo (D.) So that from hence we may juſtly infer, that every note whatſoever

L 2 is

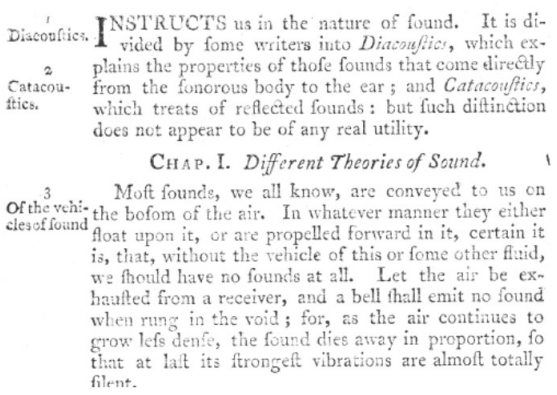
(C) It is certain, that in proportion to the ſimplicity of relations in ſound, the ear is pleaſed with its combinations; but this is not to be admitted as the cauſe why muſicians have confined all harmony to an octave. Diſcriminated ſounds, whoſe vibrations either never coincide, or at leaſt very rarely, do not only ceaſe to pleaſe, but violently grate, the ear. Harmony and diſcord, therefore, are neither diſcriminated by the judgment of hearers, nor the inſtitution of muſicians, but by their own eſſential and immutable nature.

(D) Vid. Memoires de l'Academie de Berlin, 1753, p. 153.

3. *ACOUSTICS* EN LA 3ª EDICIÓN DE LA *ENCYCLOPÆDIA BRITANNICA*

La entrada sobre Acústica (*Acoustics*) en la 3ª edición de la *Británica* abarca de la página 79 a la 92, y es integrada por: definiciones generales, 4 capítulos, una sección de "experimentos de entretenimiento y artilugios", y un conjunto de imágenes impresas en páginas (láminas) separadas del cuerpo principal de la enciclopedia [1].

La definición establecida para el término es: *Nos instruye en la naturaleza de sonido.*



1 Diacouſtics. INSTRUCTS us in the nature of ſound. It is divided by ſome writers into *Diacouſtics*, which explains the properties of thoſe ſounds that come directly from the ſonorous body to the ear; and *Catacouſtics*, which treats of reflected ſounds: but ſuch diſtinction does not appear to be of any real utility.

2 Catacouſtics.

CHAP. I. *Different Theories of Sound.*

3 Of the vehicles of ſound. Moſt ſounds, we all know, are conveyed to us on the boſom of the air. In whatever manner they either float upon it, or are propelled forward in it, certain it is, that, without the vehicle of this or ſome other fluid, we ſhould have no ſounds at all. Let the air be exhauſted from a receiver, and a bell ſhall emit no ſound when rung in the void; for, as the air continues to grow leſs denſe, the ſound dies away in proportion, ſo that at laſt its ſtrongeſt vibrations are almoſt totally ſilent.

Y nos indica que según algunos escritores la acústica está dividida en:

Diacoustics: que explica las propiedades de aquellos sonidos que van directamente del cuerpo sonoro al oído.

Catacoustics: Trata sobre los sonidos reflejados.

Seguido de lo cual declara: *Pero dicha distinción no parece ser de ninguna utilidad real.*

Este comentario demuestra una gran visión de largo plazo, pues no se usan actualmente y en español no aparecen en el Diccionario de la Lengua Española de la RAE [7].

El término *Acoustics* se desarrolla en los siguientes capítulos:

Cap. I. Diferentes teorías de sonido. Este capítulo inicia tratando los "vehículos de sonido" y aunque establece que el aire es el principal, continúa discutiendo que "el aire no es el único". Luego discute "qué es el sonido, y como se propaga" afirmando que en lo primero hay acuerdo entre los estudiosos, para luego indicar que en cuanto a la propagación hay discrepancias entre un enfoque ondulatorio y uno de rayos, entrando en una oscura, pero típica discusión entre el enfoque de Newton y otras teorías y las objeciones a cada una. Para complicar se divaga en aspectos de acústica musical. Todas estas discusiones, que indican un conocimiento en evolución, son por demás antididácticas, muy para especialistas.

Cap. II. De la propagación del sonido. Doctrina de Newton explicada y vindicada. En este capítulo después de aceptar las dificultades y oscuridades en los trabajos de Newton entra en su defensa en base a los trabajos de Young para vindicarlo, centrándose en los aspectos de la propagación de sonido con un estilo por demás académico.

Cap. III. De la velocidad, y la c. del sonido. Axiomas. Una vez discutida la propagación, en este capítulo se centra en la velocidad del sonido, estableciendo que "*los sonidos viajan espacios iguales en tiempos iguales*", describiendo la constante "c", indicando que la teoría concuerda con los experimentos y que incluso el sonido se puede usar para medir distancias.

Cap. IV. Los sonidos reverberados. En este capítulo se centra en los sonidos reflejados, llegando sólo a aspectos de eco y reverberación tratada en forma básica, lejos del conocimiento actual.

En esta conferencia no hay tiempo para analizar a detalle cada parte de dichos capítulos, por lo que para los interesados se agrega al final, como anexo, la entrada completa, incluyendo imágenes, para el término "acústica" en la Británica de 1797.

Se consideró importante puntualizar algunos aspectos: …

a.- Se evidencia una ciencia de la acústica en construcción, donde las diferencias y discusiones están aún vivas.

b.- Se está en la búsqueda de la aplicabilidad del conocimiento científico, en su uso, como se evidencia en la gran atención puesta a su propagación.

c – No se incluyen demostraciones sofisticadas, sólo trigonometría y álgebra básica.

d.- Aunque una enciclopedia es para la divulgación de conocimiento, a veces se pierde en discusiones oscuras, más académicas de lo necesario.

Después de los capítulos antes mencionados aparece la sección de "*Experimentos de entretenimiento y artilugios*", en la cual se describen una serie de experiencias prácticas de utilidad para mostrar, demostrar y promover aspectos de la acústica, una manera de divulgación de la ciencia utilizada por muchos siglos.

Los experimentos propuestos son:

I.- *The conversive statue*. La experiencia de transmisión de sonidos entre los focos de dos espejos cóncavos uno frente a otro, aún muy usada en los museos científicos para niños.

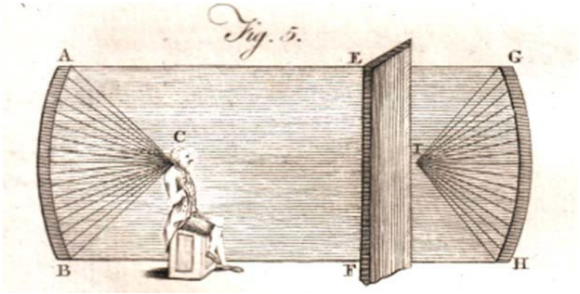


Figura 4. Una estatua para conversar. *The conversive statue* [1]

II.- *The communicative busts*. A un par de cabezas sobre pedestales se les colocan tubos ocultos (cruzados entre boca y oído) para transmitir el sonido entre ellas.

III.- *The oracular head*. Algo similar a lo anterior pero es una estatua que simula un oráculo, mientras otra persona en otro recinto escucha y contesta las preguntas al oráculo.

IV.- *A solar sonata*. En el camino a las máquinas autómatas se utiliza un órgano que se activa automáticamente gracias a los vapores producidos por un líquido calentado por el sol.

V.- *Automatous harpsichord*. Clavecín o teclado automatizado con un cilindro con salientes que mueven las teclas según se programe. El teclado es movido por un mecanismo de chimenea (smoke jack).

VI.- *Ventosal symphony*. Otro mecanismo autónomo. Básicamente una gran caja de música activada por el viento, pudiéndose cambiar las salientes en el cilindro, que activan campanas, para modificar la melodía.

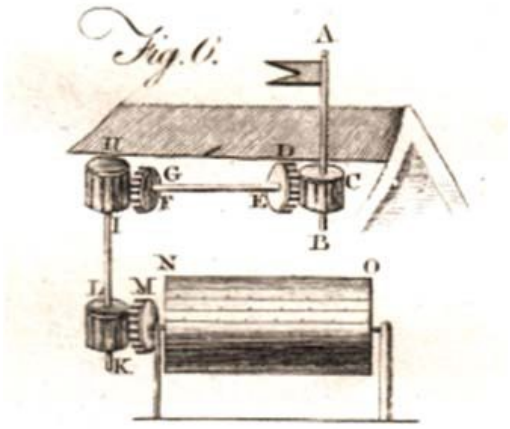


Figura 5. El viento mueve una caja de música. *Ventosal symphony* [1]

4. GRABADOS DE APOYO AL TÉRMINO "ACÚSTICA" EN LA 3ª EDICIÓN DE LA *ENCYCLOPÆDIA BRITANNICA*.

En apoyo a la entrada sobre Acústica en la 3ª edición de la Enciclopedia Británica, se incluye una serie de grabados sobre el tema, incluidas en una lámina multi-imagen la cual se muestra en la figura 6. En esta página, la placa I, se incluían imágenes de apoyo a los términos: *Aphis*, *Abacus, Acarus*, *Acoustics* y *Aerostation*. Estos grabados hechos por ANDREW BELL (1726-1809), cofundador de la Británica, para la 3ª edición de 1797, se elaboraron con placa de cobre sobre papel fabricado a mano. La página mide aproximadamente 25.5 cm x 19.7 cm. (10 x 7 ¾ pulgadas). Estos grabados de imagen múltiple originalmente se unían en un volumen de la Enciclopedia de 1797 para ilustrar varios artículos.

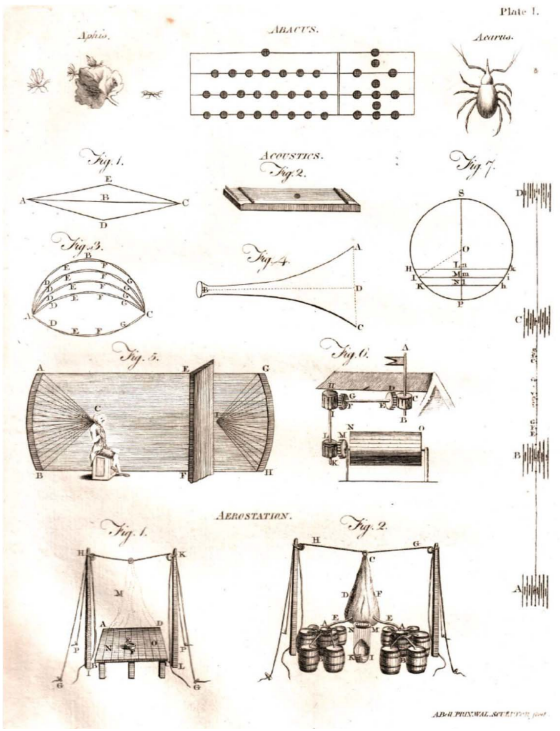


Figura 6. Grabados de apoyo al término Acústica en la 3ª edición de la *Encyclopædia Britannica*, elaborados por Andrew Bell [1]

Las imágenes fueron impresas sobre "Papel verjurado" (Laid paper) hecho a mano, el cual tiene una textura estriada, la cual es impuesta por el proceso de fabricación. En la producción (desde el siglo XII hasta el siglo XIX), el patrón de la textura es producido por el tamiz de alambre en el molde rectangular que se utiliza para producir hojas sueltas de papel. Un trabajador sumerge el molde en una tina que contiene pulpa de lino diluida, entonces lo levanta e inclina para extender la pasta uniformemente sobre el tamiz al tiempo que se golpetea el molde para que el agua drene entre los alambres, reteniendo las fibras juntas. En el proceso, el golpeteo de los cables en el tamiz queda impreso en la hoja de papel.

Bell, quien se inició como grabador de blasones, nombres, etc. en collares de perro, produjo casi la totalidad de los grabados en cobre para las ediciones 1ª a 4ª de la Británica: 160 para la 1ª , 340 para la 2ª, 542 para al 3a y 531 para la 4ª. Como anécdota, para

la 1ª edición, Bell produjo tres páginas completas de grabados anatómicamente precisas de una pelvis femenina disecada y de fetos en el útero, para ilustrar el término "partería" (obstetricia); Estas Ilustraciones habrían sorprendido al Rey George III, quien ordenó que se arrancaran las páginas de cada copia.

Andrew Bell (1726-1809) era un escocés pintoresco (Figura 1). Su estatura era de apenas 1.37 m, tenía torcidas las piernas y una enorme nariz que a veces él aumentaba un poco con una versión en papel-maché, que se colocaba cada vez que alguien miraba fijamente su nariz. A pesar de su pequeña estatura, deliberadamente montó el caballo más alto disponible en Edimburgo, descendiendo por una escalera ante la aclamación de los espectadores.

Después de que murió Macfarquhar en 1793, Bell compró su Parte de la compañía a sus herederos y se convirtió en el único propietario de la británica hasta su muerte en 1809.

5. COMENTARIOS FINALES

No deja de ser interesante, al leer la entrada de acústica en la Enciclopedia Británica, observar las particularidades del inglés del siglo XVIII, la estilística de la divulgación científica, la búsqueda de utilidad en la ciencia, las contradicciones encontradas en la ciencia durante su evolución al estado del arte actual en la acústica.

A veces se olvida el largo camino recorrido por los científicos en la creación de conocimiento y el de las sociedades en sus deseos y necesidades sociales. Esta lectura nos ayuda a visualizar el esfuerzo de las generaciones anteriores y nos recuerda de nuestra responsabilidad humana de seguir adelante.

6. REFERENCIAS

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ANEXO:
EL TÉRMINO "ACÚSTICA" EN LA 3ª EDICIÓN DE LA *ENCYCLOPÆDIA BRITANNICA* DE 1797 [1]

A C O U S T I C S

1 Diacouſtics. INSTRUCTS us in the nature of ſound. It is divided by ſome writers into *Diacouſtics*, which explains the properties of thoſe ſounds that come directly from the ſonorous body to the ear; and *Catacouſtics*, which treats of reflected ſounds: but ſuch diſtinction does not appear to be of any real utility.

2 Catacouſtics.

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3 Of the vehicles of ſound. Moſt ſounds, we all know, are conveyed to us on the boſom of the air. In whatever manner they either float upon it, or are propelled forward in it, certain it is, that, without the vehicle of this or ſome other fluid, we ſhould have no ſounds at all. Let the air be exhauſted from a receiver, and a bell ſhall emit no ſound when rung in the void; for, as the air continues to grow leſs denſe, the ſound dies away in proportion, ſo that at laſt its ſtrongeſt vibrations are almoſt totally ſilent.

4 Air not the only one. Thus air is a vehicle for ſound. However, we muſt not, with ſome philoſophers, aſſert, that it is the only vehicle; that, if there were no air, we ſhould have no ſounds whatſoever: for it is found by trial, that ſounds are conveyed through water almoſt with the ſame facility with which they move through air. A bell rung in water returns a tone as diſtinct as if rung in air. This was obſerved by Derham, who alſo remarked that the tone came a quarter deeper. Some naturaliſts aſſure us alſo, that fiſhes have a ſtrong perception of ſounds, even at the bottom of deep rivers (A). From hence, it would ſeem not to be very material in the propagation of ſounds, whether the fluid which conveys them be elaſtic or otherwiſe. Water, which, of all ſubſtances that we know, has the leaſt elaſticity, yet ſerves to carry them forward; and if we make allowance for the difference of its denſity, perhaps the ſounds move in it with a proportional rapidity to what they are found to do in the elaſtic fluid of air.

One thing however is certain, that whether the fluid which conveys the note be elaſtic or non-elaſtic, whatever ſound we hear is produced by a ſtroke, which the ſounding body makes againſt the fluid, whether air or water. The fluid being ſtruck upon, carries the impreſſion forward to the ear, and there produces its ſenſation. Philoſophers are ſo far agreed, that they all allow that ſound is nothing more than the impreſſion made by an elaſtic body upon the air or water (B), and this impreſſion carried along by either fluid to the organ of hearing. But the manner in which this conveyance is made, is ſtill diſputed: Whether the ſound is diffuſed into the air, in circle beyond circle, like the waves of water when we diſturb the ſmoothneſs of its ſurface by dropping in a ſtone; or whether it travels along, like rays diffuſed from a centre, ſomewhat in the ſwift manner that electricity runs along a rod of iron; theſe are the queſtions which have divided the learned.

5 What ſound is, and how propagated.

Newton was of the firſt opinion. He has explained the progreſſion of ſound by an undulatory, or rather a vermicular, motion in the parts of the air. If we have an exact idea of the crawling of ſome inſects, we ſhall have a tolerable notion of the progreſſion of ſound upon this hypotheſis. The inſect, for inſtance, in its motion, firſt carries its contractions from the hinder part, in order to throw its fore-part to the proper diſtance, then it carries its contractions from the fore-part to the hinder to bring that forward. Something ſimilar to this is

6 Newton's theory.

(A) Dr Hunter has proved this, and demonſtrated the auricular organ in theſe animals. See Fish, and Comparative *Anatomy*.

(B) Though air and water are both vehicles of ſound, yet neither of them ſeems to be ſo by itſelf, but only as it contains an exceedingly ſubtile fluid capable of penetrating the moſt ſolid bodies. Hence, by the medium of that fluid, ſounds can be propagated through wood, or metals, even more readily than through the open air. By the ſame means, deaf people may be made ſenſible of ſounds, if they hold a piece of metal in their mouth, one end of which is applied to the ſounding body. As it is certain, therefore, that air cannot penetrate metals, we muſt acknowledge the medium of ſound to be of a more ſubtile nature; and thus the electrical fluid will naturally occur as the proper one. But why then is ſound no longer heard in an exhauſted receiver, if the air is not the fluid by which it is conveyed, ſeeing the electrical matter cannot be excluded? The reply to this is obvious: The electrical fluid is ſo exceedingly ſubtile, and pervades ſolid bodies with ſo much eaſe, that any motion of a ſolid body in a quantity of electric matter by itſelf, can never excite a degree of agitation in it ſufficient for producing a ſound; but if the electric fluid is entangled among the particles of air, water, wood, metal, &c. whatever affects their particles will alſo affect this fluid, and produce an audible noiſe. In the experiment of the air-pump, however, there may be an ambiguity, as the gradual exhauſting of the air creates an increaſing difference of preſſure on the outſide, and may occaſion in the glaſs a difficulty of vibrating, ſo as to render it leſs fit to communicate to the air without the vibrations that ſtrike it from within. From this cauſe the diminution of ſound in an exhauſted receiver may be ſuppoſed to proceed, as well as from the diminution of the air. But if any internal agitation of its parts ſhould happen to the electrical fluid, exceeding loud noiſes might be propagated through it, as has been the caſe when large meteors have kindled at a great diſtance from the earth. It is alſo difficult to account for the exceeding great ſwiftneſs of ſound, upon the ſuppoſition that it is propagated by means of air alone; for nothing is more certain, than that the ſtrongeſt and moſt violent gale is, in its courſe, inert and ſluggiſh, compared with the motion of ſound.

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Plate I. fig. 1.

is the motion of the air when ſtruck upon by a ſounding body. To be a little more preciſe, ſuppoſe ABC, the ſtring of an harpſichord ſcrewed to a proper pitch, and drawn out of the right line by the finger at B. We ſhall have occaſion elſewhere to obſerve, that ſuch a ſtring would, if let go, vibrate to E; and from E to D, and back again; that it would continue thus to vibrate like a pendulum for ever, if not externally reſiſted, and, like a pendulum, all its little vibrations would be performed in equal times, the laſt and the firſt being equally long in performing; alſo, that, like a pendulum, its greateſt ſwiftneſs would always be when it arrived at E, the middle part of its motion. Now then, if this ſtring be ſuppoſed to fly from the finger at B, it is obvious, that whatever be its own motion, ſuch alſo will be the motion of the parts of air that fly before it. Its motion, as is obvious, is firſt uniformly accelerated forward from B to E, then retarded as it goes from E to D, accelerated back again as it returns from D to E, and retarded from E to B. This motion being therefore ſent in ſucceſſion through a range of elaſtic air, it muſt happen, that the parts of one range of air muſt be ſent forward with accelerated motion, and then with a retarded motion. This accelerated motion reaching the remoteſt end of the firſt range will be communicated to a ſecond range, while the neareſt parts of the firſt range being retarded in their motion, and falling back with the receſſion of the ſtring, retire firſt with an accelerated, then with a retarded motion, and the remoteſt parts will ſoon follow. In the mean time, while the parts of the firſt range are thus falling back, the parts of the ſecond range are going forward with an accelerated motion. Thus there will be an alternate condenſation and relaxation of the air, during the time of one vibration; and as the air going forward ſtrikes any oppoſing body with greater force than upon retiring, ſo each of theſe accelerated progreſſions have been called by Newton a *pulſe* of ſound.

Thus will the air be driven forward in the direction of the ſtring. But now we muſt obſerve, that theſe pulſes will move every way; for all motion impreſſed upon fluids in any direction whatſoever, operates all around in a ſphere: ſo that ſounds will be driven in all directions, backwards, forwards, upwards, downwards, and on every ſide. They will go on ſucceeding each other, one on the outſide of the other, like circles in diſturbed water; or rather, they will lie one without the other, in concentric ſhells, ſhell above ſhell, as we ſee in the coats of an onion.

All who have remarked the tone of a bell, while its ſounds are decaying away, muſt have an idea of the pulſes of ſound, which, according to Newton, are formed by the air's alternate progreſſion and receſſion. And it muſt be obſerved, that as each of theſe pulſes is formed by a ſingle vibration of the ſtring, they muſt be equal to each other; for the vibrations of the ſtring are known to be ſo.

Again, as to the velocity with which ſounds travel, this Newton determines, by the moſt difficult calculation that can be imagined, to be in proportion to the thickneſs of the parts of the air, and the diſtance of theſe parts from each other. From hence he goes on to prove, that each little part moves backward and forward like a pendulum; and from thence he proceeds to demonſtrate, that if the atmoſphere were of the ſame denſity every where as at the ſurface of the earth, in ſuch a caſe, a pendulum, that reached from its higheſt ſurface down to the ſurface of the earth, would by its vibrations diſcover to us the proportion of the velocity with which ſounds travel. The velocity with which each pulſe would move, he ſhows, would be as much greater than the velocity of ſuch a pendulum ſwinging with one complete vibration, as the circumference of a circle is greater than the diameter. From hence he calculates, that the motion of ſound will be 979 feet in one ſecond. But this not being conſonant to experience, he takes in another conſideration, which deſtroys entirely the rigour of his former demonſtration, namely, vapours in the air; and then finds the motion of ſound to be 1142 feet in one ſecond, or near 13 miles in a minute: a proportion which experience had eſtabliſhed nearly before.

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Thus much will ſerve to give an obſcure idea of a theory which has met with numbers of oppoſers. Even John Bernouilli, Newton's greateſt diſciple, modeſtly owns that he did not pretend to underſtand this part of the *Principia*. He attempted therefore to give a more perſpicuous demonſtration of his own, that might confirm and illuſtrate the Newtonian theory. The ſubject ſeemed to reject elucidation: his theory is obviouſly wrong, as D'Alembert has proved in his Theory of Fluids. 7 Preceding Theory oppoſed.

Various have been the objections that have been made to the Newtonian ſyſtem of ſounds. It is urged, that this theory can only agree with the motion of ſound in an elaſtic fluid, whereas ſounds are known to move forward through water that is not elaſtic. To explain their progreſs therefore through water, a ſecond theory muſt be formed: ſo that two theories muſt be made to explain a ſimilar effect; which is contrary to the ſimplicity of true philoſophy, for it is contrary to the ſimplicity of nature. It is farther urged, that this ſlow vermicular motion but ill repreſents the velocity with which ſounds travel, as we know by experience that it is almoſt 13 miles in a minute. In ſhort, it is urged, that ſuch undulations as have been deſcribed, when coming from ſeveral ſonorous bodies at once, would croſs, obſtruct, and confound each other; ſo that, if they were conveyed to the ear by this means, we ſhould hear nothing but a medley of diſcord and broken articulations. But this is equally with the reſt contradictory to experience, ſince we hear the fulleſt concert, not only without confuſion, but with the higheſt pleaſure. Theſe objections, whether well founded or not, have given riſe to another theory: which we ſhall likewiſe lay before the reader; though it too appears liable to objections, which ſhall be afterwards mentioned. 8 The objections.

Every ſound may be conſidered as driven off from the ſounding body in ſtraight lines, and impreſſed upon the air in one direction only: but whatever impreſſion is made upon a fluid in one direction, is diffuſed upon its ſurface into all directions; ſo that the ſound firſt driven directly forward ſoon fills up a wide ſphere, and is heard on every ſide. Thus, as it is impreſſed, it inſtantaneouſly travels forward with a very ſwift motion, reſembling the velocity with which we know electricity flies from one end of a line to another. 9 Another Theory.

Now, as to the pulſes, or cloſe ſhakes as the muſicians expreſs it, which a ſounding body is known to make

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make, each pulſe (ſay the ſupporters of this theory) is itſelf a diſtinct and perfect ſound, and the interval between every two pulſes is profoundly ſilent. Continuity of ſound from the ſame body is only a deception of the hearing; for as each diſtinct ſound ſucceeds at very ſmall intervals, the organ has no time to tranſmit its images with equal ſwiftneſs to the mind, and the interval is thus loſt to ſenſe: juſt as in ſeeing a flaming torch, if ſtared round in a circle, it appears as a ring of fire. In this manner a beaten drum, at ſome ſmall diſtance, preſents us with the idea of continuing ſound. When children run with their ſticks along a rail, a continuing ſound is thus repreſented, though it need ſcarce be obſerved that the ſtroke againſt each rail is perfectly diſtinct and inſulated.

According to this theory, therefore, the pulſes are nothing more than diſtinct ſounds repeated by the ſame body, the firſt ſtroke or vibration being ever the loudeſt, and travelling farther than thoſe that follow; while each ſucceeding vibration gives a new ſound, but with diminiſhed force, till at laſt the pulſes decay away totally, as the force decays that gives them exiſtence.

All bodies whatſoever that are ſtruck return more or leſs a ſound: but ſome, wanting elaſticity, give back no repetition of the ſound; the noiſe is at once begotten and dies: while other bodies, however, there are, which being more elaſtic and capable of vibration, give back a ſound, and repeat the ſame ſeveral times ſucceſſively. Theſe laſt are ſaid to have a tone; the others are not allowed to have any.

This tone of the elaſtic ſtring, or bell, is notwithſtanding nothing more than a ſimilar ſound of what the former bodies produced, but with the difference of being many times repeated while their note is but ſingle. So that, if we would give the former bodies a tone, it will be neceſſary to make them repeat their ſound, by repeating our blows ſwiftly upon them. This will effectually give them a tone; and even an unmuſical inſtrument has often had a fine effect by its tone in our concerts.

Let us now go on then to ſuppoſe, that by ſwift and equably continued ſtrokes we give any non-elaſtic body its tone: it is very obvious, that no alterations will be made in this tone by the quickneſs of the ſtrokes, though repeated ever ſo faſt. Theſe will only render the tone more equal and continuous, but make no alteration in the tone it gives. On the contrary, if we make an alteration in the force of each blow, a different tone will then undoubtedly be excited. The difference will be ſmall, it muſt be confeſſed; for the tones of theſe inflexible bodies are capable but of ſmall variation; however, there will certainly be a difference. The table on which we write, for inſtance, will return a different ſound when ſtruck with a club, from what it did when ſtruck only with a ſwitch. Thus non-elaſtic bodies return a difference of tone, not in proportion to the ſwiftneſs with which their ſound is repeated, but in proportion to the greatneſs of the blow which produced it; for in two equal non-elaſtic bodies, that body produced the deepeſt tone which was ſtruck by the greateſt blow.

We now then come to a critical queſtion, What is it that produces the difference of tone in two elaſtic ſounding bells or ſtrings? Or what makes one deep and the other ſhrill? This queſtion has always been hitherto anſwered by ſaying, that the depth or height of the note proceeded from the ſlowneſs or ſwiftneſs of the times of the vibrations. The ſloweſt vibrations, it has been ſaid, are qualified for producing the deepeſt tones, while the ſwifteſt vibrations produce the higheſt tones. In this caſe, an effect has been given for a cauſe. It is in fact the force with which the ſounding ſtring ſtrikes the air when ſtruck upon, that makes the true diſtinction in the tones of ſounds. It is this force, with greater or leſs impreſſions, reſembling the greater or leſs force of the blows upon a non-elaſtic body, which produces correſpondent affections of ſound. The greateſt forces produce the deepeſt ſounds: the high notes are the effect of ſmall efforts. In the ſame manner a bell, wide at the mouth, gives a grave ſound; but if it be very maſſy withal, that will render it ſtill graver; but if maſſy, wide, and long or high, that will make the tone deepeſt of all.

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Thus, then, will elaſtic bodies give the deepeſt ſound, in proportion to the force with which they ſtrike the air: but if we ſhould attempt to increaſe their force by giving them a ſtronger blow, this will be in vain; they will ſtill return the ſame tone; for ſuch is their formation, that they are ſonorous only becauſe they are elaſtic, and the force of this elaſticity is not increaſed by our ſtrength, as the greatneſs of a pendulum's vibration will not be increaſed by falling from a greater height.

Thus far of the length of chords. Now as to the frequency with which they vibrate the deepeſt tones, it has been found, from the nature of elaſtic ſtrings, that the longeſt ſtrings have the wideſt vibrations, and conſequently go backward and forward ſloweſt; while, on the contrary, the ſhorteſt ſtrings vibrate the quickeſt, or come and go in the ſhorteſt intervals. From hence thoſe who have treated of ſounds, have aſſerted, as was ſaid before, that the tone of the ſtring depended upon the length or the ſhortneſs of the vibrations. This, however, is not the caſe. One and the ſame ſtring, when ſtruck, muſt always, like the ſame pendulum, return preciſely ſimilar vibrations; but it is well known, that one and the ſame ſtring, when ſtruck upon, does not always return preciſely the ſame tone: ſo that in this caſe the vibrations follow one rule, and the tone another. The vibrations muſt be invariably the ſame in the ſame ſtring, which does not return the ſame tone invariably, as is well known to muſicians in general. In the violin, for inſtance, they can eaſily alter the tone of the ſtring an octave or eight notes higher, by a ſofter method of drawing the bow; and ſome are known thus to bring out the moſt charming airs imaginable. Theſe peculiar tones are by the Engliſh fiddlers called *flute-notes*. The only reaſon, it has been alleged, that can be aſſigned for the ſame ſtring thus returning different tones, muſt certainly be the different force of its ſtrokes upon the air. In one caſe, it has double the tone of the other; becauſe upon the ſoft touches of the bow, only half its elaſticity is put into vibration.

This being underſtood (continue the authors of this theory), we ſhall be able clearly to account for many things relating to ſounds that have hitherto been inexplicable. Thus, for inſtance, if it be aſked, When two ſtrings are ſtretched together of equal lengths, tenſions, and thickneſs, how does it happen, that one of them being ſtruck, and made to vibrate throughout,

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throughout, the other ſhall vibrate throughout alſo? the anſwer is obvious: The force that the ſtring ſtruck receives is communicated to the air, and the air communicates the ſame to the ſimilar ſtring; which therefore receives all the force of the former; and the force being equal, the vibrations muſt be ſo too. Again, put the queſtion, If one ſtring be but half the length of the other, and be ſtruck, how will the vibrations be? The anſwer is, The longeſt ſtring will receive all the force of the ſtring half as long as itſelf, and therefore it will vibrate in proportion, that is, through half its length. In the ſame manner, if the longeſt ſtring were three times as long as the other, it would only vibrate in a third of its length; or if four times, in a fourth of its length. In ſhort, whatever force the ſmaller ſtring impreſſes upon the air, the air will impreſs a ſimilar force upon the longer ſtring, and partially excite its vibrations.

10 Eolian Lyre. See Plate I. fig. 2.

From hence alſo we may account for the cauſe of thoſe charming, melancholy gradations of ſound in the Eolian lyre; an inſtrument (ſays Sir John Hawkins) lately obtruded upon the public as a new invention, though deſcribed above a century ago by Kircher *. This inſtrument is eaſily made, being nothing more than a long narrow box of thin dale, about 30 inches long, 5 inches broad, and 1¼ inches deep, with a circle in the middle of the upper ſide or belly about 1¼ inch diameter, pierced with ſmall holes. On this ſide are ſeven, ten, or (according to Kircher) fifteen or more ſtrings of very fine gut, ſtretched over bridges at each end, like the bridge of a fiddle, and ſcrewed up or relaxed with ſcrew-pins (B). The ſtrings are all tuned to one and the ſame note; and the inſtrument is placed in ſome current of air, where the wind can bruſh over its ſtrings with freedom. A window with the ſaſh juſt raiſed to give the air admiſſion, will anſwer this purpoſe exactly. Now when the entering air blows upon theſe ſtrings with different degrees of force, there will be excited different tones of ſound; ſometimes the blaſt brings out all the tones in full concert; ſometimes it ſinks them to the ſofteſt murmurs; it feels for every tone, and by its gradations of ſtrength ſolicits thoſe gradations of ſound which art has taken different methods to produce.

* *Vide* Kircheri Muſurgia, lib. ix.

It remains, in the laſt place, to conſider (by this theory) the loudneſs and lowneſs, or, as the muſicians ſpeak, the ſtrength and ſoftneſs of ſound. In vibrating elaſtic ſtrings, the loudneſs of the tone is in proportion to the deepneſs of the note; that is, in two ſtrings, all things in other circumſtances alike, the deepeſt tone will be loudeſt. In muſical inſtruments upon a different principle, as in the violin, it is otherwiſe; the tones are made in ſuch inſtruments, by a number of ſmall vibrations crowded into one ſtroke. The roſined bow, for inſtance, being drawn along a ſtring, its roughneſſes catch the ſtring at very ſmall intervals, and excite its vibrations. In this inſtrument, therefore, to excite loud tones, the bow muſt be drawn quick, and this will produce the greateſt number of vibrations. But it muſt be obſerved, that the more quick the bow paſſes over the ſtring, the leſs apt will the roughneſs of its ſurface be to touch the ſtring at every inſtant; to remedy this, therefore, the bow muſt be preſſed the harder as it is drawn quicker, and thus its fulleſt ſound will be brought from the inſtrument. If the ſwiftneſs of the vibrations in an inſtrument thus rubbed upon, exceed the force of the deeper ſound in another, then the ſwift vibrations will be heard at a greater diſtance, and as much farther off as the ſwiftneſs in them exceeds the force in the other.

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11 The nature of Muſical Sounds illuſtrated according to the ſame theory.

By the ſame theory (it is alleged) may all the phenomena of muſical ſounds be eaſily explained.—The fables of the ancients pretend, that muſic was firſt found out by the beating of different hammers upon the ſmith's anvil. Without purſuing the fable, let us endeavour to explain the nature of muſical ſounds by a ſimilar method. Let us ſuppoſe an anvil, or ſeveral ſimilar anvils, to be ſtruck upon by ſeveral hammers of different weights or forces. The hammer, which is double that of another, upon ſtriking the anvil will produce a ſound double that of the other: this double ſound muſicians have agreed to call an Octave. The ear can judge of the difference or reſemblance of theſe ſounds with great eaſe, the numbers being as one and two, and therefore very readily compared. Suppoſe that an hammer, three times leſs than the firſt, ſtrikes the anvil, the ſound produced by this will be three times leſs than the firſt: ſo that the ear, in judging the ſimilitude of theſe ſounds, will find ſomewhat more difficulty; becauſe it is not ſo eaſy to tell how often one is contained in three, as it is to tell how often it is contained in two. Again, ſuppoſe that an hammer four times leſs than the firſt ſtrikes the anvil, the ear will find greater difficulty ſtill in judging preciſely the difference of the ſounds; for the difference of the numbers four and one cannot ſo ſoon be determined with preciſion as three and one. If the hammer be five times leſs, the difficulty of judging will be ſtill greater. If the hammer be ſix times leſs, the difficulty ſtill increaſes, and ſo alſo of the ſeventh, inſomuch that the ear cannot always readily and at once determine the preciſe gradation. Now, of all comparifons, thoſe which the mind makes moſt eaſily, and with leaſt labour, are the moſt pleaſing. There is a certain regularity in the human ſoul, by which it finds happineſs in exact and ſtricking, and eaſily-made comparifons. As the ear is but an inſtrument of the mind, it is therefore moſt pleaſed with the combination of any two ſounds, the differences of which it can moſt readily diſtinguiſh. It is more pleaſed with the concord of two ſounds which are to each other as one and two, than of two ſounds which are as one and three, or one and four, or one and five, or one and ſix or ſeven. Upon this pleaſure, which the mind takes in compariſon, all harmony depends. The variety of ſounds is infinite; but becauſe the ear cannot compare two ſounds ſo as readily to diſtinguiſh their diſcriminations when they exceed the proportion of one and ſeven, muſicians have been content to confine all harmony within that compaſs, and allowed but ſeven notes in muſical compoſition.

Let us now then ſuppoſe a ſtringed inſtrument fitted up

(B) The figure repreſents the inſtrument with ten chords; of which ſome direct only eight to be tuned uniſons, and the two outermoſt octaves below them. But this ſeems not to be material.

Of Musical Sounds.

up in the order mentioned above. For instance: Let the first string be twice as long as the second; let the third string be three times shorter than the first; let the fourth be four times, the fifth string five times, and the sixth six times as short as the first. Such an instrument would probably give us a representation of the lyre as it came first from the hand of the inventor. This instrument will give us all the seven notes following each other, in the order in which any two of them will accord together most pleasingly; but yet it will be a very inconvenient and a very disagreeable instrument: inconvenient, for in a compass of seven strings only, the first must be seven times as long as the last; and disagreeable, because this first string will be seven times as loud also; so that when the tones are to be played in a different order, loud and soft sounds would be intermixed with most disgusting alternations. In order to improve the first instrument, therefore, succeeding musicians very judiciously threw in all the other strings between the two first, or, in other words, between the two Octaves, giving to each, however, the same proportion to what it would have had in the first natural instrument. This made the instrument more portable, and the sounds more even and pleasing. They therefore disposed the sounds between the Octave in their natural order, and gave each its own proportional dimensions. Of these sounds, where the proportion between any two of them is most obvious, the concord between them will be most pleasing. Thus Octaves, which are as two to one, have a most harmonious effect; the fourth and fifth also sound sweetly together, and they will be found, upon calculation, to bear the same proportion to each other that Octaves do. "Let it "not be supposed (says Mr Saveur), that the musical "scale is merely an arbitrary combination of sounds; "it is made up from the consonance and differences of "the parts which compose it. Those who have often "heard a fourth and fifth accord together, will be "naturally led to discover their difference at once; and "the mind unites itself to their beauties." Let us then cease to assign the coincidences of vibrations as the cause of harmony, since these coincidences in two strings vibrating at different intervals, must at best be but fortuitous; whereas concord is always pleasing. The true cause why concord is pleasing, must arise from our power, in such a case, of measuring more easily the differences of the tones. In proportion as the note can be measured with its fundamental tone by large and obvious distinctions, then the concord is most pleasing; on the contrary, when the ear measures the discriminations of two tones by very small parts, or cannot measure them at all, it loses the beauty of their resemblance: the whole is discord and pain (c).

But there is another property in the vibration of a musical string not yet taken notice of, and which is alleged to confirm the foregoing theory. If we strike the string of an harpsichord, or any other elastic sounding chord whatever, it returns a continuing sound. This till of late was considered as one simple uniform tone; but all musicians now confess, that instead of one tone it actually returns four tones, and that constantly. The notes are, beside the fundamental tone, an octave above, a twelfth above, and a seventeenth. One of the bass-notes of an harpsichord has been dissected in this manner by Rameau, and the actual existence of these tones proved beyond a possibility of being controverted. In fact, the experiment is easily tried; for if we smartly strike one of the lower keys of an harpsichord, and then take the finger briskly away, a tolerable ear will be able to distinguish, that, after the fundamental tone has ceased, three other shriller tones will be distinctly heard; first the octave above, then the twelfth, and lastly the seventeenth: the octave above is in general almost mixed with the fundamental tone, so as not to be easily perceived, except by an ear long habituated to the minute discriminations of sounds. So that we may observe, that the smallest tone is heard last, and the deepest and largest one first: the two others in order.

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In the whole theory of sounds, nothing has given greater room for speculation, conjecture, and disappointment, than this amazing property in elastic strings. The whole string is universally acknowledged to be in vibration in all its parts, yet this single vibration returns no less than four different sounds. They who account for the tones of strings by the number of their vibrations, are here at the greatest loss. Daniel Bernouilli supposes, that a vibrating string divides itself into a number of curves, each of which has a peculiar vibration; and though they all swing together in the common vibration, yet each vibrates within itself. This opinion, which was supported, as most geometrical speculations are, with the parade of demonstration, was only born soon after to die. Others have ascribed this to an elastic difference in the parts of the air, each of which, at different intervals, thus received different impressions from the string, in proportion to their elasticity. This is absurd. If we allow the difference of tone to proceed from the force, and not the frequency, of the vibrations, this difficulty will admit of an easy solution. These sounds, though they seem to exist together in the string, actually follow each other in succession: while the vibration has greatest force, the fundamental tone is brought forward: the force of the vibration decaying, the octave is produced, but almost only instantaneously; to this succeeds, with diminished force, the twelfth; and, lastly, the seventeenth is heard to vibrate with great distinctness, while the three other tones are always silent. These sounds, thus excited, are all of them the harmonic tones, whose differences from the fundamental tone are, as was said, strong, and distinct. On the other hand, the discordant tones cannot be heard. Their differences being but very small, they are overpowered, and in a manner drowned in the tones of superior difference: yet not always neither; for Daniel Bernouilli has been able, from the same stroke, to make the same string bring out its harmonic and its discordant tones also (D.) So that from hence we may justly infer, that every note whatsoever

(c) It is certain, that in proportion to the simplicity of relations in sound, the ear is pleased with its combinations; but this is not to be admitted as the cause why musicians have confined all harmony to an octave. Discriminated sounds, whose vibrations either never coincide, or at least very rarely, do not only cease to please, but violently grate the ear. Harmony and discord, therefore, are neither discriminated by the judgment of hearers, nor the institution of musicians, but by their own essential and immutable nature.

(D) Vid. Memoires de l'Academie de Berlin, 1753, p. 153.

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is only a ſucceſſion of tones; and that thoſe are moſt diſtinctly heard, whoſe differences are moſt eaſily perceivable.

11 Objections to the preceding theory.

To this theory, however, though it has a plauſible appearance, there are ſtrong and indeed inſuperable objections. The very fundamental principle of it is falſe. No body whatever, whether elaſtic or non-elaſtic, yields a graver ſound by being ſtruck with a larger inſtrument, unleſs either the ſounding body, or that part of it which emits the ſound, is enlarged. In this caſe, the largeſt bodies always return the graveſt ſounds.

In ſpeaking of elaſtic and non-elaſtic bodies in a muſical ſenſe, we are not to puſh the diſtinction ſo far as when we ſpeak of them philoſophically. A body is *muſically* elaſtic, all of whoſe parts are thrown into vibrations ſo as to emit a ſound when only part of their ſurface is ſtruck. Of this kind are bells, muſical ſtrings, and all bodies whatever that are conſiderably hollow.—Muſical non-elaſtics are ſuch bodies as emit a ſound only from that particular place which is ſtruck: thus, a table, a plate of iron nailed on wood, a bell ſunk in the earth, are all of them non-elaſtics in a muſical ſenſe, though not philoſophically ſo. When a ſolid body, ſuch as a log of wood, is ſtruck with a ſwitch, only that part of it emits a ſound which comes in contact with the ſwitch; the note is acute and loud, but would be no leſs ſo though the adjacent parts of the log were removed. If, inſtead of the ſwitch, a heavier or larger inſtrument is made uſe of, a larger portion of its ſurface then returns a ſound, and the note is conſequently more grave; but it would not be ſo, if the large inſtrument ſtruck with a ſharp edge, or a ſurface only equal to that of the ſmall one.

In ſounds of this kind, where there is only a ſingle thwack, without any repetition, the immediate cauſe of the gravity or acuteneſs ſeems to be the quantity of air diſplaced by the ſounding body; a large quantity of air diſplaced, produces a grave ſound, and a ſmaller quantity a more acute one, the force wherewith the air is diſplaced ſignifying very little.—What we hear advance is confirmed by ſome experiments made by Dr Prieſtley, concerning the *muſical tone* of electrical diſcharges. The paſſage being curious, and not very long, we ſhall here tranſcribe it:

"As the courſe of my experiments has required a great variety of electrical explоſions, I could not help obſerving a great variety in the muſical tone made by the reports. This excited my curioſity to attempt to reduce this variation to ſome meaſure. Accordingly, by the help of a couple of ſpinets, and two perſons who had good ears for muſic, I endeavoured to aſcertain the tone of ſome electrical diſcharges; and obſerved, that every diſcharge made ſeveral ſtrings, particularly thoſe that were chords to one another, to vibrate: but one note was always predominant, and ſounded after the reſt. As every explоſion was repeated ſeveral times, and three of us ſeparately took the ſame note, there remained no doubt but that the tone we fixed upon was at leaſt very near the true one. The reſult was as follows:

"A jar containing half a ſquare foot of coated glaſs ſounded F ſharp, concert pitch. Another jar of a different form, but equal ſurface, ſounded the ſame.

"A jar of three ſquare feet ſounded C below F ſharp. A battery conſiſting of ſixty-four jars, each containing half a ſquare foot, ſounded F below the C. Of Muſical Sounds.

"The ſame battery, in conjunction with another of thirty-one jars, ſounded C ſharp. So that a greater quantity of coated glaſs always gave a deeper note.

"Differences in the degree of a charge in the ſame jar made little or no difference in the tone of the explоſion: if any, a higher charge gave rather a deeper note."

Theſe experiments ſhow us how much the gravity or acuteneſs of ſounds depend on the quantity of air put in agitation by the ſounding body. We know that the noiſe of the electric explоſion ariſes from the return of the air into the vacuum produced by the electric flaſh. The larger the vacuum, the deeper was the note: for the ſame reaſon, the diſcharge of a muſket produces a more acute note than that of a cannon; and thunder is deeper than either.

Beſides this, however, other circumſtances concur to produce different degrees of gravity or acuteneſs in ſounds. The ſound of a table ſtruck upon with a piece of wood, will not be the ſame with that produced from a plate of iron ſtruck by the ſame piece of wood, even if the blows ſhould be exactly equal, and the iron perfectly kept from vibrating.—Here the ſounds are generally ſaid to differ in their degrees of acuteneſs, according to the ſpecific gravities or denſities of the ſubſtances which emit them. Thus gold, which is the moſt denſe of all metals, returns a much graver ſound than ſilver; and metalline wires, which are more denſe than therms, return a proportionably greater ſound.—But neither does this appear to be a general rule in which we can put confidence. Bell-metal is denſer than copper, but it by no means appears to yield a graver ſound; on the contrary, it ſeems very probable, that copper will give a graver ſound than bell-metal, if both are ſtruck upon in their non-elaſtic ſtate; and we can by no means think that a bell of pure tin, the leaſt denſe of all the metals, will give a more acute ſound than one of bell-metal, which is greatly more denſe.—In ſome bodies hardneſs ſeems to have a conſiderable effect. Glaſs, which is conſiderably harder than any metal, gives a more acute ſound; bell-metal is harder than gold, lead, or tin, and therefore ſounds much more acutely; though how far this holds with regard to different ſubſtances, there are not a ſufficient number of experiments for us to judge.

In bodies muſically elaſtic, the whole ſubſtance vibrates with the ſlighteſt ſtroke, and therefore they always give the ſame note whether they are ſtruck with a large or with a ſmall inſtrument: ſo that ſtriking a part of the ſurface of any body muſically elaſtic is equivalent, in it, to ſtriking the whole ſurface of a non-elaſtic one. If the whole ſurface of a table was ſtruck with another table, the note produced would be neither more nor leſs acute whatever force was employed; becauſe the whole ſurface would then yield a ſound, and no force could increaſe the ſurface: the ſound would indeed be louder in proportion to the force employed, but the gravity would remain the ſame. In like manner, when a bell, or muſical ſtring, is ſtruck, the whole ſubſtance vibrates, and a greater ſtroke cannot increaſe the ſubſtance.—Hence we ſee the fallacy of what is ſaid concerning the Pythagorean anvils. An anvil is a body muſically elaſtic, and no difference in the tone

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can be perceived whether it is ſtruck with a large, or with a ſmall hammer; becauſe either of them are ſufficient to make the whole ſubſtance vibrate, provided nothing but the anvil is ſtruck upon: ſmiths, however, do not ſtrike their anvils, but red-hot iron laid upon their anvils; and thus the vibrations of the anvil are ſtopped, ſo that it becomes a non-elaſtic body, and the differences of tone in the ſtrokes of different hammers proceed only from the ſurface of the large hammers covering the whole ſurface of the iron, or at leaſt a greater part of it than the ſmall ones. If the ſmall hammer is ſufficient to cover the whole ſurface of the iron as well as the large one, the note produced will be the ſame, whether the large or the ſmall hammer is uſed.

Laſtly, The argument for the preceding theory, grounded on the production of what are called *flute-notes* on the violin, is built on a falſe foundation; for the bow being lightly drawn on an open ſtring, produces no *flute-notes*, but only the harmonies of the note to which the ſtring is tuned. The *flute-notes* are produced by a particular motion of the bow, quick and near the bridge, and by fingering very gently. By this management, the ſame ſounds are produced, tho' at certain intervals only, as if the vibrations were tranſferred to the ſpace between the end of the finger-board and the finger, inſtead of that between the finger and the bridge. Why this ſmall part of the ſtring ſhould vibrate in ſuch a caſe, and not that which is under the immediate action of the bow, we muſt own ourſelves ignorant: nor dare we affirm that the vibrations really are tranſferred in this manner, only the ſame ſounds are produced as if they were.

Though theſe objections ſeem ſufficiently to overturn the foregoing theory, with regard to acute ſounds being the effects of weak ſtrokes, and grave ones of ſtronger impulſes, we cannot admit that longer or ſhorter vibrations are the occaſion of gravity or acuteneſs in ſound. A muſical ſound, however lengthened, either by ſtring or bell, is only a repetition of a ſingle one, whoſe duration by itſelf is but for a moment, and is therefore termed *inappretiable*, like the ſmack of a whip, or the exploſion of an electrical battery. The continuation of the ſound is nothing more than a repetition of this inſtantaneous inappretiable noiſe after the manner of an echo, and it is only this echo that makes the ſound agreeable. For this reaſon, muſic is much more agreeable when played in a large hall where the ſound is reverberated, than in a ſmall room where there is no ſuch reverberation. For the ſame reaſon, the ſound of a ſtring is more agreeable when put on a hollow violin than when faſtened to a plain board, &c.—In the ſound of a bell, we cannot avoid obſerving this echo very diſtinctly. The ſound appears to be made up of diſtinct pulſes, or repetitions of the ſame note produced by the ſtroke of the hammer. It can by no means be allowed, that the note would be more acute though theſe pulſes were to ſucceed one another more rapidly; the ſound would indeed become more ſimple, but would ſtill preſerve the ſame tone.—In muſical ſtrings the reverberations are vaſtly more quick than in bells; and therefore their ſound is more uniform or ſimple, and conſequently more agreeable than that of bells. In muſical glaſſes*, the vibrations muſt be inconceivably quicker than in any bell, or ſtringed inſtrument: and hence they are of all others the moſt ſimple and the moſt agreeable, though neither the moſt acute nor the loudeſt.—As far as we can judge, quickneſs of vibration contributes to the uniformity, or ſimplicity, but not to the acuteneſs, nor to the loudneſs, of a muſical note.

* See *Harmonica.*

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It may here be objected, that each of the different pulſes, of which we obſerve the ſound of a bell to be compoſed, is of a very perceptible length, and far from being inſtantaneous; ſo that it is not fair to infer that the ſound of a bell is only a repetition of a ſingle inſtantaneous ſtroke, ſeeing it is evidently the repetition of a lengthened note.—To this it may be replied, that the inappretiable ſound which is produced by ſtriking a bell in a non-elaſtic ſtate, is the very ſame which, being firſt propagated round the bell, forms one of theſe ſhort pulſes that is afterwards re-echoed as long as the vibrations of the metal continue, and it is impoſſible that the quickneſs of repetition of any ſound can either increaſe or diminiſh its gravity.

Chap. II. *Of the propagation of Sound. Newton's Doctrine explained and vindicated.*

13 Propagation of ſound.

The writers on ſound have been betrayed into theſe difficulties and obſcurities, by rejecting the 47th propoſition, B. ii. of Newton, as inconcluſive reaſoning. Of this propoſition, however, the ingenious Mr Young of Trinity college, Dublin, has lately given a clear, explanatory, and able defence. He candidly owns that the demonſtration is obſcurely ſtated, and takes the liberty of varying, in ſome degree, from the method of Newton.

"1. The parts of all ſounding bodies, (he obſerves), vibrate according to the law of a cycloidal pendulum: for they may be conſidered as compoſed of an indefinite number of elaſtic fibres; but theſe fibres vibrate according to that law. *Vide Helſham, p.* 270.

"2. Sounding bodies propagate their motions on all ſides *in directum*, by ſucceſſive condenſations and rarefactions, and ſucceſſive goings forward and returnings backward of the particles. *Vide prop.* 43. *B.* 2. *Newton.*

"3. The pulſes are thoſe parts of the air which vibrate backwards and forwards; and which, by going forward, ſtrike (*pulſant*) againſt obſtacles. The latitude of a pulſe is the rectilineal ſpace through which the motion of the air is propagated during one vibration of the ſounding body.

"4. All pulſes move equally faſt. This is proved by experiment; and it is found that they deſcribe 1070 Paris feet, or 1142 London feet in a ſecond, whether the ſound be loud or low, grave or acute.

"5. Prob. To determine the latitude of a pulſe. Divide the ſpace which the pulſe deſcribes in a given time (4) by the number of vibrations performed in the ſame time by the ſounding body, (*cor.* 1. *prop.* 24. *Smith's Harmonics*), the quotient is the latitude.

"M. Sauveur, by ſome experiments on organ-pipes, found that a body, which gives the graveſt harmonic ſound, vibrates 12 times and a half in a ſecond, and that the ſhrilleſt ſounding body vibrates 51.100 times in a ſecond. At a medium, let us take the body which gives what Sauveur calls his *fixed ſound:* it performs 100 vibrations in a ſecond, and in the ſame time the pulſes deſcribe 1070 Pariſian feet; therefore the ſpace deſcribed by the pulſes whilſt the body vibrates once, that

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that is, the latitude or interval of the pulſe, will be 10.7 feet.

"6. Prob. To find the proportion which the greateſt ſpace, through which the particles of the air vibrate, bears to the radius of a circle, whoſe perimeter is equal to the latitude of the pulſe.

"During the firſt half of the progreſs of the elaſtic fibre, or ſounding body, it is continually getting nearer to the next particle; and during the latter half of its progreſs, that particle is getting farther from the fibre, and theſe portions of time are equal (*Helſham*): therefore we may conclude, that at the end of the progreſs of the fibre, the firſt particle of air will be nearly as far diſtant from the fibre as when it began to move; and in the ſame manner we may infer, that all the particles vibrate through ſpaces nearly equal to that run over by the fibre.

"Now, M. Sauveur (*Acad. Science, an.* 1700, *p.*141) has found by experiment, that the middle point of a chord which produces his *fixed ſound*, and whoſe diameter is $\frac{1}{6}$th of a line, runs over in its ſmalleſt ſenſible vibrations $\frac{1}{18}$th of a line, and in its greateſt vibrations 72 times that ſpace; that is $72\times\frac{1}{18}$th of a line, or 4 lines, that is, $\frac{1}{3}$d of an inch.

"The latitude of the pulſes of this fixed ſound is 10.7 feet (5); and ſince the circumference of a circle is to its radius as 710 is to 113, the greateſt ſpace deſcribed by the particles will be to the radius of a circle, whoſe periphery is equal to the latitude of the pulſe as $\frac{1}{3}$d of an inch is to 1.7029 feet, or 20.4348 inches, that is, as 1 to 61.3044.

"If the length of the ſtring be increaſed or diminiſhed in any proportion, *cæteris paribus*, the greateſt ſpace deſcribed by its middle point will vary in the ſame proportion. For the inflecting force is to the tending force as the diſtance of the ſtring from the middle point of vibration to half the length of the ſtring (*ſee Helſham and Martin*); and therefore the inflecting and tending forces being given, the ſtring will vibrate through ſpaces proportional to its length; but the latitude of the pulſe is inverſely as the number of vibrations performed by the ſtring in a given time, (5) that is, directly as the time of one vibration, or directly as the length of the ſtring (*prop.* 24. *cor.* 7. *Smith's Harmonics*); therefore the greateſt ſpace through which the middle point of the ſtring vibrates, will vary in the direct ratio of the latitude of the pulſe, or of the radius of a circle whoſe circumference is equal to the latitude, that is, it will be to that radius as 1 to 61.3044.

"7. If the particles of the aërial pulſes, during any part of their vibration, be ſucceſſively agitated, according to the law of a cycloidal pendulum, the comparative elaſtic forces ariſing from their mutual action, by which they will afterwards be agitated, will be ſuch as will cauſe the particles to continue that motion, according to the ſame law, to the end of their vibration.

Plate I. fig. 7.

"Let AB, BC, CD, &c. denote the equal diſtances of the ſucceſſive pulſes; ABC the direction of the motion of the pulſes propagated from A towards B; E, F, G, three phyſical points of the quieſcent medium, ſituated in the right line AC at equal diſtances from each other; E*e*, F*f*, G*g* the very ſmall equal ſpaces through which theſe particles vibrate; *ε*, *φ*, *γ* any intermediate places of theſe points. Draw the right line PS equal to E*e*, biſect it in O, and from the centre O with the radius O P deſcribe the circle SIP*b*. Let the whole time of the vibration of a particle and its parts be denoted by the circumference of this circle and its proportional parts. And ſince the particles are ſuppoſed to be at firſt agitated according to the law of a cycloidal pendulum, if at any time PH, or PHS*b*, the perpendicular HL or *hl*, be let fall on PS, and if E*e* be taken equal to PL or P*l*, the particle E ſhall be found in *ε*. Thus will the particle E perform its vibrations according to the law of a cycloidal pendulum. *Prop.* 52. *B.* 1. *Principia.*

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"Let us ſuppoſe now, that the particles have been ſucceſſively agitated, according to this law, for a certain time, by any cauſe whatſoever, and let us examine what will be the comparative elaſtic forces ariſing from their mutual action, by which they will afterwards continue to be agitated.

"In the circumference PHS*b* take the equal arches HI, IK in the ſame ratio to the whole circumference which the equal right lines EF, FG have to BC the whole interval of the pulſes; and let fall the perpendiculars HL, IM, KN. Since the points E, F, G are ſucceſſively agitated in the ſame manner, and perform their entire vibrations of progreſs and regreſs while the pulſe is propagated from B to C, if PH be the time from the beginning of the motion of E, PI will be the time from the beginning of the motion of F, and PK the time from the beginning of the motion of G; and therefore E*ε*, F*φ*, G*γ* will be reſpectively equal to PL, PM, PN in the progreſs of the particles. Whence *εφ* or EF+F*φ*—E*ε* is equal to EF—LM. But *εφ* is the expanſion of EF in the place *εφ*, and therefore this expanſion is to its mean expanſion as EF—LM to EF. But LM is to IH as IM is to OP, and IH is to EF as the circumference PHS*b* is to BC; that is, as OP is to V, if V be the radius of a circle whoſe circumference is BC; therefore, *ex æquo*, LM is to EF as IM is to V; and therefore the expanſion of EF in the place *εφ* is to its mean expanſion as V—IM is to V; and the elaſtic force exiſting between the phyſical points E and F is to the mean elaſtic force as $\frac{1}{V-IM}$ is to $\frac{1}{V}$ (*Cotes Pneum. Lect.* 9.) By the ſame argument, the elaſtic force exiſting between the phyſical points F and G is to the mean elaſtic force as $\frac{1}{V-KN}$ is to $\frac{1}{V}$; and the difference between theſe forces is to the mean elaſtic force as

$$\frac{IM-KN}{V^2-V.IM-V.KN+IM.KN}$$ is to $\frac{1}{V}$; that is, as $\frac{IM-KN}{V^2}$ is to $\frac{1}{V}$; or as IM—KN is to V; if only (upon account of the very narrow limits of the vibration) we ſuppoſe IM and KN to be indefinitely leſs than V. Wherefore, ſince V is given, the difference of the forces is as IM—KN, or as HL—IM (becauſe KH is biſected in I); that is, (becauſe HL—IM is to IH as OM is to OI or OP, and IH and OP are given quantities) as OM; that is, if F*f* be biſected in Ω as Ω*φ*.

"In the ſame manner it may be ſhown, that if PHS*b* be the time from the beginning of the motion of E, PHS*i* will be the time from the beginning of the motion of F, and PHS*k* the time from the beginning of the

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the motion of G; and that the expanſion of EF in the place ϕ is to its mean expanſion as EF+$F\phi$—$E\phi$, or as EF+lm is to EF, or as V+hl is to V in its regreſs; and its elaſtic force to the mean elaſtic force as $\frac{1}{V+hl}$ is to $\frac{1}{V}$; and that the difference of the elaſtic forces exiſting between E and F, and between F and G is to the mean elaſtic force as kn—im is to V; that is, directly as $\Omega\phi$.

" But this difference of the elaſtic forces, exiſting between E and F, and between F and G, is the comparative elaſtic force by which the phyſical point ϕ is agitated: and therefore the comparative accelerating force, by which every phyſical point in the medium will continue to be agitated both in progreſs and regreſs, will be directly as its diſtance from the middle point of its vibration; and conſequently, will be ſuch as will cauſe the particles to continue their motion, undiſturbed, according to the law of a cycloidal pendulum. *Prop.* 38. *l.* 1. *Newton.*

" Newton rejects the quantity $\overline{+V\times IM+KN}+IM\times KN$, on ſuppoſition that IM and KN are indefinitely leſs than V. Now, although this may be a reaſonable hypotheſis, yet, that this quantity may be ſafely rejected, will, I think, appear in a more ſatisfactory manner from the following conſiderations derived from experiment: PS, in its greateſt poſſible ſtate, is to V as 1 is to 61.3044 (6); and therefore IM or KN, in its greateſt poſſible ſtate, (that is, when the vibrations of the body are as great as poſſible, and the particle in the middle point of its vibration) is to V as 1 is to 122.6. Hence V^2=15030.76,—$V\times\overline{IM+KN}$=245.2 and IM×KN=1; therefore V^2 is to V^2—$V\times\overline{IM+KN}+IM\times KN$ as 15.03076 is to 14786.56; that is, as 61 is to 60 nearly.

" Hence it appears, that the greateſt poſſible error in the accelerating force, in the middle point, is the $\frac{1}{61}$ſt part of the whole. In other points it is much leſs; and in the extreme points the error entirely vaniſhes.

" We ſhould alſo obſerve, that the ordinary ſounds we hear are not produced by the greateſt poſſible vibrations of which the ſounding body is capable; and that in general IM and KN are nearly evaneſcent with reſpect to V. And very probably the diſagreeable ſenſations we feel in very loud ſounds, ariſe not only from IM or KN bearing a ſenſible proportion to V, by which means the cycloidal law of the pulſes may be in ſome meaſure diſturbed, but alſo from the very law of the motion of the ſounding body itſelf being diſturbed. For, the proof of this law's being obſerved by an elaſtic fibre is founded on the hypotheſis that the ſpace, through which it vibrates, is indefinitely little with reſpect to the length of the ſtring. *See Smith's Harmonics, p.* 237, *Helſham, p.* 270.

" 8. If a particle of the medium be agitated, according to the law of a cycloidal pendulum, the comparative elaſtic force, acting on the adjacent particle, from the inſtant in which it begins to move, will be ſuch as will cauſe it to continue its motion according to the ſame law.

" For let us ſuppoſe, that three particles of the medium had continued to move for times denoted by the arches PK, PI, PH, the comparative elaſtic force, acting on the ſecond during the time of its motion, would have been denoted by HL—IM, that is, would have been directly as MO (7). And if this time be diminiſhed till I becomes coincident with P, that is, if you take the particles in that ſtate when the ſecond is juſt beginning to move, and before the third particle has yet been ſet in motion; then the point M will fall on P, and MO become PO; that is, the comparative elaſtic force of the ſecond particle, at the inſtant in which it begins to move, will be to the force with which it is agitated in any other moment of time, before the ſubſequent particle has yet been ſet in motion, directly as its diſtance from the middle point of vibration. Now this comparative elaſtic force, with which the ſecond particle is agitated in the very moment in which it begins to move, ariſes from the preceding particle's approaching it according to the law of a pendulum; and therefore, if the preceding particle approaches it in this manner, the force by which it will be agitated, in the very moment it begins to move, will be exactly ſuch as ſhould take place in order to move it according to the law of a pendulum. It therefore ſets out according to that law, and conſequently the ſubſequent elaſtic forces, generated in every ſucceſſive moment, will alſo continue to be of the juſt magnitude which ſhould take place, in order to produce ſuch a motion.

" 9. The pulſes of the air are propagated from ſounding bodies, according to the law of a cycloidal pendulum. The point E of any elaſtic fibre producing a ſound, may be conſidered as a particle of air vibrating according to the law of a pendulum (1). This point E will therefore move according to this law for a certain time, denoted by the arch IH, before the ſecond particle begins to move; for ſound is propagated in time through the ſucceſſive particles of air (4). Now from that inſtant, the comparative elaſtic force which agitates F, is (8) directly as its diſtance from the middle point of vibration. F therefore ſets out with a motion according to the law of a pendulum: and therefore the comparative elaſtic force by which it will be agitated until G begins to move, will continue that law (8). Conſequently F will approach G in the ſame manner as E approached F, and the comparative elaſtic force of G, from the inſtant in which it begins to move, will be directly as its diſtance from the middle point of vibration; and ſo on in ſucceſſion. Therefore all the particles of air in the pulſes ſucceſſively ſet out from their proper places according to the law of a pendulum, and therefore (7) will finiſh their entire vibrations according to the ſame law. Plate I. fig. 7.

" *Cor.* 1. The number of pulſes propagated is the ſame with the number of vibrations of the tremulous body, nor is it multiplied in their progreſs: becauſe the little phyſical line $\phi\gamma$, (*fig.* 7.) as ſoon as it returns to its proper place, will there quieſce; for its velocity, which is denoted by the fine IM, then vaniſhes, and its denſity becomes the ſame with that of the ambient medium. This line, therefore, will no longer move, unleſs it be again driven forwards by the impulſe of the ſounding body, or of the pulſes propagated from it.

" *Cor.* 2. In the extreme points of the little ſpace through which the particle vibrates, the expanſion of the air is in its natural ſtate; for the expanſion of the phyſical line is to its natural expanſion as $V\overline{+IM}$ is to

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to V; but IM is then equal to nothing. In the middle point of the progreſs the condenſation is greateſt; for IM is then greateſt, and conſequently the expanſion V—IM leaſt. In the middle of the regreſs, the rarefaction is greateſt; for *im*, and conſequently V+*im*, is then greateſt.

" 10. To find the velocity of the pulſes, the denſity and elaſtic force of the medium being given.

" This is the 49th prop. B. 2. Newton, in which he ſhows, that whilſt a pendulum, whoſe length is equal to the height of the homogeneous atmoſphere, vibrates once forwards and backwards, the pulſes will deſcribe a ſpace equal to the periphery of a circle deſcribed with that altitude as its radius.

" *Cor.* 1. He thence ſhows, that the velocity of the pulſes is equal to that which a heavy body would acquire in falling down half the altitude of that homogeneous atmoſphere; and therefore, that all pulſes move equally faſt, whatever be the magnitude of PS, or the time of its being deſcribed; that is, whether the tone be loud or low, grave or acute. See *Hales de Sonis*, § 49.

" *Cor.* 2. And alſo, that the velocity of the pulſes is in a ratio compounded of the direct ſubduplicate ratio of the elaſtic force of the medium, and the inverſe ſubduplicate of its denſity. Hence ſounds move ſomewhat faſter in ſummer than in winter. See *Hales de Sonis*, p. 141.

" 11. The ſtrength of a tone is as the moment of the particles of air. The moment of theſe particles, (the medium being given) is as their velocity; and the velocity of theſe particles is as the velocity of the ſtring which ſets them in motion (9). The velocities of two different ſtrings are equal when the ſpaces which they deſcribe in their vibrations are to each other as the times of theſe vibrations: therefore, two different tones are of equal ſtrength, when the ſpaces, through which the ſtrings producing them vibrate, are directly as the times of their vibration.

2d Plate II. " 12. Let the ſtrength of the tones of the two ſtrings AB, CD, which differ in tenſion only (fig. 1, 2.) be equal. Quere the ratio of the inflecting forces F and *f*. From the hypotheſis of the equality of the ſtrength of the tones, it follows (11), that the ſpace GE muſt be to the ſpace HF as $f^{\frac{1}{2}}$ to $F^{\frac{1}{2}}$, (*Smith's Harm. Prop.* 24. *Cor.* 4.) Now the forces inflecting AB, CD through the equal ſpaces GE, HP are to each other as the tending forces, that is, as F to *f*, (*Malcolm's Treatiſe on Muſic*, p. 52.) But the force inflecting CD through HP is to the force inflecting it through HF as HP or GE to HF, (*ib.* p. 47.) that is, by the hyp. as $f^{\frac{1}{2}}$ to $F^{\frac{1}{2}}$. Therefore, *ex æquo*, the forces inflecting AB and CD, when the tones are equally ſtrong, are to each other as $F \times f^{\frac{1}{2}}$ to $f \times F^{\frac{1}{2}}$, or as $F^{\frac{1}{2}}$ to $f^{\frac{1}{2}}$. That is, the forces neceſſary to produce tones of equal ſtrength in various ſtrings which differ only in tenſion, are to each other in the ſubduplicate ratio of the tending forces, that is, inverſely as the time of one vibration, or directly as the number of vibrations performed in a given time. Thus, if CD be the acute octave to AB, its tending force will be quadruple that of AB, (*Malcolm's Treatiſe on Muſic*, p. 53); and therefore to produce tones of equal ſtrength in theſe ſtrings, the force impelling CD muſt be double that impelling AB; and ſo in other caſes.

N° 3.

" Suppoſe, now, that the ſtrings AB, CD, (fig. 2, 3.) differ in length only. The force inflecting AB through GE is to the tending force, which is given, as GE to AG; and this tending force is to the force inflecting CD through the ſpace HP equal to GE, as HD to HP. Therefore, *ex æquo*, the forces inflecting AB and CD through the equal ſpaces GE and HP, are to each other as HD to AG, or as CD to AB. But the force inflecting CD through HP is to the force inflecting it through HF, as HP or GE to HF, that is, becauſe theſe ſpaces are as the times (11), as AB to CD. Therefore, *ex æquo*, the forces inflecting AB and CD, when the tones are equally ſtrong, are to each other in a ratio of equality. Hence we ſhould ſuppoſe, that in this caſe, an equal number of equal impulſes would generate equally powerful tones in theſe ſtrings. But we are to obſerve, that the longer the ſtring, the greater, *cæteris paribus*, is the ſpace through which a given force inflects it (*Malcolm*); and therefore whatever diminution is produced in the ſpaces through which the ſtrings move in their ſucceſſive vibrations, ariſing either from the want of perfect elaſticity in the ſtrings, or from the reſiſtance of the air, this diminution will bear a greater proportion to the leſs ſpace, through which the ſhorter ſtring vibrates. And this is confirmed by experience; for we find that the duration of the tone and motion of the whole ſtring exceeds that of any of its ſubordinate parts. Therefore, after a given interval of time, a greater quantity of motion will remain in the longer ſtring; and conſequently, after the ſucceſſive equal impulſes have been made, a greater degree of motion will ſtill ſubſiſt in it. That is, a given number of equal impulſes being made on various ſtrings differing in length only, a ſtronger ſound will be produced in that which is the longer."

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2d Plate II.

CHAP. III. *Of the Velocity, &c. of Sound. Axioms.*

14 Velocity of ſound.

EXPERIENCE has taught us, that ſound travels at about the rate of 1142 feet in a ſecond, or near 13 miles in a minute; nor do any obſtacles hinder its progreſs, a contrary wind only a ſmall matter diminiſhing its velocity. The method of calculating its progreſs is eaſily made known. When a gun is diſcharged at a diſtance, we ſee the fire long before we hear the ſound. If then we know the diſtance of the place, and know the time of the interval between our firſt ſeeing the fire and then hearing the report, this will ſhow us exactly the time the ſound has been travelling to us. For inſtance, if the gun is diſcharged a mile off, the moment the flaſh is ſeen, you take a watch and count the ſeconds till you hear the ſound; the number of ſeconds is the time the ſound has been travelling a mile.—Again, by the above axiom, we are enabled to find the diſtance between objects that would be otherwiſe immeaſurable. For example, ſuppoſe you ſee the flaſh of a gun in the night at ſea, and tell ſeven ſeconds before you hear the report, it follows therefore, that the diſtance is ſeven times 1142 feet, that is, 24 yards more than a mile and a half. In like manner, if you obſerve the number of ſeconds between the lightning and the report of the thunder, you know the diſtance of the cloud from whence it proceeds.

15 Its progreſs calculated.

16 Diſtances calculated by means of ſound.

17. All ſounds travel at the ſame rate.

Derham has proved by experience, that all ſounds whatever travel at the ſame rate. The ſound of a gun, and

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and the ſtriking of a hammer, are equally ſwift in their motions; the ſofteſt whiſper flies as ſwiftly, as far as it goes, as the loudeſt thunder.

To theſe axioms we may add the following.

18 Smooth and clear ſounds proceed from bodies that are homogeneous, and of an uniform figure; and harſh or obtuſe ſounds, from ſuch as are of a mixed matter and irregular figure.

19 The velocity of ſound is to that of a briſk wind as fifty to one.

20 The ſtrength of ſounds is greateſt in cold and denſe air, and leaſt in that which is warm and rarefied.

21 Every point againſt which the pulſes of ſound ſtrike, becomes a centre from which a new ſeries of pulſes are propagated in every direction.

22 Sound deſcribes equal ſpaces in equal times.

CHAP. IV. *Of Reverberated Sounds.*

23 SOUND, like light, after it has been reflected from ſeveral places, may be collected in one point, as into a focus; and it will be there more audible than in any other part, even than at the place from whence it proceeded. On this principle it is that a whiſpering gallery is conſtructed.

24 Whiſpering Gallery, Plate I. fig. 3. The form of this gallery muſt be that of a concave hemiſphere (E), as ABC; and if a low ſound or whiſper be uttered at A, the vibrations expanding themſelves every way will impinge on the points DDD, &c. and from thence be reflected to EEE, and from thence to the points F and G, till at laſt they all meet in C, where, as we have ſaid, the ſound will be the moſt diſtinctly heard.

25 Speaking-trumpet, fig. 4. THE augmentation of ſound by means of ſpeaking-trumpets, is uſually illuſtrated in the following manner: Let ABC be the tube, BD the axis, and B the mouth-piece for conveying the voice to the tube. Then it is evident, when a perſon ſpeaks at B in the trumpet, the whole force of his voice is ſpent upon the air contained in the tube, which will be agitated through the whole length of the tube; and, by various reflections from the ſide of the tube to the axis, the air along the middle part of the tube will be greatly condenſed, and its *momentum* proportionably increaſed, ſo that when it comes to agitate the air at the orifice of the tube AC, its force will be as much greater than what it would have been without the tube, as the ſurface of a ſphere, whoſe radius is equal to the length of the tube, is greater than the ſurface of the ſegment of ſuch a ſphere whoſe baſe is the orifice of the tube. For a perſon ſpeaking at B, without the tube, will have the force of his voice ſpent in exciting concentric ſuperficies of air all around the point B; and when thoſe ſuperficies or pulſes of air are diffuſed as far as D every way, it is plain the force of the voice will there be diffuſed through the whole ſuperficies of a ſphere whoſe radius is BD; but in the trumpet it will be ſo confined, that at its exit it will be diffuſed through ſo much of that ſpherical ſurface of air as correſponds to the orifice of the tube. But ſince the force is given, its intenſity will be always inverſely as the number of particles it has to move; and therefore in the tube it will be to that without, as the ſuperficies of ſuch a ſphere to the æra of the large end of the tube nearly. Reverberated Sounds.

But it is obvious, Mr Young obſerves, that the confinement of the voice can have little effect in increaſing the ſtrength of the ſound, as this ſtrength depends on the velocity with which the particles move. Were this reaſoning concluſive, the voice ſhould iſſue through the ſmalleſt poſſible orifice; cylindrical tubes would be preferable to any that increaſed in diameter; and the leſs the diameter, the greater would be the effect of the inſtrument; becauſe the plate or maſs of air to be moved, would, in that caſe, be leſs, and conſequently the effect of the voice the greater; all which is contradicted by experience.

The cauſe of the increaſe of ſound in theſe tubes muſt therefore be derived from ſome other principles: and amongſt theſe we ſhall probably find, that what the ingenious Kircher has ſuggeſted in his Phonurgia is the moſt deſerving of our attention. He tells us, that "the augmentation of the ſound depends on its reflection from the tremulous ſides of the tube; which reflections, conſpiring in propagating the pulſes in the ſame direction, muſt increaſe its intenſity." Newton alſo ſeems to have conſidered this as the principal cauſe, in the ſcholium of prop. 50. B. 2. Princip. when he ſays, "we hence ſee why ſounds are ſo much increaſed in ſtentorophonic tubes, for every reciprocal motion is, in each return, increaſed by the generating cauſe.

Farther, when we ſpeak in the open air, the effect on the tympanum of a diſtant auditor is produced merely by a ſingle pulſe. But when we uſe a tube, all the pulſes propagated from the mouth, except thoſe in the direction of the axis, ſtrike againſt the ſides of the tube, and every point of impulſe becoming a new centre, from whence the pulſes are propagated in all directions, a pulſe will arrive at the ear from each of thoſe points; thus, by the uſe of a tube, a greater number of pulſes are propagated to the ear, and conſequently the ſound increaſed. The confinement too of the voice may have ſome effect, though not ſuch as is aſcribed to it by ſome; for the condenſed pulſes produced by the naked voice, freely expand every way; but in tubes, the lateral expanſion being diminiſhed, the direct expanſion will be increaſed, and conſequently the velocity of the particles, and the intenſity of the ſound. The ſubſtance alſo of the tube has its effect; for it is found by experiment, that the more elaſtic the ſubſtance of the tube, and conſequently the more ſuſceptible it is of theſe tremulous motions, the ſtronger is the ſound.

If the tube be laid on any non-elaſtic ſubſtance, it deadens the ſound, becauſe it prevents the vibratory motion of the parts. The ſound is increaſed in ſpeaking-trumpets, if the tube be ſuſpended in the air; becauſe the agitations are then carried on without interruption. Theſe tubes ſhould increaſe in diameter from the mouth-piece, becauſe the parts, vibrating in directions perpendicular to the ſurface, will conſpire in impelling forward the particles of air, and conſequently, by increaſing their velocity, will increaſe the intenſity of the ſound: and the ſurface alſo increaſing, the number of points of impulſe and of new propagations will increaſe pro-

(E) A cylindric or elliptic arch will anſwer ſtill better than one that is circular.

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proportionally. The ſeveral cauſes, therefore, of the increaſe of ſound in theſe tubes, Mr Young concludes to be, 1. The diminution of the lateral, and conſequently the increaſe of the direct, expanſion and velocity of the included air. 2. The increaſe of the number of pulſes, by increaſing the points of new propagation. 3. The reflections of the pulſes from the tremulous ſides of the tube, which impel the particles of air forward, and thus increaſe their velocity.

26 Echoes.

An echo is a reflection of ſound ſtriking againſt ſome object, as an image is reflected in a glaſs: but it has been diſputed what are the proper qualities in a body for thus reflecting ſounds. It is in general known, that caverns, grottoes, mountains, and ruined buildings, return this image of ſound. We have heard of a very extraordinary echo, at a ruined fortreſs near Louvain, in Flanders. If a perſon ſung, he only heard his own voice, without any repetition: on the contrary, thoſe who ſtood at ſome diſtance, heard the echo but not the voice; but then they heard it with ſurpriſing variations, ſometimes louder, ſometimes ſofter, now more near, then more diſtant. There is an account in the memoirs of the French academy, of a ſimilar echo near Rouen.

As (by n° 21 and 22) every point againſt which the pulſes of ſound ſtrike becomes the centre of a new ſeries of pulſes, and ſound deſcribes equal diſtances in equal times; therefore, when any ſound is propagated from a centre, and its pulſes ſtrike againſt a variety of obſtacles, if the ſum of the right lines drawn from that point to each of the obſtacles, and from each obſtacle to a ſecond point, be equal, then will the later be a point in which an echo will be heard. "Thus let A be the point from which the ſound is propagated in all directions, and let the pulſes ſtrike againſt the obſtacles C, D, E, F, G, H, I, &c. each of theſe points becomes a new centre of pulſes by the firſt principle, and therefore from each of them one ſeries of pulſes will paſs through the point B. Now if the ſeveral ſums of the right lines $\overline{AC+CB}$, $\overline{AD+DB}$, $\overline{AE+EB}$, $\overline{AG+GB}$, $\overline{AH+HB}$, $\overline{AI+IB}$, &c. be all equal to each other, it is obvious that the pulſes propagated from A to theſe points, and again from theſe points to B, will all arrive at B at the ſame inſtant, according to the ſecond principle; and therefore, if the hearer be in that point, his ear will at the ſame inſtant be ſtruck by all theſe pulſes. Now it appears from experiment (*ſee Muſſchenbroek, V.* ii. *p.* 210), that the ear of an exerciſed muſician can only diſtinguiſh ſuch ſounds as follow one another at the rate of 9 or 10 in a ſecond, or any ſlower rate: and therefore, for a diſtinct perception of the direct and reflected ſound, there ſhould intervene the interval of $\frac{1}{9}$th of a ſecond; but in this time ſound deſcribes $\frac{1142}{9}$ or 127 feet nearly. And therefore, unleſs the ſum of the lines drawn from each of the obſtacles to the points A and B exceeds the interval AB by 127 feet, no echo will be heard at B. Since the ſeveral ſums of the lines drawn from the obſtacles to the points A and B are of the ſame magnitude, it appears that the curve paſſing through all the points C, D, E, F, G, H, I, &c. will be an ellipſe, (*prop.* 14. *B.* 2. *Ham. Con.*) Hence all the points of the obſtacles which produce an echo, muſt lie in the ſurface of the oblong ſphæroid, generated by the revolution of this ellipſe round its major axis.

Reverberated Sounds.

"As there may be ſeveral ſphæroids of different magnitudes, ſo there may be ſeveral different echoes of the ſame original ſound. And as there may happen to be a greater number of reflecting points in the ſurface of an exterior ſphæroid than in that of an interior, a ſecond or a third echo may be much more powerful than the firſt, provided that the ſuperior number of reflecting points, that is, the ſuperior number of reflected pulſes propagated to the ear, be more than ſufficient to compenſate for the decay of ſound which ariſes from its being propagated through a greater ſpace. This is finely illuſtrated in the celebrated echoes at the lake of Killarney in Kerry, where the firſt return of the ſound is much inferior in ſtrength to thoſe which immediately ſucceed it.

"From what has been laid down it appears, that for the moſt powerful echo, the ſounding body ſhould be in one focus of the ellipſe which is the ſection of the echoing ſphæroid, and the hearer in the other. However, an echo may be heard in other ſituations, though not ſo favourably; as ſuch a number of reflected pulſes may arrive at the ſame time at the ear as may be ſufficient to excite a diſtinct perception. Thus a perſon often hears the echo of his own voice; but for this purpoſe he ſhould ſtand at leaſt 63 or 64 feet from the reflecting obſtacle, according to what has been ſaid before. At the common rate of ſpeaking, we pronounce not above three ſyllables and an half, that is, ſeven half ſyllables in a ſecond; therefore, that the echo may return juſt as ſoon as three ſyllables are expreſſed, twice the diſtance of the ſpeaker from the reflecting object muſt be equal to 1000 feet; for, as ſound deſcribes 1142 feet in a ſecond, $\frac{6}{7}$ths of that ſpace, that is, 1000 feet nearly, will be deſcribed while ſix half or three whole ſyllables are pronounced: that is, the ſpeaker muſt ſtand near 500 feet from the obſtacle. And in general, the diſtance of the ſpeaker from the echoing ſurface, for any number of ſyllables, muſt be equal to the ſeventh part of the product of 1142 feet multiplied by that number.

"In churches we never hear a diſtinct echo of the voice, but a confuſed ſound when the ſpeaker utters his words too rapidly; becauſe the greateſt difference of diſtance between the direct and reflected courſes of ſuch a number of pulſes as would produce a diſtinct ſound, is never in any church equal to 127 feet, the limit of echos.

"But though the firſt reflected pulſes may produce no echo, both on account of their being too few in number, and too rapid in their return to the ear; yet it is evident, that the reflecting ſurface may be ſo formed, as that the pulſes which come to the ear after two reflections or more may, after having deſcribed 127 feet or more, arrive at the ear in ſufficient numbers, and alſo ſo nearly at the ſame inſtant, as to produce an echo, though the diſtance of the reflecting ſurface from the ear be leſs than the limit of echoes. This is confirmed by a ſingular echo in a grotto on the banks of the little brook called the Dinan, about two miles from Caſtlecomber, in the county of Kilkenny. As you enter the cave, and continue ſpeaking loud, no return of the voice is perceived; but on your arriving at

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a certain point, which is not above 14 or 15 feet from the reflecting ſurface, a very diſtinct echo is heard. Now this echo cannot ariſe from the firſt courſe of pulſes that are reflected to the ear, becauſe the breadth of the cave is ſo ſmall, that they would return too quickly to produce a diſtinct ſenſation from that of the original ſound: it therefore is produced by thoſe pulſes, which, after having been reflected ſeveral times from one ſide of the grotto to the other, and having run over a greater ſpace than 127 feet, arrive at the ear in conſiderable numbers, and not more diſtant from each other, in point of time, than the ninth part of a ſecond."

This article ſhall be diſmiſſed with a few inventions founded on ſome of the preceding principles, which may amuſe a number of our readers.

Entertaining Experiments and Contrivances.

27 I. The Converſive Statue, Plate I. fig. 5.

I. PLACE a concave mirror of about two feet diameter, as A B (G), in a perpendicular direction. The focus of this mirror may be at 15 or 18 inches diſtance from its ſurface. At the diſtance of about five or ſix feet let there be a partition, in which there is an opening E F, equal to the ſize of the mirror; againſt this opening muſt be placed a picture, painted in water-colours, on a thin cloth, that the ſound may eaſily paſs through it (H).

Behind the partition, at the diſtance of two or three feet, place another mirror G H, of the ſame ſize as the former, and let it be diametrically oppoſite to it.

At the point C let there be placed the figure of a man ſeated on a pedeſtal, and let his ear be placed exactly in the focus of the firſt mirror: his lower jaw muſt be made to open by a wire, and ſhut by a ſpring; and there may be another wire to move the eyes: theſe wires muſt paſs through the figure, go under the floor, and come up behind the partition.

Let a perſon, properly inſtructed, be placed behind the partition near the mirror. You then propoſe to any one to ſpeak ſoftly to the ſtatue, by putting his mouth to the ear of it, aſſuring him that it will anſwer inſtantly. You then give the ſignal to the perſon behind the partition, who, by placing his ear to the focus I, of the mirror G H, will hear diſtinctly what the other ſaid; and, moving the jaw and eyes of the ſtatue by the wires, will return an anſwer directly, which will in like manner be diſtinctly heard by the firſt ſpeaker.

This experiment appears to be taken from the Century of Inventions of the Marquis of Worceſter; whoſe deſigns, at the time they were publiſhed, were treated with ridicule and neglect as being impracticable, but are now known to be generally, if not univerſally practicable. The words of the Marquis are theſe: "How to make a brazen or ſtone head in the midſt of a great field or garden, ſo artificial and natural, that though a man ſpeak ever ſo ſoftly, and even whiſper into the ear thereof, it will preſently open its mouth, and reſolve the queſtion in French, Latin, Welſh, Iriſh, or Engliſh, in good terms, uttering it out of its mouth, and then ſhut it until the next queſtion be aſked."—The two following, of a ſimilar nature, appear to have been inventions of Kircher, by means of which (as he informs us *) he uſed to "utter feigned and ludicrous conſultations, with a view to ſhow the fallacy and impoſture of ancient oracles."

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* *Phonurgia Nova*, ſect. vi. c. 1.

28 The Communicative Buſts.

II. LET there be two heads of plaſter of Paris, placed on pedeſtals, on the oppoſite ſides of a room. There muſt be a tin tube of an inch diameter, that muſt paſs from the ear of one head, through the pedeſtal, under the floor, and go up to the mouth of the other. Obſerve, that the end of the tube which is next the ear of the one head, ſhould be conſiderably larger than that end which comes to the mouth of the other. Let the whole be ſo diſpoſed that there may not be the leaſt ſuſpicion of a communication.

Now, when a perſon ſpeaks, quite low, into the ear of one buſt, the ſound is reverberated thro' the length of the tube, and will be diſtinctly heard by any one who ſhall place his ear to the mouth of the other. It is not neceſſary that the tube ſhould come to the lips of the buſt.—If there be two tubes, one going to the ear, and the other to the mouth, of each head, two perſons may converſe together, by applying their mouth and ear reciprocally to the mouth and ear of the buſts; and at the ſame time other perſons that ſtand in the middle of the chamber, between the heads, will not hear any part of their converſation.

29 The Oracular Head.

III. PLACE a buſt on a pedeſtal in the corner of a room, and let there be two tubes, as in the foregoing amuſement, one of which muſt go from the mouth and the other from the ear of the buſt, through the pedeſtal, and the floor, to an under apartment. There may be likewiſe wires that go from the under jaw and the eyes of the buſt, by which they may be eaſily moved.

A perſon being placed in the under room, and at a ſignal given applying his ear to one of the tubes, will hear any queſtion that is aſked, and immediately reply; moving at the ſame time, by means of the wires, the mouth and the eyes of the buſt, as if the reply came from it.

30 A Solar Sonata.

IV. IN a large caſe, ſuch as is uſed for dials and ſpring-clocks, the front of which, or at leaſt the lower part of it, muſt be of glaſs, covered on the inſide with gauze, let there be placed a barrel-organ, which, when wound up, is prevented from playing, by a catch that takes a toothed wheel at the end of the barrel. To one end of this catch there muſt be joined a wire, at the end of which there is a flat circle of cork, of the ſame dimenſion with the inſide of a glaſs tube, in which it is to riſe and fall. This tube muſt communicate with a reſervoir that goes acroſs the front part of the bottom of the caſe, which is to be filled with ſpirits, ſuch as is uſed in ther-

(G) Both the mirrors here uſed may be of tin or gilt paſteboard, this experiment not requiring ſuch as are very accurate.

(H) The more effectually to conceal the cauſe of this alluſion, the mirror AB may be fixed in the wainſcot, and a gauze or any other thin covering thrown over it, as that will not in the leaſt prevent the ſound from being reflected. An experiment of this kind may be performed in a field or garden, between two hedges, in one of which the mirror AB may be placed, and in the other an opening artfully contrived.

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thermometers, but not coloured, that it may be the better concealed by the gauze.

This case being placed in the sun, the spirits will be rarefied by the heat; and rising in the tube, will lift up the catch or trigger, and set the organ in play: which it will continue to do as long as it is kept in the sun; for the spirits cannot run out of the tube, that part of the catch to which the circle is fixed being prevented from rising beyond a certain point by a check placed over it.

When the machine is placed against the side of a room on which the sun shines strong, it may constantly remain in the same place, if you inclose it in a second case, made of thick wood, and placed at a little distance from the other. When you want it to perform, it will be only necessary to throw open the door of the outer case, and expose it to the sun.

But if the machine be moveable, it will perform in all seasons by being placed before the fire; and in the winter it will more readily stop when removed into the cold.

A machine of this sort is said to have been invented by Cornelius Dreble, in the last century. What the construction of that was, we know not; it might very likely be more complex, but could scarce answer the intention more readily.

31 Automatous Harpsichord.

V. Under the keys of a common harpsichord let there be fixed a barrel, something like that in a chamber organ, with stops or pins corresponding to the tunes you would have it play. These stops must be moveable, so that the tunes may be varied at pleasure. From each of the keys let there go a wire perpendicular down: the ends of these wires must be turned up for about one-fourth of an inch. Behind these wires let there be an iron bar, to prevent them from going too far back. Now, as the barrel turns round, its pins take the ends of the wires, which pull down the keys, and play the harpsichord. The barrel and wires are to be all inclosed in a case.

In the chimney of the same room where the harpsichord stands, or at least in one adjacent, there must be a smoke jack, from whence comes down a wire, or cord, that, passing behind the wainscot adjoining the chimney, goes under the floor, and up one of the legs of the harpsichord, into the case, and round a small wheel fixed on the axis of that first mentioned. There should be pullies at different distances, behind the wainscot and under the floor, to facilitate the motion of the chord.

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This machinery may be applied to any other keyed instrument as well as to chimes, and to many other purposes where a regular continued motion is required.

An instrument of this sort may be considered as a perpetual motion, according to the vulgar acceptation of the term; for it will never cease going till the fire be extinguished, or some parts of the machinery be worn out.

32 A Ventosal Symphony, Plate I. fig. 6.

VI. At the top of a summer-house, or other building, let there be fixed a vane AB, on which is the pinion C, that takes the toothed wheel D, fixed on the axis EF, which at its other end carries the wheel G, that takes the pinion H. All these wheels and pinions are to be between the roof and the ceiling of the building. The pinion H is fixed to the perpendicular axis IK, which goes down very near the wall of the room, and may be covered after the same manner as are bell-wires. At the lower end of the axis IK there is a small pinion L, that takes the wheel M, fixed on the axis of the great wheel NO. In this wheel there must be placed a number of stops, corresponding to the tunes it is to play. These stops are to be moveable, that the tunes may be altered at pleasure. Against this wheel there must hang 12 small bells, answering to the notes of the gamut. Therefore, as the wheel turns round, the stops striking against the bells, play the several tunes. There should be a fly to the great wheel, to regulate its motion when the wind is strong. The wheel NO, and the bells, are to be inclosed in a case.

There may be several sets of bells, one of which may answer to the tenor, another to the treble, and a third to the bass; or they may play different tunes, according to the size of the wheel. As the bells are small, if they are of silver, their tone will be the more pleasing.

Instead of bells, glasses may be here used, so disposed as to move freely at the stroke of the stops. This machinery may likewise be applied to a barrel-organ; and to many other uses.

Acqs || Acqui.

ACQS, a town at the foot of the Pyrenæan mountains, in the government of Foix in France. It takes its name from the hot waters in these parts. E. long. 1. 40. lat. 43. 0.

ACQUAPENDENTE, a pretty large town of Italy, in the territory of the church, and patrimony of St Peter, with a bishop's see. It is seated on a mountain, near the river Paglia, ten miles W. of Orvietto, and 57 N. by W. of Rome. E. long. 11. 53. Lat. 42. 43.

ACQUARIA, a small town of Italy, in Frigana, a district of Modena, which is remarkable for its medicinal waters. It is 12 miles south of the city of Modena. E. long. 11. 17. Lat. 44. 24.

ACQUEST, or Acquist, in law, signifies goods got by purchase or donation. See Conquest.

ACQUI, a town of Italy, in the duchy of Montferrat, with a bishop's see, and commodious baths. It was taken by the Spaniards in 1745, and retaken by the Piedmontese in 1746; but after this, it was taken again and dismantled by the French, who afterwards forsook it. It is seated on the river Bornio, 25 miles N. W. of Genoa, and 30 S. of Casal. E. long. 8. 30. Lat. 44. 40.

Acquisition || Acquittance.

ACQUISITION, in general, denotes the obtaining or procuring something. Among lawyers, it is used for the right or title to an estate got by purchase or donation.

ACQUITTAL, a discharge, deliverance, or setting of a person free from the guilt or suspicion of an offence.

ACQUITTANCE, a release or discharge in writing for a sum of money, witnessing that the party has paid the said sum.—No man is obliged to pay a sum of money

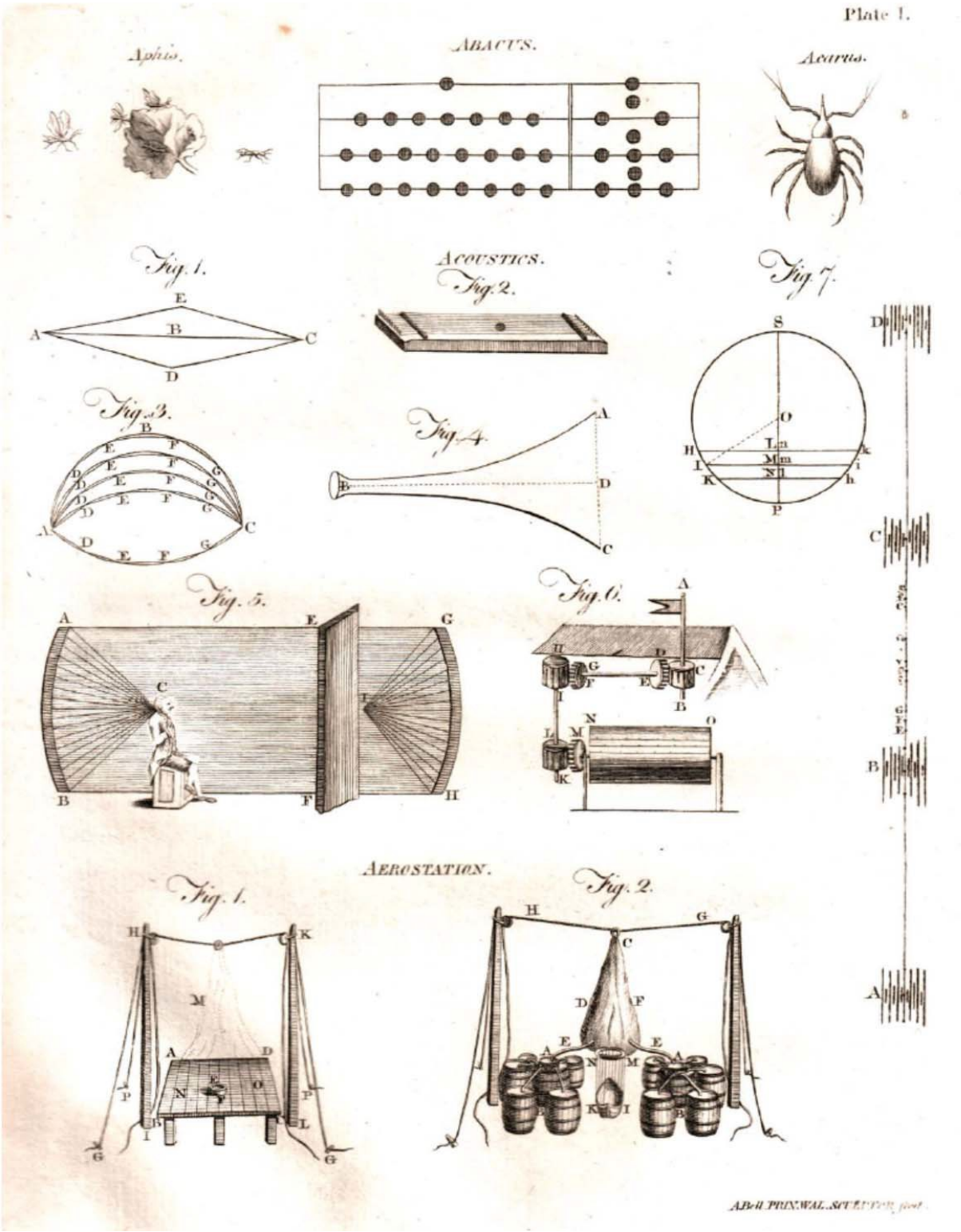
Plate 1.
Aphis.
ABACUS.
Acarus.
Fig. 1.
ACOUSTICS.
Fig. 2.
Fig. 7.
Fig. 3.
Fig. 4
Fig. 5.
Fig. 6.
AEROSTATION.
Fig. 1.
Fig. 2.