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SCIENTIFIC WRITINGS

OF

JOSEPH HENRY.

VOLUME II.



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SCIENTIFIC WRITINGS OF JOSEPH HENRY.

PART II.—Continued.

(1847 to 1878.)

ON ACOUSTICS APPLIED TO PUBLIC BUILDINGS.

(Proceedings American Association Adv. of Science, vol. x, pp. 119–135.)

August 22, 1856.

At the meeting of the American Association in 1854, I gave a verbal account of the plan of a lecture-room adopted for the Smithsonian Institution, with some remarks on acoustics as applied to apartments intended for public speaking.* At that time the room was not finished, and experience had not proved the truth of the principles on which the plan had been designed. Since then the room has been employed two winters for courses of lectures to large audiences; and I believe it is the general opinion of those who have been present, that the arrangements for seeing and hearing, considering the size of the apartment, are entirely unexceptionable. The room has fully answered all the expectations which were formed in regard to it, previous to its construction. The origin of the plan was as follows:

Professor Bache and myself had directed our attention to the subject of acoustics as applied to buildings, and had studied the peculiarities in this respect of the hall of the House of Representatives, when the President of the United States referred to us for examination the plans proposed by Captain M. C. Meigs of the Engineer Corps, U. S. A., for the rooms about to be constructed under his direction in the new wings of the Capitol. After visiting with Captain Meigs the principal halls and churches of the cities of Philadelphia, New York, and Boston, we reported favorably on the general plans proposed by him, and which were subsequently adopted.

The facts we have collected on this subject may be referred to a few well-established principles of acoustics, which have

*["On the Arrangement of Lecture Rooms, with reference to Sound and Sight."—Proceedings of the American Association for the Advancement of Science, May, 1854; vol. VIII, p. 106. Only the title published.]

been applied in the construction of the Smithsonian lecture-room. To apply them generally however in the construction of public halls, required a series of preliminary experiments.

In a small apartment it is an easy matter to be heard distinctly at every point; but in a large room, unless provision be made in the original plan of the building for a suitable arrangement, on acoustic principles, it will be difficult, and indeed in most cases impossible, to produce the desired effect. The same remark may be applied to the lighting, heating, and ventilation, and to all the special purposes to which a particular building is to be applied. I venture therefore to make some preliminary remarks on the architecture of buildings, bearing upon this point, which, though they may not meet with universal acceptance, will I trust commend themselves to the common sense of the public in general.

Architectural limitations.—In the erection of a building, the uses to which it is to be applied should be clearly understood, and provision definitely made, in the original design, for every desired object.

Modern architecture is not, like painting or sculpture, a fine art, *par excellence*. The object of these latter is to produce a moral emotion,—to awaken the feelings of the sublime and the beautiful; and we greatly err when we apply their productions to a merely utilitarian purpose. To make a fire-screen of Rubens' Madonna, or a candelabrum of the Apollo Belvidere, would be to debase those exquisite productions of genius, and do violence to the feelings of the cultivated lover of art. Modern buildings are made for other purposes than artistic effect, and in them the æsthetical must be subordinate to the useful; though the two may co-exist, and an intellectual pleasure be derived from a sense of adaptation and fitness, combined with a perception of harmony of parts, and the beauty of detail.

The buildings of a country and an age should be ethnological expressions of the wants, habits, arts, and feelings of the time in which they were erected. Those of Egypt,

Greece, and Rome were intended (at least in part) to transmit to posterity, without the art of printing, an impression of the character of the periods in which they were erected. It was by their monuments that these nations sought to convey to future ages an idea of their religious and political sentiments.

The Greek architect was untrammelled by any condition of utility. Architecture was with him in reality a fine art. The temple was formed to gratify the tutelar deity. Its minutest parts were exquisitely finished, since nothing but perfection on all sides and in the smallest particulars could satisfy an all-seeing and critical eye. It was intended for external worship, and not for internal use. It was without windows, entirely open to the sky, or if closed with a roof, the light was merely admitted through a large door. There were no arrangements for the heating or ventilation. The uses therefore to which buildings of this kind can be applied in modern times are exceedingly few; and though they were objects of great beauty, and fully realized the intention of the architect by whom they were constructed, yet they cannot be copied in our day without violating the principles which should govern architectural adaptation.

Every vestige of ancient architecture which now remains on the face of the earth should be preserved with religious care; but to servilely copy these, and to attempt to apply them to the uses of our day, is as preposterous as to endeavor to harmonize the refinement and civilization of the present age with the superstition and barbarity of the times of the Pharaohs. It is only when a building expresses the dominant sentiment of an age, when a perfect adaptation to its use is joined to harmony of proportions and an outward expression of its character, that it is entitled to our admiration. It has been aptly said, that it is one thing to *adopt* a particular style of architecture, but a very different one to *adapt* it to the purpose intended.

Architecture should change not only with the character of the people, and in some cases with the climate, but also with the material to be employed in construction. The use

of iron and of glass requires an entirely different style from that which sprung from the rocks of Egypt, the masses of marble with which the lintels of the Grecian temples were formed, or the introduction of brick by the Romans.

The great tenacity of iron, and its power of resistance to crushing, should suggest for it, as a building material, a far more slender and apparently lighter arrangement of parts. An entire building of iron, fashioned in imitation of stone, might be erected at small exercise of invention on the part of the architect, but would do little credit to his truthfulness or originality. The same may be said of our modern pasteboard edifices, in which, with their battlements, towers, pinnacles, "fretted roofs and long drawn aisles," cheap and transient magnificence is produced by painted wood or decorated plaster.

Lecture-room Acoustics.—To return to the subject of acoustics, as applied to apartments intended for public speaking: While sound, in connection with its analogies to light, and in its abstract principles, has been investigated within the last fifty years with a rich harvest of results, few attempts have been successfully made to apply these principles to practical purposes. Though we may have a clear conception of the simple operation of a law of nature, yet when the conditions are varied, and the actions multiplied, the results frequently transcend our powers of logic, and we are obliged to appeal to experiment and observation to assist in deducing new consequences, as well as to verify those which have been arrived at by mathematical deduction. Furthermore, though we may know the manner in which a cause acts to produce a given effect, yet in all cases we are obliged to resort to actual experiment to ascertain the measure of effect under given conditions.

The science of acoustics as applied to buildings, perhaps more than any other, requires this union of scientific principles with experimental deductions. While on the one hand, the application of simple deductions from the established principles of acoustics would be unsafe from a want of knowledge of the constants which enter into our formulæ,

on the other hand empirical data alone are in this case entirely at fault, and of this any person may be convinced who will examine the several works written on acoustics by those who are deemed practical men.

Sound is a motion of matter capable of affecting the ear with a sensation peculiar to that organ. It is not in all cases a motion simply of the air, for there are many sounds in which the air is not concerned; for example, the impulses which are conveyed along a rod of wood from a tuning-fork to the teeth. When a sound is produced by a single impulse, or an approximation to a single impulse, it is called a noise; when by a series of impulses, a continued sound, &c.; if the impulses are equal in duration among themselves, a musical sound. This has been illustrated by a quill striking against the teeth of a wheel in motion. A single impulse from one tooth is a noise, from a series of teeth in succession a continued sound; and if all the teeth are at equal distances, and the velocity of the wheel is uniform, then a musical note is the result. Each of these sounds is produced by the human voice, though they apparently run into each other. In speaking however a series of irregular sounds of short duration is usually emitted,—each syllable of a word constitutes a separate sound of appreciable duration, and each compound word and sentence an assemblage of such sounds. It is no little surprising that in listening to a discourse, the ear can receive so many impressions in the space of a second, and that the mind can take cognizance of and compare them.

That a certain force of impulse and a certain time for its continuance are necessary to produce an audible impression on the ear, is evident, but it may be doubted whether the impression of a sound on this organ is retained appreciably longer than the continuance of the impulse itself, certainly it is not retained the $\frac{1}{10}$th of a second. If this were the case it is difficult to conceive why articulated discourse, which so pre-eminently distinguishes man from the lower animals, should not fill the ear with a monotonous hum; but whether the ear continues to vibrate, or whether the impression re-

mains a certain time on the sensorium, it is certain that no sound is ever entirely instantaneous, or the result of a single impression, particularly in enclosed spaces. The impulse is not only communicated to the ear but to all bodies around, which in turn become themselves centres of reflected impulses. Every impulse must give rise to a forward and afterward a backward motion of a small portion of the medium.

Sound from a single explosion in air equally elastic on all sides tends to expand equally in every direction; but when the impulse is given to the air in a single direction, though an expansion takes place on all sides, yet it is much more intense in the line of the impulse. For example, the impulse of a single explosion, like that of the detonation of a bubble of oxygen and hydrogen, is propagated equally in all directions, while the discharge of a cannon, though heard on every side, is much louder in the direction of the axis; so also a person speaking is heard much more distinctly directly in front than at an equal distance behind. Many experiments have been made on this point, and I may mention those repeated in the open space in front of the Smithsonian Institution. In a circle 100 feet in diameter, the speaker in the centre, and the hearer in succession at different points of the circumference, the voice was heard most distinctly directly in front, gradually less so on either side, until in the rear it was scarcely audible. The ratio of distance for distinct hearing directly in front, on the sides, and in the rear was about as 100, 75, and 30. These numbers may serve to determine the form in which an audience should be arranged in an open field in order that those on the periphery of the space may all have a like favorable opportunity of hearing, though such a disposition should not be recommended as the form of an apartment where a reflecting wall would be behind the speaker.

The impulse producing sound requires time for its propagation, and this depends upon the intensity of repulsion between the atoms, and secondly, on the specific gravity of the matter itself. If the medium were entirely rigid sound

would be propagated instantaneously; the weaker the repulsion between the atoms the greater will be the time required to transmit the motion from one to the other; and the heavier the atoms the greater will be the time required for the action of a given force to produce in them a given amount of motion. Sound also, in meeting an object, is reflected in accordance with the law of light, making the angle of incidence equal to the angle of reflection. The tendency however to divergency in a single beam of sound appears to be much greater than in the case of light. The law nevertheless appears to be definitely followed in the case of all beams that are reflected in a direction near the perpendicular. It is on the law of propagation and reflection of sound that the philosophy of an echo depends. Knowing the velocity of sound it is an easy matter to calculate the interval of time which must elapse between the original impulse and the return of the echo. Sound moves at the rate of 1125 feet in a second at the temperature of 60°.

If therefore we stand at half this distance before a wall, the echo will return to us in one second. It is however a fact known from universal experience that no echo is perceptible from a near wall, though in all cases one must be sent back to the ear. The reason of this is that the ear cannot distinguish the difference between similar sounds, as for example, that from the original impulse and its reflection if they follow each other at less than a given interval, which can only be determined by actual experiment, and as this is an important element in the construction of buildings the attempt was made to determine it with some considerable degree of accuracy. For this purpose the observer was placed immediately in front of the wall of the west end of the Smithsonian building at the distance of 100 feet; the hands were then clapped together. A distinct echo was perceived; the difference between the time of the passage of the impulse from the hand to the ear, and that from the hand to the wall and back to the ear, was sufficiently great to produce two entirely distinct impressions. The observer then gradually approached the building until no echo or perceptible pro-

longation of the sound was observed. By accurately measuring this distance and doubling it we find the interval of space within which two sounds may follow each other without appearing separately. But if two rays of sound reach the ear after having passed through distances the difference between which is greater than this, they produce the effect of separate sounds. This distance we have called the *limit of perceptibility* in terms of space. If we convert this distance into the velocity of sound, we ascertain the limit of perceptibility in time.

In the experiment first made with the wall a source of error was discovered in the fact that a portion of the sound returned was reflected from the cornice under the eaves, and as this was at a greater distance than the part of the wall immediately perpendicular to the observer the moment of cessation of the echo was less distinct. In subsequent experiments with a louder noise, the reflection was observed from a perpendicular surface of about 12 feet square, and from this more definite results were obtained. The limit of the distance in this case was about 30 feet, varying slightly perhaps with the intensity of the sound and the acuteness of different ears. This will give about the sixteenth part of a second as the limit of time necessary for the ear to separately distinguish two similar sounds. From this experiment we learn that the reflected sound may tend to strengthen the impression, or to confuse it, according as the difference of time between the two impressions is greater or less than the limit of perceptibility. An application of the same principle gives us the explanation of some phenomena of sound which have been considered mysterious. Thus, in the reflection of an impulse from the edge of a forest of trees each leaf properly situated within a range of 30 feet of the front plane of reflection will conspire to produce a distinct echo, and these would form the principal part of the reflecting surfaces of a dense forest, for the remainder would be screened; and being at a greater distance, any ray which might come from them would serve to produce merely a low continuation of the sound.

On the same principle we may at once assert that the panelling of a room, or even the introduction of reflecting surfaces at different distances will not prevent the echo, provided they are in parallel planes, and situated relatively to each other within the limit of perceptibility.

Important advantage may be taken of the principle of reflection of sound by a proper arrangement of the reflecting surfaces behind the speaker. We frequently see in churches, as if to diminish the effect of the voice of the preacher, a mass of drapery placed directly in the rear of the pulpit. However satisfactory this may be in an æsthetical point of view, it is certainly at variance with correct acoustic arrangements, the great object of which should be to husband every articulation of the voice, and to transmit it unmingled with other impulses and with as little loss as possible to the ears of the audience.

Another effect of the transmission and reflection of sound is that which is called reverberation, which consists of a prolonged musical sound, and is much more frequently the cause of indistinctness of perception of the articulations of the speaker than the simple echo.

Reverberation is produced by the repeated reflection of a sound from the walls of the apartment. If for example a single detonation takes place in the middle of a long hall with naked and perpendicular walls, an impulse will pass in each direction, will be reflected from the walls, cross each other again at the point of origin, be again reflected, and so on until the original impulse is entirely absorbed by the solid materials which confine it. The impression will be retained upon the ear during the interval of the transmission past it of two successive waves, and thus a continued sound will be kept up, particularly if the walls of any part of the room are within 30 feet of the ear. If a series of impulses, such as that produced by the rapid snaps of a quill against the teeth of a wheel be made in unison with the echoes, a continued musical sound will be the result. Suppose the wheel to be turned with such velocity as to cause a snap at the very instant the return echo passes the point

at which the apparatus is placed, the second sound will combine with the first, and thus a loud and sustained vibration will be produced. It will be evident from this that every room has a key-note, and that to an instrument of the proper pitch it will resound with great force. It must be apparent also, that the continuance of a single sound and the tendency to confusion in distinct perception, will depend on several conditions;—first, on the size of the apartment; secondly, on the strength of the sound or the intensity of the impulse; thirdly, on the position of the reflecting surfaces; and fourthly, on the nature of the material of the reflecting surfaces.

In regard to the first of these, the larger the room the longer time will be required for the impulse along the axis to reach the wall; and if we suppose that at each collision a portion of the original force is absorbed, it will require double the time to totally extinguish it in a room of double the size, because, the velocity of sound being the same, the number of collisions in a given time will be inversely as the distance through which the sound has to travel.

Again, that it must depend upon the loudness of the sound or the intensity of the impulse, must be evident, when we consider that the cessation of the reflections is due to the absorption by the walls, or to irregular reflection, and that consequently the greater the amount of original disturbance the longer will be the time required for its complete extinction. This principle was abundantly shown by our observations on different rooms.

Thirdly, the continuance of the resonance will depend upon the position of the reflecting surfaces. If these are not parallel to each other, but oblique, so as to reflect the sound not to the opposite but to the adjacent wall, without passing through the longer axis of the room, it will evidently be sooner absorbed. Any obstacle, also, that may tend to break up the wave and interfere with the reflection through the axis of the room will serve to lessen the resonance of the apartment. Hence, though the panelling, the ceiling, and the introduction of a variety of oblique surfaces, may not pre-

vent an isolated echo, provided the distance be sufficiently great and the sound sufficiently loud, yet that they do have an important effect in stopping the resonance is evident from theory and experiment. In a room 50 feet square in which the resonance of a single intense sound continued six seconds, when cases and other objects were placed around the wall its continuance was reduced to two seconds.

Fourthly, the duration of the resonance will depend upon the nature of the material of the wall. A reflection always takes place at the surface of a new medium, and the amount of this will depend upon the elastic force or power to resist compression and the density of the new medium. For example, a wall of nitrogen, if such could be found, would transmit nearly the whole of a wave of sound in air, and reflect but a very small portion; a partition of tissue-paper would produce nearly the same effect. A polished wall of steel however, of sufficient thickness to prevent yielding, would reflect for practical purposes all the impulses through the air which might fall upon it. The rebound of the wave is caused, not by the oscillation of the wall, but by the elasticity and mobility of the air. The striking of a single ray of sound against a yielding board would probably increase the loudness of the reverberation but not its continuance. On this point a series of experiments was made by the use of the tuning-fork. In this instrument the motion of the foot and of the two prongs gives a sonorous vibration to the air, which, if received upon another tuning-fork of precisely the same size and form, would re-produce the same vibrations.

It is a fact well established by observation that when two bodies are in perfect unison, and separated from each other by a space filled with air, vibrations of the one will be taken up by the other. From this consideration it is probable that relatively the same effect ought to be produced in transmitting immediately the vibration of a tuning-fork to a reflecting body as to duration and intensity as in the case of transmission through air. This conclusion is strengthened by floating a flat piece of wood on water in a vessel standing

upon a sounding-board; placing a tuning-fork on the wood the vibrations will be transmitted to the board through the water, and sounds will be produced of the same character as those emitted when the tuning-fork is placed directly upon the board.

A tuning-fork suspended from a fine cambric thread and vibrated in air was found, from the mean of a number of experiments, to continue in motion 252 seconds. In this experiment, had the tuning-fork been in a perfect vacuum suspended without the use of a string, and further, had there been no ætherial medium, the agitation of which would give rise to light, heat, electricity, or some other form of ætherial motion, the fork would have continued its vibration forever.

The fork was next placed upon a large, thin pine board—the top of a table. A loud sound in this case was produced which continued less than *ten* seconds. The whole table as a system was thrown into motion, and the sound produced was as loud on the under side as on the upper side. Had the tuning-fork been placed against a partition of this material a loud sound would have been heard in the adjoining room; and this was proved by sounding the tuning-fork against a door leading into a closed closet. The sound within was apparently as loud as that without.

The rapid decay of sound in this case was produced by so great an amount of the motive power of the fork being communicated to a large mass of wood. The increased sound was due to the increased surface. In other words the shortness of duration was compensated for by the greater intensity of effect produced.

The tuning-fork was next placed upon a circular slab of marble about three feet in diameter and three-quarters of an inch thick. The sound emitted was feeble, and the undulations continued *one hundred and fifteen* seconds, as deduced from the mean of six experiments.

In all these experiments, except the one in a vacuum, the time of the cessation of the motion of the tuning-fork was determined by bringing the mouth of a resounding cavity

near the end of the fork, this cavity having previously been adjusted to unison with the vibrations of the fork, gave an audible sound when none could be heard by the unaided ear.

The tuning-fork was next placed upon a cube of India-rubber, and this upon the marble slab. The sound emitted by this arrangement was scarcely greater than in the case of the tuning-fork suspended from the cambric thread, and from the analogy of the previous experiments, we might at first thought suppose the time of duration would be great, but this was not the case. The vibrations continued only about forty seconds. The question may here be asked, What became of the impulses lost by the tuning-fork? They were neither transmitted through the India-rubber nor given off to the air in the form of sound, but were probably expended in producing a change in the matter of the India-rubber, or were converted into heat, or both. Though the inquiry did not fall strictly within the line of this series of investigations, yet it was of so interesting a character in a physical point of view to determine whether heat was actually produced that the following experiment was made.

A cylindrical piece of India-rubber about an inch and a quarter in diameter was placed in a tubulated bottle with two openings, one near the bottom and the other at the top. A stuffing-box was attached to the upper opening, through which a metallic stem with a circular foot to press upon the India-rubber was made to pass air-tight. The lower opening was closed with a cork, in a perforation of which a fine glass tube was cemented. A small quantity of red ink was placed in the tube to serve as an index. The whole arrangement thus formed a kind of air-thermometer, which would indicate a certain amount of change of temperature in the enclosed air. On the top of the stem the tuning-fork was screwed, and consequently its vibrations were transmitted to the rubber within the bottle. The glass was surrounded with several coatings of flannel to prevent the influence of external temperature. The tuning-fork was then sounded, and the vibrations were kept up for some time. No reliable indications

of an increase of temperature were observed. A more delicate method of making the experiment next suggested itself. The tube containing the drop of red ink, with its cork, was removed, and the point of a compound wire formed of copper and iron was thrust into the substance of the rubber, while the other ends of the wire were connected with a delicate galvanometer. The needle was suffered to come to rest, the tuning-fork was then vibrated, and its impulses transmitted to the rubber. A very perceptible increase of temperature was the result. The needle moved through an arc of from one to two and a half degrees. The experiment was varied and many times repeated; the motions of the needle were always in the same direction, namely, in that which was produced when the point of the compound wire was heated by momentary contact with the fingers. The amount of heat generated in this way however is small, and indeed in all cases in which it is generated by mechanical means the amount evolved appears very small in comparison with the labor expended in producing it. Joule has shown that the mechanical energy generated in a pound weight by falling through a space of seven hundred and fifty feet elevates the temperature of a pound of water one degree.

It is evident that an object like India-rubber actually destroys a portion of the sound, and hence in cases in which entire non-conduction is required this substance can probably be employed with perfect success.

The tuning-fork was next pressed upon a solid brick wall, and the duration of the vibration from a number of trials was eighty-eight seconds. Against a wall of lath and plaster the sound was louder and continued only eighteen seconds.

From these experiments we may infer that if a room were lined with a wainscot of thin boards and a space left between the wall and the wood, the loudness of the echo of a single noise would be increased while the duration of the resonance would be diminished. If however the thin board were glued or cemented in solid connection to the wall, or embedded in the mortar, then the effect would be a feeble echo and a long continued resonance, similar to that from the

slab of marble. This was proved by first determining the length of continuance of the vibrations of a tuning-fork on a thin board, which was afterwards cemented to a flat piece of marble.

A series of experiments was next commenced with reference to the actual reflection of sound. For this purpose a parabolic mirror was employed, and the sound from a watch received on the mouth of a hearing-trumpet furnished with a tube for each ear. The focus was near the apex of the parabola, and when the watch was suspended at this point it was six inches within the plane of the outer circle of the mirror. In this case the sound was confined at its origin, and prevented from expanding. No conjugate focus was produced, but on the contrary the rays of light, when a candle was introduced, constantly diverged. The ticking of the watch could not be heard at all when the ear was applied to the outside of the mirror, while directly in front it was distinctly heard at the distance of thirty feet, and with the assistance of the ear trumpet at more than double that distance. When the watch was removed from the focus the sound ceased to be audible. This method of experimenting admits of considerable precision, and enables us to directly verify, by means of sound transmitted through air, the results anticipated in the previous experiments. A piece of tissue-paper placed within the mirror and surrounding the watch without touching it, slightly diminished the reflection. A single curtain of flannel produced a somewhat greater effect, though the reflecting power of the metallic parabola was not entirely masked by three thicknesses of flannel; and I presume very little change would have been perceived had the reflector been lined with flannel glued to the surface of the metal. The sound was also audible at the distance of ten feet when a large felt hat without stiffening was interposed between the watch and the mirror. Care was taken in these experiments so to surround the watch that no ray of sound could pass *directly* from it to the reflecting surface.

With a cylindrical mirror, having a parabolic base, very little increased reflection was perceived. The converging

beams in this case were merely in a single plane, perpendicular to the mirror, and passing through the ear, while to the focal point of the spherical mirror a solid cone of rays was sent.

The reflection from the cylindrical mirror forms what is called a *caustic* in optics, while that from a cylindrical mirror gives a true focus, or in other words collects the sounds from all parts of the surface and conveys them to one point of space. These facts furnish a ready explanation of the confusion experienced in the Hall of Representatives, which is surmounted by a dome, the under surface of which acts as an immense concave mirror, reflecting to a focus every sound which ascends to it, leaving other points of space deficient in sonorous impulses.

Water, and all liquids which offer great resistance to compression, are good reflectors of sound. This may be shown by the following experiment. When water is gradually poured into an upright cylindrical vessel, over the mouth of which a tuning-fork is vibrated, until it comes within a certain distance of the mouth, it will reflect an echo in unison with the vibration of the fork, and produce a loud resonance. This result explains the fact, which had been observed with some surprise, that the duration of the resonance of a newly plastered room was not perceptibly less than that of one which had been thoroughly dried.

There is another principle of acoustics which has a bearing on this subject. I allude to the refraction of sound. It is well known that when a ray of sound passes from one medium to another a change in velocity takes place, and consequently a change in the direction or a refraction must be produced. The amount of this can readily be calculated where the relative velocities are known. In rooms heated by furnaces, and in which streams of heated air pass up between the audience and speaker, a confusion has been supposed to be produced and distinct hearing interfered with by this cause. Since the velocity of sound in air at 32° of Fahrenheit has been found to been 1090 feet in a second, and since the velocity increases 1·14 feet for every degree of

Fahrenheit's scale, if we know the temperature of the room and that of the heated current the amount of angular refraction can be ascertained. But since the ear does not readily judge of the difference of direction of two sounds emanating from the same source, and since two rays do not confuse the impression which they produce upon the ear though they arrive by very different routes, provided they are within the limit of perceptibility, we may conclude that the indistinctness produced by refraction is comparatively little. Professor Bache and myself could perceive no difference in distinctness in hearing, from rays of sound passing over a chandelier of the largest size in which a large number of gas jets were in full combustion. The fact of disturbance from this cause however, (if any exist,) may best be determined by the experiment with a parabolic mirror and the hearing-trumpet before described.

These researches might be much extended; they open a field of investigation equally interesting to the lover of abstract science and to the practical builder; and I hope, on behalf of the committee, to give some further facts with regard to this subject at another meeting.

The Smithsonian Lecture-room.—I shall now briefly describe the lecture-room of the Smithsonian Institution, which has been constructed in accordance with the facts and principles previously stated, so far at least as they could be applied.

There was another object kept in view in the construction of this room besides the accurate hearing, namely the distinct seeing. It was desirable that every person should have an opportunity of seeing the experiments which might be performed, as well as of distinctly hearing the explanation of them.

By a fortunate co-incidence of principles, it happens that the arrangements for insuring unobstructed sight do not interfere with those necessary for distinct hearing.

The law of Congress authorizing the establishment of the Smithsonian Institution directed that a lecture-room should be provided; and accordingly in the first plan one-half of the first story of the main building was devoted to this pur-

pose. It was found impossible however to construct a room on acoustic principles in this part of the building, which was necessarily occupied by two rows of columns. The only suitable place which could be found was therefore on the second floor. The main building is two hundred feet long and fifty feet wide; but by placing the lecture room in the middle of the story a greater width was obtained by means of the projecting towers.

The main gallery is in the form of a horse-shoe occupying three sides of the room. The speaker's platform is placed between two oblique walls. The corners of the room which are cut off by these walls afford recesses for the stairs into the galleries. The opposite corners are also partitioned off so as to afford recesses for the same purpose.

The general appearance of the room is somewhat fan-shaped, and the speaker is placed in the mouth as it were of an immense trumpet. The sound directly from his voice and that from reflection immediately behind him is thrown forward upon the audience; and as the difference of distance travelled by the two rays is much within the limit of perceptibility no confusion is produced by direct and reflected sound.

Again, on account of the oblique walls behind the speaker and the multitude of surfaces, including the gallery, pillars, stair-screens, &c., as well as the audience, directly in front, all reverberation is stopped.

The walls behind the speaker are composed of lath and plaster, and therefore have a tendency to give a more intense though less prolonged sound than if of solid masonry. They are also intended for exhibiting drawings to the best advantage.

The seats are arranged in curves and were intended to rise in accordance with the *panoptic curve*, originally proposed by Professor Bache, which enables each individual to see over the head of the person immediately in front of him. The original form of the room however did not allow of this intention being fully realized, and therefore the rise is somewhat less than the curve would indicate.

The ceiling is twenty-five feet high, and therefore within the limit of perceptibility. It is perfectly smooth and unbroken with the exception of an oval opening nearly over the speaker's platform through which light is admitted.

No echo is given off from the ceiling, while this assists the hearing in the gallery by the reflection to that place of the oblique rays.

The architecture of this room is due to Captain B. S. Alexander, of the corps of Topographical Engineers. He fully appreciated all the principles of sound which I have given, and varied his plans until all the required conditions as far as possible were fulfilled.

ACCOUNT OF A LARGE SULPHURIC-ACID BAROMETER IN THE HALL OF THE SMITHSONIAN INSTITUTION.

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The opinion has been frequently advanced that a barometer in which the material used to balance the pressure of the atmosphere is of less specific gravity than mercury, and consequently of a wider range of fluctuation, might throw some new light on several important points of meteorology. The fluid usually proposed for this purpose has been oil or water, the viscid character of the former and its tendency to a change of condition has induced a preference for the latter. Several water-barometers have accordingly been constructed; but as far as I am informed, the indications of the instruments have not been reliable.

Mariotte used one of this character; also Otto von Guericke constructed a philosophical toy to which he gave the name of aëroscope, on the principle of a water-barometer. It consisted of a tube more than thirty feet high elevated on a long wall and terminated by a tall and rather wide glass cylinder hermetically sealed, in which was placed a toy in the shape of a man. All the tube except a portion of