THE PROBLEM OF THE STETHOSCOPE.

An Enquiry, Experimental and Philosophical, into the Properties of this Instrument and the Physics of Auscultation.

JAMES P. DAVIE, M.A.,B.Sc.,M.B.,Ch.B.1923.

---oooOooo---

March 1926.

THE PROBLEM OF THE STETHOSCOPE.

An Enquiry, Experimental and Philosophical, into the Properties of this Instrument and the Physics of Auscultation.

JAMES P. DAVIE, M.A., B.Sc., M.B., Ch.B. 1923.

March 1926. M.D.

CONTENTS.

……

PREFACE.

My interest in Stethoscopy dates back to the time when I first entered the class of Clinical Medicine. I had previously, while on war service, been interested in the propagation of sound in sea water, and finding that acoustics played so important a part in the diagnosis of pulmonary and cardiac conditions, I naturally sought to understand both the nature of intrathoracic vibratory disturbances and the mechanism of their conveyance to the ear.

In those early days two great difficulties confronted me. Firstly, the difficulty of recognising the various pulmonary signs even when directed what to listen for; secondly, the difficulty of following the explanations tendered for the mechanism of their propagation and production.

By the time I had finished my classes the former had been partly overcome, the latter remained. And so, immediately after graduation I found myself engrossed in the literature of auscultation. The more I read the more I became impressed with the need for greater scientific precision, so many of the observations amounting to little more than mere impressions.

As it seemed logical that we should first endeavour to understand the mechanism of our instruments, I was ultimately led to undertake the work of this thesis, not relying merely upon observations and impressions, but taking as my guide the concepts and propositions framed chiefly by those great master minds in sound and sound sensation, Lord Rayleigh and Helmholtz.

....

INTRODUCTION.

Of all the instruments that have been invented to assist the medical practitioner in the art of physical diagnosis there is probably none over which a greater amount of time and effort has been expended that the stethoscope.

It is now just over a hundred years since the celebrated Laenec first published his epoch making discovery, and since that time year after year has brought forth new ideas, new inventions, new claims, and an endless succession of controversies over the design and use of this instrument.

The number of ~~writers~~ workers concerned is legion. It is a formidable task in itself to take note of all those whose articles and discussions have found their way into the medical journals, and in addition to these there must be hundreds more who have had original ideas and had instruments executed according to their own designs.

The catalogues of the various makers give one an idea of the enormous variety of instruments now on the market and at the same time serves as an index of the difficulties in determining satisfactorily the physical principals underlying its use. To the student beginning his clinical studies it is all very conflicting and confusing. One advises him to purchase instrument A another instrument B. He is generally wise enough to choose one similar in type to that employed by his clinical teacher. Or again, he may be informed that it is a matter of indifference which instrument he selects provided he adheres to his selection.

This is an implicit statement of one of the fundamental principles of stethoscopy viz. that we have to learn to analyse the complex sensations percieved. Certain of the auscultated elements are due to the particular instrument in use and have therefore to be neglected. The success of the auscultator depends at least in part on his ability, consciously or subconsciously, to discount these instrumental factors.

But such advice warranted as it is by clinical experience does not lessen the importance of the fact, that the intracorporeal vibrations as received by the ear have been subjected to considerable diverse modifications depending on the particular instrument employed for their detection.

Not unreasonably therefore we may postulate the possibilty of devising an instrument superior in its intrinsic characteristics. It may appear that in the first instance, we ought to aim at possessing a stethoscope that will receive and conduct the intracorporeal vibrations with a mimimum loss of intensity and a mimimum change in character. While we may with experience learn to use successfully an instrument that adds adventitious elements, or distorts the transmitted sounds, it is making the process of physical interpretation more indirect and difficult. The physics of the problem may be complicated but it ought to be possible at least to surmise, if not to demonstrate, the importance of the various factors concerned; and we cannot hope to make any real advance in the interpretation of intracorporeal acoustic phenomena unless we have a shrewd idea of the behaviour of the instruments in use for their detection. So long as investigators continue to use instruments varying appreciably in their behaviour and in a manner unknown we cannot hope to correlate strictly the results of their findings.

I have endeavoured in this thesis to enquire into the mechanism of both the monaural and the binaural forms, and to review the various ideas that have from time to time been put forward. It makes fascinating reading to trace the development of the present day instruments, and to appreciate the ideas behind the various improvements, but the further one goes into the subject, the more one is impressed with the empirical nature of many of the **claims** put forward. The great bulk of argument is devoid of scientific precision. Not a little of it is stupid and some frankly ridiculous. There has been comparatively little research work carried out along unimpeachable lines.

Of course we must not forget that the evolution of the great majority of musical instruments owes but little to the mathematician and the physicist, and we must hesitate is criticise empirical methods when we recall that the violin, the product of such empiricism appears to be an almost perfect resonator not merely for a few notes but for the whole range of tones that can be produced on its strings. What strikes one most however in reading the history of the subject is the relatively small amount of real progress that has been made since Laenec's time. This has no doubt been due to several factors.

Firstly, acoustics is one of the most difficult branches of natural philosophy. Secondly, the stethoscope stands rather apart from musical instruments, and the results of empirical modifications are not so easily capable of satisfactory evaluation. Thirdly, the stethoscope, as such, has but little interest for the musician, the mathematician and the physicist. Lastly, for a successful handling of the subject one would require an intimate knowledge of the medical aspects of the problem in addition to an advanced training in physics and mathematics.

But now, an account of the large amount of research work in hand in connection with the problems of broadcasting, reproduction of sound by gramaphone, and long distance telephone communication, we are learning new facts of great practical importance. The minds of a great army of workers are being trained to a more precise conception of the physical nature of sonorous vibratory disturbances in different media and we may reasonably hope for some further developments in stethoscopy in the near future. Just such fundamental conceptions as to the nature, the production and the transmission of sonorous vibrations is being gradually recognized as a prime necessity for the intelligent understanding of the results of auscultation and percussion in witness whereof I cannot do better than refer the reader to the space devoted to diagostic acoustics in that excellent modern text book by Norris and Landis "Diseases of the Chest and the Principles of Physical (1)
Diagnosis."

The field is a large one and it is easy to foresee the possibilities of developments in various directions. The subject of sound analysis for example, by the principles of selective resonance has been engaging the attention of various scientists. It may be possible by such means to gain further insight into the nature of intracorporeal vibrations, especially in heart murmurs. Such claims have indeed from time to time been put forward by various stethoscope designers but thier efforts so far are hardly worthy of serious consideration.

There are presumably also great possibilities based on the use of the oscillation valve. In this apparatus we have a means of obtaining magnified effects by using the original small energy manifestations to control the output.of larger sources.

The idea of using the oscillation valve as an amplifier must now have occurred to a great many practitioners. Several experiments have been tried to broadcast the sounds of the heart.

The great difficulty however to be overcome is the designing of a receiving instrument sufficiently sensitive, for in auscultation we are mainly interested in vibrations of very small intensity.

As there is nothing more irritating in reading a thesis of this sort than to assume that the reader has recently digested a standard textbook on the subject, I have included articles on sound in general where such have been required for the understanding of the argument. By so doing, while it has necessarily lengthened the work it has I hope, made it intelligible without obliging the reader to refer to a textbook on sound.

…………….

SHORT HISTORY OF THE STETHOSCOPE.

The principle upon which Auscultation rests was known to Hippocrates but very little advance was made on his observations till the beginning of last century. Prior to that in 1755the cognate art of percussion as applied to the diagnosis of thoracic conditions had been discovered by Auenbrugger, though it remained for Corvisart to introduce it into popular use. It had however been applied in early Grecian times for the differentiation of ascites from tympanites. Direct or immediate auscultation viz. by the application of the ear to the body surface was practised before the beginning of the 19th century, but for obvious reasons it had never become very popular, and up to the year 1816 very little progress had been made in the discovery, classification and interpretation of what we know as auscultation signs.

In that year Laenec, the inventor of the stethoscope made his great discovery and introduced mediate or indirect auscultation.

The discovery like many others was made almost by accident and without forethought. He was one day consulted by a young buxom girl obviously suffering from cardiae disease. Being unwilling to apply immediate auscultation for reasons of delicacy he suddenly recollected the fact that sound could be conveyed to the ear from a vibrating body by the interposing of a rod of wood. Looking around for some article by which he could apply this principle he found nothing in the shape of a rod at hand; so, picking up a quire of paper he rolled it up and applying one end to her breast applied his ear to the other.

He was agreeable surprised to find he could hear the heart sounds better than he ahd ever heard them before. This immediately set him experimenting with the object of improving and applying his invention.

He first tried a solid rod of wood, but finding that it did not transmit so well as the quire of paper, which incidentally he could not roll up tight enough to exclude a central perforation he was led to appreciate the significance of the column of air.

Subsequently he experimented with a variety of materials of different density, hollowing out the chest piece end into a funnel and later the ear piece, the latter modification being originally introduced for the benefit of Sir Charles Scudamore who was unable to use the ordinary form on account of the shape of his auricle.

The next improvement was by M. Piorry who reduced the stem to a fingers thickness and found that it conducted equally well.

By some of the foremost men in Vienna, Edinburgh, Dublin, and London, more so than in the inventor's own city Paris, The importance of the discovery was very soon appreciated, although others less far seeing sought to deride it as a toy. The publication of his masterpiece "Traite de L'Auscultation Médiate" ought to have convinced anyone open to reason, but for years afterwards the stethoscope was not at all popular in France.

By 1830 the medical journals had begun to contain numerous references to the use or non use of the instrument, and the long train of discussion regarding the nature, mode of production and transmission of intracorporeal vibratory disturbances which is still going on had been initiated as a natural consequence of the invention. We find for example, Corrigan of Dublin writing in the Lancet of 1828 on the subject of (3) aneurism strongly advocating the use of the stethoscope and dealing with the arguments of its opponents. In the same volume The Lancet criticises Glasgow Royal Infir- (4) mary for the death of a patient under treatment for fistula in ano. At the post mortem the lungs were found to be consolidated. The Lancet points out that this condition ought to have been discovered ante mortem if the stethoscope had been employed.

A curious little rhyme published in the Lancet of 1829 entitled 'Auscultation Extraordinary' gives us (5) perhaps a better idea of the early reception of the instrument than a whole host of references would do.

"Quoth Rod'rick I'll a place contrive,
So dark and safe no man alive,
Shall to our private meetings grope.
"Egad" cries Johnny," that won't do,
If there's no crack to listen through,
They'll take 'reports' by stethoscope."

A reference in the same volume gives professor (6) Duncan of Edinburgh the credit of being the first in this country to recognise the value of the instrument and advocate its general use. Duncan had himself attended La Charité where Laenec did so much of his work, and obtained his model from Laenec's own instrument maker.

This reference is corroborated by another in the Edinburgh Medical Journal (No. 104 1830) by Dr.Gregory, Physician to the Royal Infirmary; while to Gregory (7) himself falls the credit of formulating what is now a well known dictum in stethoscopy viz. that as much depends on the listener as on the stethoscope.

It was not long before the need was felt for an instrument more adaptable for convenient use with patients too ill to be moved. Some twenty years ago following the publication of a lecture on Laenec and the stethoscope in the British Medical Journal by Theodore Williams (8)
a controversy arose as to whom the credit of first introducing the flexible binaural stethoscope should belong.

Dr. Leard, referred to below, claimed this distinction, but Williams says that his ancestor Dr. C.J.B. Williams had the idea as early as 1829.

The credit however appears really to belong to Nicholus P. Comins of Edinburgh Royal Infirmary who contributes an artivle in the Lancet of 1829 on a (9) "Flexible Stethoscope." His idea was a hinged instrument constituting essentially a bent tube. He confut~~t~~ed the objections that a bent tube should not conduct as well as a straight one, and suggested a modification to permit of the use of both ears;

in other words be predicted the advent of the binaural pattern.

The next advance on this was Dr. Golding Bird's (10) Flexible Tube -- a monaural form with a flexible tube made of iron wire covered with caoutchouc. This was introduced on 1840.

Edinburgh seems to have been well to the front in those early days, one of the house surgeons Robert Spittal publishing in 1830 a book of 280 pages entitled "A treatise on Auscultation illustrated by cases and dissections.

During the next fifteen years all the possible uses of the instrument had been exploited from obstetrical to cerebral auscultation, and the journals teem with names still familiar to the medical student, Nagle, Stokes, Skoda, Beau, Graves, Williams and Corrigan; but a leading article in the Lancet of (11) 1843 indicates that even then auscultation was still a debated subject.

In 1840 M. Beau put forward a new theory of respiration which was criticised later by Corrigan of (12) Dublin. Then almost immediately afterwards we find in (13(the Edinburgh Medical and Surgical Journal a brilliant (14) article by Skoda of Vienna (communicated by Dr. William) Drysdale and Dr. John Russell), in which there is more sound philosophical reasoning than in anything that had previously been published. It is in this article that Skoda puts forward his famous theory of consonance. In London the two authorities were Dr. Herbert Davies and Dr. C.J.B. Williams to both of whom is due a considerable amount of credit for making the instrument popular in England.

Dr. Davies's lecture published in 1850 is well (15) worthy of consultation. I have refered in a subsequent article to his experiments quoted in this lecture.

Dr. CJ.B. Williams Published in 1828 a book that remained a classic for many years. "Physical Signs of the Diseases of the Lungs and Pleura." He also introduced the trumpet shape chest piece as an advance on the bell shaped which had previously been in vogue.

He claimed that the trumpet form was more comfortable and less subject to "reverberations".

In the early fifties the binaural instrument with
flexible tubes began to take shape. Comins's suggestion
already referred to does not seem to have come to any-
thing, and though there does not appear to be any (16)
doubt that Dr. Williams had a binaural instrument with
metal tubes many years before, the first publication
and exhibition of an instrument with two tubes appears to be
due to Dr. Leard, who displayed his invention in the (17)
Great Exhibition in 1851. His tubes were made of
gutta percha.

In 1855 Dr. Cammon of New York patented an instru- (18)
ment with some new features. He introduced the knob
form of ear piece to fit into the meatus and curved
the head tubes like the modern instrument and bound
them together by an elastic band.

The idea of a multiple stethoscope whereby
several persons could listen simultaneously appears to
be due to M. Landouzy of Paris who in 1850 constructed (19)
an instrument having a number of gum elastic tubes;
while the earliest indication of the idea of a dia-
phragmatic instrument is the invention of Dr. N.B. (20)
Marsh of Cincinnati who in 1851 patented a stethos-
cope with two gum elastic tubes and a membrane applied
over its objective end.

In 1857 Dr. Scott Alison of the Brompton (21)
Hospital introduced the differential stethoscope.
He used two chest pieces simultaneously with the idea
of comparing at once the sounds of healthy parts with
diseased. His idea has lain dormant for many years
but it is likely to be resuscitated and reapplied with
the advance of our knowledge of acoustics.

In a paper before the Royal Society on this (22)
differential stethoscope he referred to some highly
interesting acoustic Phenomena which had not hitherto
been noted, e.g. the deprivation of hearing sound in one
ear by simply giving a little advantage to the other
e.g. increasing the length of one limb of a binaural
stethoscope.

The past fifty of sixty years has seen the publication of a long list of different patterns but with little essentially new. There have been hundreds of minor alterations in detail having practically no acoustic importance. An idea of these will be obtained by a glance through the collection of prints in the appendix.

We might make a brief notice of a few outstanding modifications.

Bowles pattern consists of a flat shallow chest piece with a diaphragm introduced on account of its convenience of use in patients too ill to sit up; the phonendoscope, a larger type of diaphragm with a central piece for applying to the chest -- an instrument now generally condemmed by experienced auscultators; Arnolds phonophone, invented in 1894 which appears to be constructed on a mistaken idea; and lastly a modern form Marr's which has a perforated diaphragm to divide up the air chamber.

Many of the modifications have been suggested purely on account of considerations of convenience of portability or use.

Lastly the advent of the oscillation valve appears to be about to inaugurate a new era in stethoscopy. I have elsewhere referred to this both in the introduction and in the article on the future of auscultation.

THE NATURE OF THE PROBLEM

Let us examine first of all what precisely is entailed in the problem with which we are concerned.

In a lecture delivered before the Royal Medical and Chirurgical Society in London in 1873 Dr. C.J.B. Williams M.D. F.R.S. whose labours played no small part in bringing the stethoscope into popular use in England, enunciated its principles as being "to conduct sound from the chest to the ear both by its solid materials and through the enclosed column of air". He was referring of course to the monaural type. (23)

Norris and Landis, in their article on the stethoscope define the main functions of the binaural form as being, (24)

(1) To prevent lateral radiation of the vibrations with which the air it contains is charged thus conducting a larger proportion to the ear, and

(2) To exclude extraneons sounds.

These statements taken together from a comprehensive definition of the functions of auscultation instruments in general.

Our problem is to enquire into the exact mechanism by which these functions are performed.

By tracing the sequence of events from the origin of the sounds within the chest to their reception by the ear we may draw up a list of all the points requiring investigation having in view in the first instance the use of the binaural form.

It may at first sight appear that the problem should begin with the application of the chest-piece to the body surface; that we can so to speak as a starting point visualise the sonorous vibrations arrived at the surface of the body. This is not so.

Before that, it is necessary to enquire into the nature and mode of transmission within the body of the external physical disturbances associated with auscultation signs. Particular points of importance are,

(1) Is their propagation through the tissues comparable to propagation through air, water, a solid mass of metal or wood, i.e. is it essentially a propagation of an undulatory disturbance of a molecular order in a conducting <u>medium</u>?

(2) Or on the other hand do the structures act as bodies in a state of vibration as a whole?

This question requires special answer in reference to the behaviour of the chest wall.

(3) What is the character of the vibrations? Are they regular or periodic (partaking of the nature of tones), or aperiodic (partaking of the nature of noises)?

This is very important consideration although attention does not seem to have been hitherto directed to it. For such vibrations as are aperiodic the terms selective resonance and sympathetic vibrations occurring so frequently in the literature of stethoscopy must be considered to be applied in a mistaken sense.

These questions being considered we suppose ourselves dealing with an area of vibration emitting body surface to which the chest piece is applied. Here our first concern is the mode of transference of sound energy from the body surface to the chest piece and its contained air. Chest pieces for the purpose of this consideration may be grouped into two great classes,

(1) The open mouth form in which the skin is in direct contact with the imprisoned air,

(2) The closed form in which a diaphragm or other structure intervenes between the skin and enclosed air.

Consider first a simple open mouth form applied to the body surface. (See Fig 1.)

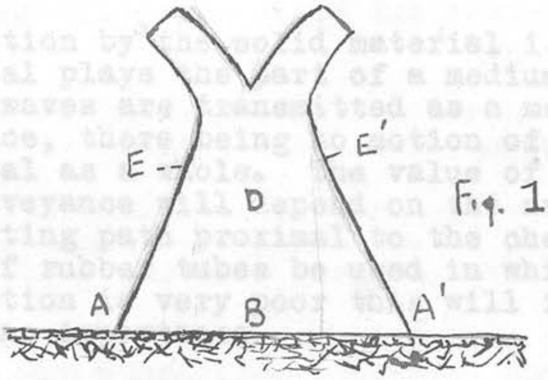


Fig. 1

Two possibilities immediately present themselves.

(1) Direct transference of sound energy from the body surface B to the enclosed D.

(2) Transference to the solid material EE' of the chest piece by virtue of its contact with the body surface at AA'.

As regards the former we have to endeavour to form an exact physical concept of the passage of vibratory disturbances from chest wall to air. Again there are two possibilities.

(a) The vibrations internal to the skin may be conceived as a molecular disturbance in which case their transference to the air of D is an example of the refraction of sound from one medium to another. An analogous problem is the audibility in air of sound produced in water.

(b) On the other hand the whole area B can be considered in a vibrating state, in which case it acts like a source of sound. The problem is then comparable to a closed air chamber with rigid walls having a window closed by a vibrating membrane.

As regards the transference by the solid material in virtue of its contact with the body surface, again there is more than one possiblity.

(1) Conduction by the solid material i.e. the solid material plays the part of a medium in which sound waves are transmitted as a molecular disturbance, there being no motion of the solid material as a whole. The value of this means of conveyance will depend on the nature of the conducting path proximal to the chest piece. Thus if rubber tubes be used in which sound conduction is very poor this will in any case be of no importance.

(2) The walls of the chest piece may be set into a <u>state</u> of vibration. Such vibrations must necessarily be of a very complex character, but by way of illustrating possibilities consider Fig 2, which is a simple funnel applied to the chest wall.

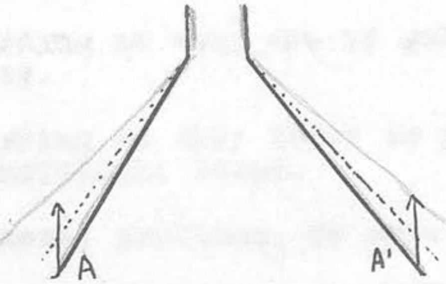


fig 2.

Pressure applied at AA' in a direction at right angles to the body surface will tend to deform the sloping sides, which might in the simplest case be assumed to take the contour indicated by the dotted line with each compression.

Or again, the circular section might be assumed to become ellipitical.

In actual practice the alterations in shape must be very complex, but the important point is that the vibrations of the solid parts will set up corresponding vibrations in the enclosed air and we should be happy if we could determine to what extent this mechanism operates in a given chest piece.

Further problems arise in those cases where the mouth of the chest piece is closed by a diaphragm. Transference is then first to the diaphragm. The behaviour of such diaphragm calls for a special investigation.

A number of minor problems arise before we pass to the consideration of chest pieces, such as,

(1) Delimitation of the area from which vibrations can be supposed to be received by the chest piece in a given position.

(2) The effect of the application of pressure on the stethoscope. Sewall has written widely on this subject. (25)

The subject of chestpieces next engages our attention. Broadly the problems here may be classified into two great groups.

(1) According as they are of general applicability.

(2) According as they refer to peculiarties of individual forms.

Of the general problems, we have to enquire,

(1) What is the optimum area of chest wall to be enclosed by the mouth piece, and what shape should the mouth piece take (e.g. circular or elliptical)?

(2) To what changes are the vibrations subjected in their passage through the chest piece? What alteration if any takes place in the intensity of the component vibrations i.e. how is the sound modified by (a) the metal parts (b) the enclosed air?

(3) Is the contained air or the solid frame capable of acting as a resonator? Various instruments have been specially designed either to act as resonators or to avoid such a possibility.

(4) What interchanges of energy takes place between the systems formed by (a) the enclosed air, (6) the solid parts. In other words trace the subsequent history of the energy transmitted direct to the contained air and that transmitted to the solid walls.

Coming to the group of problems depending on the particular form of chest piece we note that chest pieces in general for binaural stethoscopes are usually,

(1) A modification of a cone.

(2) A tympanic arrangement.

(3) Bell form.

(1) The Cone Type:- Problems are,

i. What value should the solid angle of the cone have?

ii. Can we deduce its behaviour by following a wave front advancing from the base to the apex?

iii. What should be the diameter of the leading off tubes and should they both open into the conical part?

iv. What modifications of a simple cone are desirable e.g. a trumpet form?

The bell type calls for similar treatment with some special consideration in peculiar forms like Arnold's Phonophore.

The type of the chest piece closed by a diaphragm is rather a different problem. We require to consider the behaviour of the diaphragm as regards its reception of sounds from the chest and its transmission of them to the air beyond. Thereafter similar problems as before arise as regards the behaviour of the air chamber and the solid walls.

In particular we must endeavour to find an explanation for the very marked difference in sensation observed in using the diaphragm pattern as compared with the open cone.

Having dealt with the acoustic properties of chest pieces we try to visualise the vibrations passing on to the conducting tubes. At the junction with chest piece we imagine aerial vibrations being transmitted to the column of air, and vibrations both transverse and longitudinal being handed on to the material of which the tubes are made by the solid part of the chest piece.

We have to try and follow the sequence of events to the other end of the conducting tubes. Plainly here we have the simple problem of vibration in tubes, but also we have to think of the possibility of conduction by the solid walls.

Finally we come to the ear pieces themselves. There are many minor problems here for it is common knowledge that badly fitting ear pieces greatly reduce the value of the stethoscope. Briefly these problems are as follows.

(1) In what respect does the introduction of ear pieces into the meatus alter the normal mode of sound reception?

(2) What part does the auricle play?

(3) The relative importance of bone and air conduction.

This investigation should normally terminate when we have seen so to speak the vibratory disturbances affecting the tympanic membrane, but the behaviour of the ear as a recording device is so peculiar and differs to markedly from the behaviour of a mechanical device that it will be necessary to refer briefly to both the physiology and psychology of hearing. It is hardly worth while endeavouring to understand any problem in acoustics without previously trying to follow the part played by the ear.

So far the investigation has concerned itself mainly with the binaural form. With the monaural form similar but simpler problems arise.

Apart from acoustics the factors that control the design are mainly ease of application and portability.

The above is a list of the details involved in the problem of the stethoscope. We shall not deal with them all in particular but attempt rather to arrive at the general principles from which each may be readily solved.

……

METHODS AND MEANS BY WHICH THE PROBLEMS MAY BE STUDIED.

Acoustic problems in general like other branches of physics may be investigated.

(1) Experimentally.
(2) By a process of mathematical deduction.

Of the two methods the latter has hitherto been the more important and instructive.

Experimental methods are beset with unusual difficulties arising out of the fact that the energy associated with sonorous vibrations may be of extremely small dimensions. In consequence, sound delecting devices which are independent of the ear e.g. the vibration microphone are very crude in comparison with the delicacy of discrimination of the auditory apparatus. In stethoscopy these difficulties are still greater. The sounds in which we are mainly interested are of extreme feebleness, and though it may be safely anticipated that it will one day be possible to amplify these and study them by other means, at the present we have to be content with the natural ear as the means of detecting and measuring their effects. Experimental work in stethoscopy therefore reduces to listening to a given souce of sound with different instruments and comparing the effects. This method is open to the serious objection that there is a very large personal factor and that the consciousness of sound sensations is related to the external physical disturbances in a very intricate and variable manner.

Mathematical investigation in the hands of Helmholtz and Rayleigh has yeilded wonderfully exact results in the case of simpler problems, and has proved very suggestive and instructive in more complex ones. An analytical mathematical investigation however of the stethoscope is quite an impossibility. Rayleigh states that our knowledge of mathematics is not yet sufficient(26) to enable us to deal with general problems in sound.

It need only be mentioned that to follow the treatment of some of the simpler component problems would require a ready acquaintance with the calculus and differential equations, with something more than a working knowledge of analytical dynamics and some of the functions of Higher Analysis e.g. Bessel functions.

Dr. J.C. Blackwell therefore putting forward (27) the claims for his instrument that it is mathematically and physically correct can only be admired for his audacity.

But while it is impossible to give even an approximate mathematical treatment of any part of the stethoscope the results obtained for simple problems can be used to guide us to the general principles underlying its use.

The inclusion of mathematical work as an essential part of the argument would however at present be unjustifiable in a medical thesis. I have therefore rigorously excluded such with a few important exceptions, but even these can be entirely neglected without detriment to the understanding of the argument. The inclusion of mathematical reasoning would, I fear, necessitate its taking such a form as would, to borrow a phrase from a recent writer on RELATIVITY, while still making the medical man feel giddy would make the mathematician feel sick.

....

SOUND.

The word sound is commonly used in two different senses.

1. To denote the sensations perceived by the ear when the auditory nerves are stimulated.
2. To denote the external physical disturbances which under ordinary conditions suitably excite the auditory nerves.

It is rather important to keep this distinction in mind.

It is a matter of common knowledge that the source of sound is always a body in state of vibration. The body may be a solid e.g. the string of a violin, or a fluid e.g. a column of air in a wind instrument.

But in order to produce sound it is not sufficient to have some body in a state of vibration as its source. We require also, some medium to receive and transmit the vibratory motion, otherwise neither the sensation of sound nor the external disturbances would be present.

It is further imperative that the vibrating body should have such size, shape and motion as to cause a disturbance to advance through the medium and not merely such as to produce a local flow and reflow.

Our ear enables us to perceive the sensation of sound only when the frequencies of the vibrations lie within certain limits.

All sounds can be roughly classified into:-

(a) Tones.

(b) Noises.

At the extremes the distinction is well marked but there is no strict line of demarcation.

Tones are believed to arise from vibrations which are regular i.e. which can be represented by a periodic mathematical function, the simplest being a harmonic function. (Sine function).

Noises are not properly understood. They may possibly be produced (a) by vibrations occurring at irregular intervals, (b) by a succession of trains of regular vibrations each train being of very short duration.

Sound is propagated by a wave motion in the conducting medium, the characteristic of such motion being that there is no mass displacement of the medium. The individual particles of the medium vibrate through a small amplitude round their original undisturbed positions.

Sound waves in air are longitudinal i.e. the direction of propagation is the same as the line of motion.

Certain terms relating to vibrations require to be defined.

(1) Period. The time from the instant that a given point passes througha given position to the time when it passes through the same position moving in the same direction.

(2) Frequency. Number of vibrations per unit time.

(3) Amplitude. Maximum displacement of the particle during its cycle of motion.

(4) Phase. The state of displacement and motion at any instant in question.

All musical sounds are characterized by three features.

(1) Pitch. (2) Quality. (3) Intensity.

(1) Pitch depends upon the frequency of vibration.

(2) Intensity is a purely physical quantity independent of the ear. It is a measure of the wave energy passed per unit time through unit area.

Loudness is a different thing. It varies with intensity but in a very complex manner. It is partly subjective and is not capable of exact physical measurement.

(3) Quality is dependent upon the displacement and motion at each instant, and this is determined by the aggregation of overtones in association with the fundamental tone.

Any problem in acoustics therefore involves a study of

(1) Vibrating bodies and their possible rates of vibration.

(2) The propagation through air or other media of the disturbances which these vibrations generate.

(3) The reception of the vibratory disturbances and the effects produced by them.

A body in a state of vibration goes through periodic deformations from its normal undisturbed configuration, and our aim in endeavouring to understand the behaviour of any vibrating system is to be able to follow these successive deformations in configuration and the rates at which they take place. Analysed still further this comes down to appreciating the relative successive positions of adjacent particles of which the body is composed, the paths of their motion, and their velocity at any instant of time.

Vibrations in a medium we study from a different point of view. The medium does not vibrateas a whole. In this respect it differs from a vibrating system. We are simply concerned with the relative displacements and motions of adjacent local particles. The wave motion so to speak passes on through the medium

The study of the propagation of a wave motion through media requires a fair training in higher mathematics but Huyghen's introduced a valuable principle by means of which we can trace the wave front as it advances through the medium and by so doing we are able to gauge very approximately the actual condition of things.

The basis of his principle is this.

If a single particle of a medium be disturbed we obtain a wave motion radiating in the form of a circle or sphere according as we are dealing with the surface of a medium like water or a three dimensional problem as in air.

Successive outlines of the wave front (in first case) will then be represented by concentive circles, 1. 2. 3. fig.3.

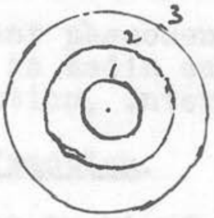


fig 3.

Now Huyghens' principle states that the wave front at any instant can be derived from a preceding wave front by considering each ~~wave~~ point on the preceding wave front to have become a centre of a point disturbance.

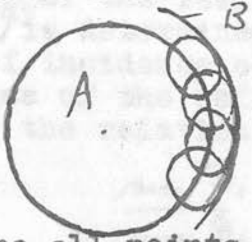


fig 4.

Thus if we imagine all points on circle A fig. 4 to become centres of disturbance, the new wave fronts derived from them would take the form of a series of circles of equal radii and centres lying on the circumference of A, and the envelope of all these small circles viz. the circle B becomes the new wave front of the original disturbance. This principle enables us to study many problems e.g. it demonstrates how sound coming through a small opening radiates into the surrounding space and is not propagated like light in a straight line.

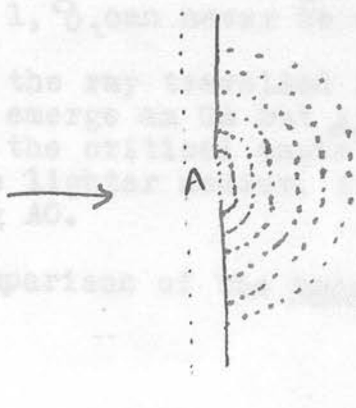


fig 5.

Thus if a plane wave arrives ~~in~~ at a small orifice A fig. 5. successive waves fronts will be as shown in sketch.

A simple application of this principle enables us to understand why sound is propagated without loss in tubes, no matter whether they be straight or curved. Huyghens' principle is not simply a conventional concept. The photographs in Professor C.V. Boys' experiments show that it has a sound physical basis. (28)

Four important phenomena associated with the propagation of sound in media call for special notice viz. Reflection, Refraction, Interferance, Diffraction.

Reflection and Refraction.

When a ray of light in air falls upon the surface of a volume of still water part of it is reflected back into the air and part of it is refracted into the water.

In the case of the reflected part the direction of the reflected ray is determined by the simple relation that the angle of incidence equals the angle of reflection. In the case of the refracted ray its direction is determined by the relation.

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\mu_2}{\mu_1}$$

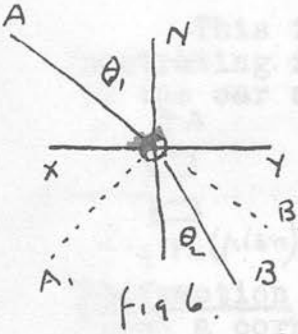


fig 6.

When θ_1 is the angle which the incident ray AO makes with the normal NO, and θ_2 is the similar angle for the refracted ray OB. μ_1 and μ_2 being the refractive indices in air and water.

$$\text{i.e.}\quad \sin\theta_1 = \frac{\mu_2}{\mu_1}\sin\theta_2$$

Now sin θ_1 cannot be greater than 1 and as $\frac{\mu_2}{\mu_1}$ is greater than 1, θ_2 can never be a right angle.

Now if the ray travelled in the reverse direction BO, it would emerge as OA but if the angle θ_2 were greater than the critical angle e.g. BO, ~~e.g.~~ then none could emerge to the lighter medium; it would be totally reflected along AO.

The comparison of the amount of energy reflected with that refracted is a more difficult problem. The amount refracted is greater the nearer the incident ray approximates to the normal.

Experimental work in sound demonstrates that when sound waves produced is one medium fall upon the surface of a second medium of markedly different density e.g. air and water, practically total reflection takes place even when the angle of incidence is in the line of the normal, and it is doubtful indeed if the part refracted persists at all to any depth as a wave motion in the second medium. As will be shown later, the transmission of sound through the walls of a closed room is not to be explained by refraction but by the variation in pressure over an extended area of surface setting the walls into molar motion.

Interference. Physicists object to this term as a misnomer. When we are dealing with more than a single train of waves in any medium, the motion and displacement of any article at any instant is obtained by summating in the extended geometrical sense, the motions of the practicle under the influence of each disturbance in the absence of the others. It may so happen that this gives a constantly zero value to the motion of a particular particle or (for practical purpose) of a localised area of the medium, in which case no sensation of sound can be obtained from that area.

This is called Interference. A simple way of illustrating it is to hold a vibrating tuning fork close to the ear and turn it through an angle of 90^0.

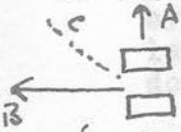


fig 7. (plan)

Two sets of waves emanate from ~~which~~ such a fork, one in direction A, the other in direction B; they interfere along the line C.

Diffraction is the term applied to the bending of waves round a corner.

It is a very marked phenomenon in the realm of sound in contrast to light. The explanation hinges on the magnitude of the wave lengths.

……………………

SOUND SENSATION AND HEARING.

The final appeal in all questions of sound must necessarily be to the ear. It is therefore expedient in dealing with any problem in acoustics to have in mind the phenomena of hearing. This is the more important because of the indirect and variable relationship between physical disturbances and the conscious appreciation of the sensations they produce. Loudness and intensity for example are very different things.

Theories of hearing however are very involved, and for our purpose we shall have to be content with the brief reference mainly to the phenomena that are of importance in stethoscopy.

(1) Noises and tones.

As already atated the whole range of auditory sensations can be devided up into two great groups, tones and noises.

The psychological definition of noises (29)
(according to Watt) is that they are auditory masses characterised by extreme departure from the regularity and balance of tones, this departure from regularity of mass being attainable by various means especially by the rapid oscillation of vibration rates, by which means the dominance of pitch is more or less obliterated.

(2) Analysis of Complex Sounds.

This is undoubtedly one of the most remarkable properties of the mechanism of hearing and in conjunction with the phenomena of attention constitutes the basis of that great dictum "Choose your stethoscope and stick to it."

Simultaneious vibrations in any medium gave a compound wave form, and if this compound wave form be made visible by one of the optical methods in common use, a complex outline is obtained from which the eye cannot recognise the prime constituents. But if two notes be sounded together say

C and G the ear recognises their individual presence, though, depending on the interval a certain amount of fusion may take place, the one note appearing to run through the other. Only in the case of octaves does fusion become so marked as to render it difficult to appreciate the presence of bitonal mass.

This analytical property becomes exceedingly marvellous when we consider how the ear is able to recognise and identify individually a whole range of different sounds simultaneously Somewhere between the external air and consciousness there must be a mechanism for resolving the complex wave impulse received upon the tympanic membrane.

Numerous theories have been proposed to explain this analytical power especially since the work of Bowman Corti and Helmholtz, but all with the exception perhaps of Sir Thomas Wrightson's must be considered to be more or less guess work.

The hitherto most popular theory has been that put forward by Helmholtz. He approached the subject from the point of view of the physicist. Being acquainted in physics with no other mechanism besides that of selective resonance for the analysis of complex sounds, he assumed that the Organ of Corti must represent a very elaborate series of resonators, The theory is plausible , but only in so far as one is ignorant of the structure of the internal ear. Various modifications have from time to time been suggested, but it is difficult for the physiologist to accept and be satisfied with any one of them. Others have assumed analysis to be entirely a cerebral process. This does not get over the difficulty, and it is in any case hard to understand such a complex structure as the Organ of Corti without ascribing to it morethan the function of being excited by sound vibrations.

Sir Thomas Wrightson in 1918 published a new theory an Impulse theory. He made a study by a mechanical piece of apparatus of the complex wave derived by compounding two simple harmonic curves.

From certain points on the complex curves, (maxima and minima and crossing points) he found he was able to derive the primes. He then showed that these points could correspond to impulses on the hairlets in contact with the membrana tectoria. One of the best features of the volume is that the second half comprises an appendix by Keith on the anatomy of the ear. This is an excellent work for Keith besides adding to the common stock of knowledge by personal observation has studied the minute details of the internal ear from the functional rather than the architectural point of view.

But this analysis is limited in both directions. On the one hand it is seldom carried so far as to recognise the constituent vibrations of which a complex sound is composed. We stop short at sound masses, molecules so to speak. Thus in the street we recognise each more or less as a unit, the rumble of the car, the clatter of a horse's hoofs, the hoot of a motor etc., and for obvious utilitarian reasons do not seek to analyse them further. On the other hand when the number of sources becomes very great we are no longer able to identify each individually e.g. the babble of voices of a large assembly of people. Interesting as all this is however, I must rest content with pointing out that in virtue of these observations we can hardly expect to arrive at the same conclusions in regard to the stethoscope as we would if the place of the ear were taken by a recording device.

III Attention.

Hardly less important and wonderful is the ability we possess of attending more or less exclusively to one particular source out of a conglomeration of sounds. This is obviously a matter of great interest in auscultation. It must necessarily be purely a cerebral function, and is capable of marked development by education. For this reason an instrument is not to be condemned because it adds adventitious elements.

We can learn to read faint sounds through more intense ones, a problem that often confronts the wireless telegraphist, and we may be able ultimately to hear sounds that we specially wish to recognise better with an instrument that is guilty of adding adventitious sounds either by way of sympathetic vibrations or otherwise, than with an instrument designed to exclude such foreign elements, but which in consequense of its design renders the sounds we wish to detect very faint. Of course it should be noted that faint sounds are normally heard best in the absence of other sounds. This is easily understood if the volume of two sources can be considered additive, for when we have a satisfactory means of measuring intensity Weber's law will probably be found to hold good.

Sound Direction.

Localisation of the source of sound is apparently dependent on a variety of factors but is relatively poorly developed. In the normal individual it appears in some measure to be dependent on the sense of sight, or perhaps it is better to state that the eye partly usurps the place of the ear; for when we see the vibrating body giving rise to the sound we no longer require the aid of the ear for localisation. This explains the better development of direction finding in the blind.

The part played by the auricle has not been completely evaluated. That it plays some part is obvious from the fact that sounds are heard better from in front than from behind. The most obvious explanation is the angle at which the auricle is inclined to the head.

Intensity and phase difference are probably the only other important factors. Variation in intensity can only be due to the shadow cast by the head. A sound coming from the right would affect the right tympanic membrane more intensely than the left. The vibrations of the left membrane would also be slightly retarded in phase as compared with the right and there is an interesting observation which would lead us to attach considerable importance to the difference of phase.

When we listen to a sound of moderate intensity with a binaural stethoscope in which the limbs are of equal length we hear the sound equally in both ears. If now one limb be gradually lengthened the degree of loudness in the corresponding ear becomes markedly diminished and finally is heard only in the ear connected with the shorter limb. Moreover when the limbs are equally the sound is referred to the chest piece as originating there; when,one tube is longer than the other it appears to have its source in the ear itself. These phenomena are presumable cerebral manifestations intimately connected with the mechanism of projection and orientation. They were applied during the war to the problem of sound direction in sea water.

THE ACOUSTICS OF THE EXTERNAL EAR.

While is is necessary to have an intimate knowledge of the mechanism of the hearing apparatus internal to the tympanic membrane if we wish to appreciate what is involved in the study of any problem in acoustics, in Stethoscopy we are really more specially interested in the external ear owing to the manner in which the instrument has to be applied to the auricle.

The external ear consists acoustically of two parts, the auricle, which subserves several functions, and the meatus -- a conducting tube closed internally by a membrane to which it conducts the aerial vibrations.

The acoustics of this part of the auditory apparatus has not received a great deal of scientific attention. This is natural on account of its relative unimportance in contrast to the structure of the internal and middle ear. Its main functions however can be readily surmised.

The meatus is essentially a curved tube measured from the bottom of the concha it is about one inch long. Its cross section varies at different parts but the variation has no acoustical significance. It is simply for sound reception purposes, a short curved cylinder. On account of its shortness in comparison with the length of the waves of auditory vibrations the aerial vibrations entering the open end may be considered as impinging unaltered upon the tympanic membrane.

The extreme delicacy of the Organ of Corti renders it essential that it should be carefully isolated from all likely sources of injury. The tympanic membrane with the ear ossicles froms a very delicately balanced vibrating system of small inertia which also requires protection. These are obviously the reasons for a conducting meatus.

The curving of the meatus must be looked upon as a further protective device against possible injury from the entrance of foriegn bodies.

In dealing then with the problem of the binaural stethoscope with earpieces that fit into the meatus, full account would be taken of the meatus by considering the tubes to be corresponding lengthened.

The auricle is a very irregular structure. Various claims have been put forward for it e.g.

(1) It acts as a sound collector.

(2) It assists in determining direction.

(3) The various elevations and depressions are concerned in the clear preception of sounds.(31) (J. Williams).

In the first place we note that the tragus is obviously a further protective device against the entrance of foriegn bodies and the reason for the cavum conchae follows at once when we appreciate the part played by the tragus. The auricles are inclined at an angle of about 30° to the side of the head. Looked at from the front we can see both projecting and we see that the antihelix projecting more laterally than the tragus must assist in concentrating the sound waves and reflecting them into the meatus. We commonly see this mechanism enhanced by the use of the hand as a reflector in those who are partially deaf. The part distal to the antihelix plays a subsidiary function. In some cases the angle it makes with the normal to the entrance of the meatus is such that it cannot act as a collector at all, any vibrations it receives being reflected away from the meatus

....

The human ear has undergone great morphological changes. Few races now possess the power of voluntary movement and it is difficult to see that the structural details of the auricle can subserve an acoustic purpose. Moreover the great variety of auricles among different mammals makes it presumptive that any such function as rendering the sounds "clear" is highly improbable.

But at any rate we may well agree that the effective receptive area of the auricle must give an effect tantamount multiplying several times the diameter of the meatus. As a direction finder various attributes have been postulated for the auricle based upon its action as a collecting device, and the relative spatial positions and inclination of the two auricles. It is believed with apparent good reason that the bilateral use of the ears enables us to project our sound sensations and locate the source.

This may in part be due to the difference in intensities, the head causing a sound shadow. Weight is given to this assumption by the simple experiment of trying to locate a source of sound with the eyes blindfolded. If one ear be aided by using the hand as a reflector the direction indicated is altered in such a way as to bring the source of sound nearer the assisted ear.

The suggestion made by J. Williams can only be given for what it is worth. There is no logical reason why the external disturbances should have to undergo such a modification. The reason why we perceive sounds unaccompanied by the tinnyness of the gramaphone means that the vibrations arriving at the ear undergo no relative changes in their constituent primes. The mechanism of the middle ear including the diaphragm appears to act as a perfect vibrator - dead beat, and not responding unduly to certain frequences.

We are now in a position to consider the problems that arise in connection with the application of the ear pieces to the auricle.

……………………………

BONE CONDUCTION.

The question of Bone Conduction has considerable interest for the Stethoscop~~e~~IST more especially in connection with the use of the monaural form.

In the normal mechanism of hearing the part played by bone conduction is relatively small, and the contribution it gives to the normal sound sensation is probably negligible.

Such a result is due to the well known difficulty with which ~~sonorous~~ SOUND IS refracted from one medium to another differing so widely in their mechanical properties as air and bone. The interface between the media acts as an almost perfect reflector.

When however a vibrating body is placed in direct contact with the cranium, the craniun is directly forced to vibrate; transference of energy takes place readily, and bone conduction becomes an important consideration.

The mechanism of bone conduction is still a matter of speculation. Prior to the publication of Sir Thomas Wrightson's work when the resonator action of the elements of the organ of Corti was still commonly accepted, the general impression appears to have been that the cochlear walls were responsible for setting up a wave disturbance in the perilymph and endolymph, and that such wave disturbance being propagated like an ordinary wave motion in a fluid medium directly affected the vibrating elements of the organ of Corti.

Keith and Wrightson however have been led to form a different and more plausible conception. They imagine the motion of the perilymph and endolymph to consist of a mass displacement as if it were a rigid body this on account of the small volume of the fluid.

They think the process essentially different from a simple propagated wave disturbance. Such molar motion would be impossible in a closed unyielding chamber, so against the motion of the stapes they conceive the fenestra rotunda set to permit of such a mass movement of the fluid.

Keith quotes an interesting phenomenon seeming to lend weight to his argument, viz. that bone conduction is improved by anything that interferes with the motion of the stapes. The explanation is tolerable obvious. A rigid stapes leaves only the fenestra rotunda as the yielding structure permitting as in normal hearing motion of the fluid, The vibrations of the cochlear walls taking the place of the vibrating stapes.

When both stapes and ferestra rotunda are free to move, owing to their respective anatomical situations relief is found for the compression to which the cochlear walls subject the enclosed fluid without involving molar motion of the fluid past the elements of the organ of Corti to the same extent as when the stapes is rigid.

The increase in bone conduction consequent upon occluding the external meatus is a fact of similar significance. This has been called an artificial lesion of the sound conducting apparatus, and the phenomenon brought under the well known Weber's test for such lesions

The manner in which occlusion of the meatus interferes with the motion of the stapes can be illustrated by the simple experiment of

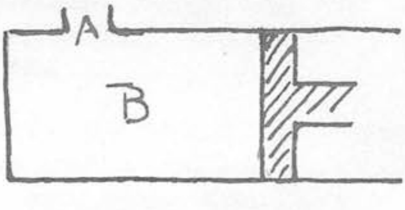


fig 8

a piston moving in a closed cylinder fig. 8. If the air chamber B is closed the pressure very rapidly rises and resists the motion of the piston, but if a free communication be established with the external atmosphere as at A a much greater motion of the piston takes place for a given applied force.

These facts and illustrations have some significance as we shall see when we come to consider the application of the ear piece to the ear

---

THE APPLICATION OF THE STETHOSCOPE TO THE EAR.

Up to the present the stethoscope has been applied to the ear in one of two general forms viz. either as a disc applied to the auricle as in the monaural form or as a knob inserted into the meatus.

We have to enquire as to which of these results in more faithful and better transmission; and whether any alternative modification can be suggested.

Of all possible devices we might make three classes:

1. Instruments which do not make contact with the ear.
2. Instruments applied over the auricle like the earpiece of the monaural type, or like a pair of head phones.
3. Intramental earpieces.

I think there is good reason to suppose (2) and (3) and especially (3) somewhat interferes with the normal mechanism of hearing. The introduction of intramental earpieces besides somewhat distracting the attention by their presence acts as a slight partial obstruction and may be looked upon as a variation from the normal mode of reception equivalent to a slight lesion of the sound conducting apparatus.

Somewhat similar reasoning may be applied to the disc form applied to the auricle. The closed chamber formed by the cavum conchae altering the normal mode of application of the external disturbances impinging on the tympanic membrane.

Instruments of the first class are so far represented only by the apparatus built up of amplifying valves and a loud speaker. Assuming absolutely faithful reproduction they would have the advantage of imitating more closely the normal mechanism of hearing. They have the disadvantage that they domot exclude external sound. It is obvious that no direct device can fall in this class, an accessory intermediate source of energy being essential to bring up the intensity. There is nothing more to be

fig10

said about these at present. It remains for the future to see them developed and introduced into general use.

As regards the choice between the other two classes. The diameter of the conducting tubes of the stethoscope can be definitely fixed as far as their upper limit is concerned. Practical considerations have in general limited the internal diameter of the chestpiece to 2.5cms. This entails an upper limit of 1.8cms for the diameter of the conducting tubes, for as seen elsewhere, no reflection takes place at the division of the air chamber into the two conducting tubes provided the combined cross section of the tubes equals that of the chestpiece.

The meatus is only .9cms in diameter, so the choice between (2) and (3) depends on whether it is better to reduce the tubes sufficiently to make their column of air continuous with that in the meatus viz. by using intrameatal earpieces, or to keep the diameter of the tubes throughout at 1.8cms and allow the cavum conchae to do its usual work as a sound collector. This would involve using a disc earpiece as illustrated in diagram

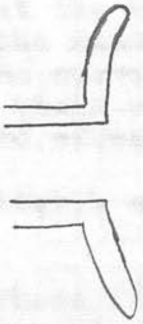


fig 9

It will be obvious that no good purpose can be served by expanding the proximal end of the tubes to allow for example of a conical earpiece to be applied over the auricle.

I have experimented with the casing of a pair of head phones fig. 10 introducing the conducting tubes into the metal casing as shown in figure.

fig 10.

The expanded end I find means a tremendous reduction in intensity.

The main objection to the use of the intrameatal form is the awkward interference in the normal mechanism of hearing. We become aware as it were of a foreign body in the meatus. It distracts our attention and interferes with the normal sense perception.

A form devised along the lines indicated in fig.(9) above would suffer less from these disadvantages. On the other hand, (1) it would not exclude extraneous sounds so well, (2) the application of such a form to the auricle with comfort so as to make a complete closed air chamber is difficult so that a certain amount of lateral radiation must follow, and (3) the intrameatal form gives a greater pressure variation in the air column of the meatus and so louder signals.

INTRAMEATAL EARPIECES.

If earpieces for insertion into the meatus are to be used the conditions which determine their construction are readily known. The size of the earpiece is obviously controlled by the size of the meatus. It is absolutely essential that they should fit comfortably. They should be so inclined that the normal to the end area lies in the direction of the meatus when inserted. This is provided for by the curving of the metal tubes now in common use, while their union by spring bands facilitates their adjustment to effect an easy fit.

A common suitable shape is shown in figure (11)

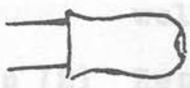


fig 11

These fit comfortably into the enlarged outer end of the meatus. They are best made of some bad conduct~~ion~~ors of heat for the auscultator's comfort. Rubber ones are preferred by some but these seem to increase the sense of a foreign body in the meatus.

A cross section should show the internal bore as in figure (12).

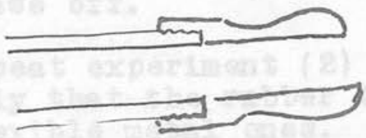


fig 12.

In the specimens I have examined I find an almost invariable fault shown in Fig. (13).

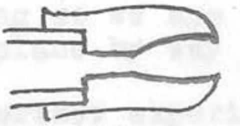


fig 13.

There is no reason why the diameter should be so constricted, and the constriction must, if only to a slight extent diminish the intensity of the received signals.

But there is another important factor in connection with the insertion of earpieces into the meatus viz. so called "bone conduction". For reasons that will appear in the course of the argument I am of the opinion that bone conduction as applied to stethoscopy is largely a misnomer. From experiments here described it will appear that the mechanism of the transference of sound energy from the earpieces other than by the medium of the air in the meatus and thence to the tympanic membrane is not chiefly by way of bone conduction but by the meatal walls to the apparatus of the middle ear.

Exp (1) Using a binaural stehtoscope with rubber conducting tubes apply the chestpiece to a watch making contact. The tick of the watch is heard well and loudly.

Exp (2) Repeat the same experiment but block the earpieces with plasticene. Nothing is heard.

Rubber tubes have been seen elsewhere to be very bad conductors of sound so that in these two experiments we are entirely dependent on the vibrations in the enclosed column of air, and the plug of plasticene completely cuts these off.

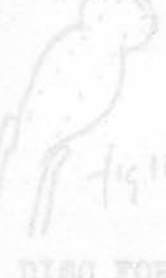


fig 14

Exp (3) Repeat experiment (2) with this difference only that the rubber tubes are replaced by flexible metal ones. The ticking is again heard as loud as in experiment (1).

These experiments demonstrate incidentally the advantage of metal conducting tubes. It is plain that the sensations perceived in experiment (3) depend on direct conduction to the earpieces by the metal tubes. Now it is clearly highly improbable that the earpiece blocked by a mass of plasticene can directly set the air in the maetus vibrating so we are left to conclude that transmission takes place by way of the meatal walls.

If the further experiment of applying the earpieces firmly against the zygoma be tried (using metal tubes) the sounds are either very faint or inaudible. The same is found if the metal tubes be held firmly between the teeth but if the earpieces be applied around the tragus the sounds remain relatively loud.

I think then the so called "bone conduction") even in the monaural wooden stethoscope, is really in large measure conduction by the meatal walls to the middle ear apparatus, and thence by the motion of the stapes as in normal hearing,not as in true bone conduction to the bony wall of the cochlea.

Furhter interesting experiments on the question of "Pseudo Bone Conduction" in stethoscopy can be carried out by a tuning fork. If, while it is vibrating too feebly to be detected by the usual bone conduction method in Weber's test, but still audible by air conduction one inserts the end into the cavum conchae, a marked increase in loudness results on touching the walls of the cavum with the base of the fork.

Vibrations too feeble to be detected by applying the fork to the mastoid can still be detected by this means.

fig 14

Earpieces without a metal spring and directly attached to the rubber tubes as shown in sketch fig. 14 are preferred by some. The point against them is that they require to be pushed further into the meatus to secure them and enable them to bear the weight of the attached tubes. Their easy portability is their most obvious special merit.

DISC FORM OF EARPIECE.

The disc form of earpiece is practically now only represented by the monaural stethoscope. I have already referrd to the possibility of using it with the binaural form and what its advantages under this use would be.

The use of the flattened earpiece with the rigid stem as in the monaural stethoscope is quite a different problem from its use with flexible tubes. In the monaural stethoscope the whole instrument vibrates and the flattened earpiece moves like a vibrating disc, so that when to the auricle it sets the air enclosed between it and the base of the cavum vibrating. It is worthy of note that to better use this fact the earpiece is usually hollowed out as shown in sketch.

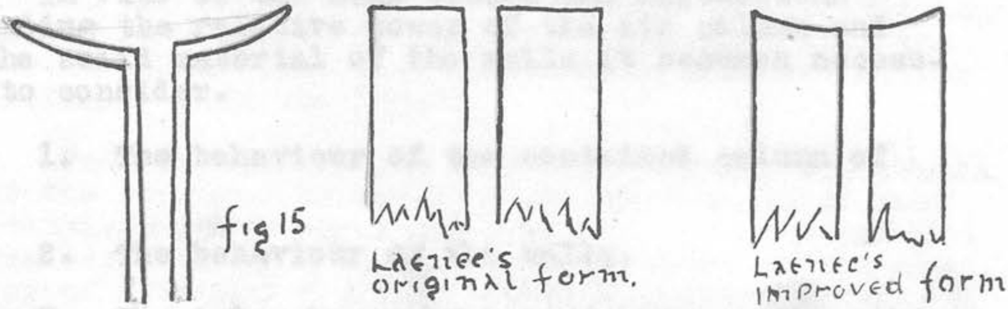


fig 15

Laenec himself first used a flat type. The hollowed out type was specially designed by him for the benefit of a distinguished English Physician Sir Charles Scudamore who was unable to hear well with the flattened form owing to the peculiarity of his auricle.

Note:- Since writing this article I find that the flat earpiece as applied to the financial stethoscope has been recently introduced to the notice of the profession by Dr. A.F.G. Spinks (Newcastle-on-Tyne) B.M.J. March 13/26 (See appendix last print).

The suggestion is not new however. Thiswas the form Dr. C.J.B. williams used nearly a hundred years ago.

....

VIBRATIONS IN TUBES.

The theory of the propagation of sound in tubes is a subject of considerable interest in the application of both the monaural and binaural forms of the stethoscope.

In view of the many claims and discussions regarding the relative power of the air column and of the solid material of the walls it becomes necessary to consider.

1. The behaviour of the contained column of air.

2. The behaviour of the walls.

3. The interchange of energy between the vibrating systems constituted by the contained column of air and that formed by the solid walls.

The behaviour of the contained column of air. This part of the subject has many illustrations and applications in physics e.g. the theory of the organ pipe. There are really two problems to consider. (1). The propagation of a train of waves along an enclosed column of air (2). Stationary waves.

In a subsequent chapter on the behaviour of the enclosed mass of air in the chest piece an entirely different method is used. There it will be seen that no progress can be made by trying to follow the course of a sound wave in the contained air. In the case of tubes however the behaviour of the air is the same at all points along the column so that the only rational method is to regard the waves as passing along from one end to the other.

Following Rayleigh Vol. ii 44, consider first a vibration in one plane. Suppose a cylindrical surface be introduced with its axis in the line of propagation, no disturbance would be caused for the air has no tendency to move across the cylindrical surface.

Consequently the conditions of vibration in the cylinder depend only on the mechanical conditions at its end.

This is the simplest possible case viz. the propagation of a plane wave along a straight tube.

Suppose now that the incident wave be not plane but of any form whatever. In nature and in auscultation in particular the wave form must be very complicated and asymmetrical. If we make the restriction that the wave length is large in comparison with the diameter of the tube then the problem does not differ essentially from the former.

For the area of the tube being small, all points over the end must be sensibly in the same phase and of sensibly equal amplitude i.e. we can consider ourselves dealing with a plane wave which in the absence of friction would be propagated without loss along the column of air, the condition of its propagation being determined by the mechanical conditions at the ends of the tube.

This leads to the conclusion as Rayleigh demonstrates that, subject to certain assumptions, sound waves are propagated along a straight tube without loss in intensity or alteration in form. The assumptions are,

(1) The diameter of the tube is small in comparison with the wave length.
(2) Perfect reflection from the walls of the tube.
(3) No surface friction between the air and the walls of the tube. All of which assumptions are very approximately true in stethoscopy.

In 1837 Mr. Barratt very ingeniously endeavoured to design a stethoscope along mathematical lines. He suggested for the chest piece a paraboloid, and for the stem an ellipsoid. (32)

The focus of the paraboloid was to coincide with one of the foci of the ellipsoid, and the other focus with the air exit applied to the ear. He was apparently working on the analogy of light in which the essential condition viz. the length of the waves relative to the size of the reflector is essentially different. This fallacy vitiates the argument. Such an ellipsoid would have to be of impossibly large dimensions in order to obtain an appreciable concentration at the focus. In any case the intensity at the second focus could not exceed that at the first i.e. the best it could do would be to propagate without loss, a condition readily satisfied by a simple tube.

The case of a curved tube has also received rigorous mathematical treatment at the hands of Rayleigh. He demonstrates that the curving makes no sensible difference.

In the thirties when a flexible stethoscope was first suggested a great deal of discussion arose over this point. Strong objection was raised that a bent tube would not conduct the sound so well as a straight one.

The underlying concept that formed the basis of this mistaken idea was again the analogy with the propagation of light.

The important facts arising when the tube length bears a definite relation to the wave length of the transmitted vibrations will be considered later in the article on "Resonance in Tubes".

Another point to be noted before concluding this section is that where a tube bifurcates no reflection takes place at the bifurcation provided the cross section of the tube equals the combined section of the tubes into which it is divided.

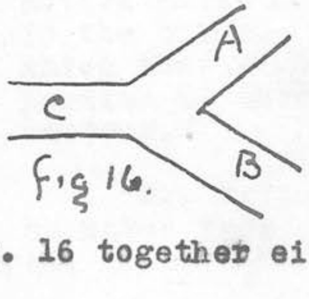


Fig 16.

This point seems to have generally escaped notice. All the Y pieces in common use having the three limbs of equal bore. Reflection takes place when the area of A and B fig. 16 together either exceeds or is less than C.

If they exceed, a wave of rarefaction arises, if less a wave of condensation.

Of course we must not be oblivious to the fact that because of the small dimensions of the instrument in relation to the sound waves all these points are of minor significance.

"CONDUCTION" OF THE TUBE WALL AND THE ENERGY INTERCHANGE BETWEEN TUBE WALL AND CONTAINED COLUMN OF AIR.

This section of our subject was thoroughly thrashed out as early as the middle of the last century.

Quite by accident Laenec discovered that a solid stethoscope did not record so well as one with a central perforation. In his original experiments he had looked about for a solid body but had been obliged to improvise one by rolling up a quire of paper. He could not do this without leaving a perforation, an accident that put him on the right lines. Laenec himself experimented with a variety of materials and from his time to the middle of the century every conceivable convenient material has been tried.

In 1850 Dr. Herbert Davies who along with Dr. (33) C.J.B. Williams was among the leading men in stethoscopy in his time published a lecture containing a record of some interesting and conclusive experiments.

Up to that time the majority of writers following the opinion of Dr. Williams ascribed the active power of the instrument (the monaural type) to the column of air contained in the interior which they supposed to be set in vibration by the portion of chest area included within its bounding contour.

Dr. Davies's experiments and the deductions he makes from them are well worthy of being recalled.

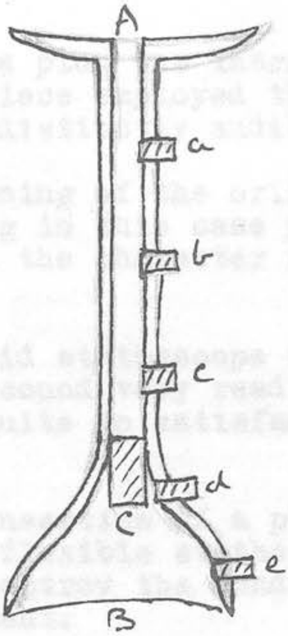


fig 17

The diagram illustrates the instrument he used and explains his experiments.

Exp.1. The holes being closed by small wooden pegs the instrument becoming a common hollow stethoscope conveyed when placed over a healthy chest a free and distinct respiratory murmur to the ear.

Exp.2. The holes being opened one by one the murmur became gradually and when all the orifices were opened remarkably dimimished in its distinctness and fullness. A weak murmur did not reach the ear.

Exp.3. The insertion of a plug into the shaft in C only slightly impaired the distinctness of the murmur.

Exp.4. The plug remaining in the instrument, a remarkable diminution in the intensity of the sound followed upon the removal of the small plugs.

Exp.5. When a plug was introduced at A or a solid ear piece employed the corresponding sound became distinctly audible.

The opening of the orifices and the closure of B by a plug in this case produced little or ne difference in the character or intensity of the sound.

Exp.6. A solid stethoscope was found to communicate sound very readily to the ear although not quite so satisfactorily as the ordinary form.

Exp.7. The insertion of a plug into the chest end of a flexible stethoscope impaired ~~and~~ but did not destroy the conducting power of the instrument.

Davies's conclusion from these experiments are,

(1) That the conducting power principally depends upon the column of air confined in its interior, for the opening of the holes in the shaft by allowing the divergence of the vibrations, (radiation of energy to the external atmosphere) reduced by a corresponding amount the energy passed on to the tympanic membrane.

(2) That the central column of air is not chiefly set into vibration by the portion of the chest wall included under the hollow end of the instrument for a thick plug introduced into the lower end of the shaft only slightly impaired the conducting power of the stethoscope.

(3) That the enclosed column of air can only owe its vibrations to thosevwhich are communicated to it from the solid parts surrounding it, and that the sounds of the chest are therefore in the first instance propagated through the wood to the air within the tubes, and thence by reason of the continuity of the column of air into the interior of the external ear.

The experiments are extremely interesting and instructive but they force us to get down to the minute details of sound vibrations in endeavouring to understand the basal facts involved. It will repay to confine our attention for the moment to the monaural form.

Of the great variety of materials metal, compressed gold beaters skin, bone, wood of various kinds, ebonite, a preference seems soon to have been formed for those made of light cedar or pine wood. The value of the acoustic properties of such wood is seen in the preference of pine for the sounding board of the violin. The secret appears to be in the long straight fibres.

To take first the simplest case of conduction in solid material consider the use of a solid rod of wood as in stethoscope. This is found to enable us to auscultate louder sounds but is very much inferior to the perforated rod for weaker sounds.

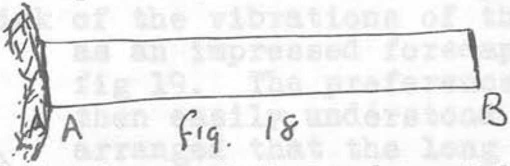


fig. 18

The behaviour of the rod must be considered to be either a simple propagation of a compression and rarefaction of adjacent thin lamina of which it may be supposed to be formed; or the whole rod may to supposed to execute molar vibrations in the direction A B fig 18; or again it may be considered to behave exactly as a column of air would do (see article on vibrations in tubes), all of which ideas of course are the same thing. The relative conducting properties of rods of different material will depend mainly upon the relation between the stresses and strains associated with the vibrations. The presence of a formed structure like the fibres of wood considerably modify this relation.

In the case of the rod shaped, hollowed, and perforated to form the common monaural form, the setting up of vibrations in the contained column of air entails its being subjected to alternate compressions and rarefactions.

If as Davies's experiments seem to show, the column of air owes its motion in part to the vibration of the solid walls of the tubes, then these walls must vibrate in such a way as to cause the required compression and rarefaction.

This may be affected in at least two possible ways.

(1) Longitudinal vibrations similar to those in the solid rod entail compression and rarefactions of the segmemtal elements of which the tube may be conceived to be formed and these cause a reduction and increase in the diameter of the air column, so that the air is subjected to a lateral compression.

More probably however the walls of the tube vibrate transversely as well. The generation of such transverse vibrations is easily understood when we think of the vibrations of the chest walls as an impressed force applied at A fig 19. The preference for wood is then easily understood if it be so arranged that the long fibres are distributed more or less longitudinally along the walls of the tube.

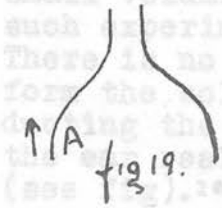


fig 19.

Returning now to the consideration of the binaural form with rubber tubes.

From a few simple experiments it is easy to demonstrate that the part played by the rubber tubes in the conduction of auscultation signs is negligible.

If we listen to a moderately loud sound and compress the tubes occluding the bore, practically the whole of the sound is cut off no matter where the tubes are occluded. Norris and Landis point (34) out that it is not a matter of indifference what thickness of rubber be used, but I am inclined to think the part they play is of very minor significance.

The reason for this lies of course in the very low modulus of elasticity possessed by the rubber. The alterations in volume for given stresses are very large and there is a very heavy dissipation of energy in the substance of the rubber.

Rubber tubes were ~~tubes were~~ introduced because of their convenience and the only part they play acoustically is that they form the boundary walls of the tube and prevent lateral radiation.

The possibilities as regards the utilisation of the tube walls for their conducting properties are best illustrated in flexible metal tubes. I have experimented with one such and find that by occluding the lumen at either end ~~or~~ the sounds are not entirely cut off, in fact the solid parts contribute a very definite element to the volume of sound.

I am inclined to think that Davies's makes too much of the transmission of vibrations from the tube walls to the contained air. We have no satisfactory means of measuring the intensity of small volumes of sound and the personal bias in such experiments as he conducted is very great. There is no question that in the simple monaural form the solid material plays a large part in conducting the sounds. The flattened end applied to the ear really acts as a kind of vibrating Disc (see fig).20

So open to question is the relative conducting power of air column and walls that we find a record of a great argument in 1869 between Dr. Niemeyer of Madgeburg and Dr. Sommerbrodt of Breslau on this point. (35) It may have occurred to the reader that if the tubes are of flexible metal and contribute a large part to the transmitted sound they may, by conducting more rapidly than the air column alter the character of the sound. For short waves indeed, the difference in the velocity of propagation would be such that the element due to the conduction by the tube walls might be half a wave length in advance of those coming from the column of air and we might expect these to interfere.

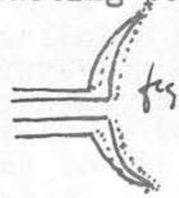


fig 20

This is not so. Helmhotz demonstrated that in a compound vibration no alteration is caused in the sense perceptions by altering the phase of one vibration relative to another.

Such a shifting of phase studied in the light of Sir T. Wrightson's compound diagrams makes a very great difference in the form of the compound wave, but the ear does not appear to take cognisance of the wave form, but only of intervals corresponding to wave lengths.

……………………

PULMONARY ACOUSTIC PHENOMENA.

The nature of the physical disturbances within the tissues giving rise to auditory signs and the mechanism of their transmission to the surface of the body have been subjects of never ending enquiry since before the invention of the Stethoscope.

The most distinguished worker in early days was Skoda of Vienna, whose labours did much towards placing auscultation on a sound scientific basis. Yet even now after the lapse of over 80 years the fallacies that were current in his time have not been completely eradicated from present day teaching.

Discussion and debates have for the most part centred around pulmonary acoustic phenomena any theory which would satisfactorily explain these being capable of easy modification to be of general applicability.

The study of the literature of the subject brings out one great central fact viz. that practically the whole difficulty arises out of our inability to grasp from want either of sound philosophical or experimental demonstration the exact physical concepts as to the actual and relative motions of the particles of which the tissues are composed.

In physics, problems so far investigated have been concerned with structures in which it is possible to form a more or less clear visual image of the motion of the particles of the vibrating system. Bodies in state of vibration have been relatively simple structures such as strings, columns of air, bells, thin discs etc., and the study of the propagation of sound has generally been limited to cases of isotropic conducting media, e.g. air and water,

Such a clear visual concept is almost a primary necessity for the physicist in order that he may be able to write down the equations from which the motion is to be deduced.

In the thorax and its contents however we have a structure, which, if it be regarded as a vibrating system is so extremely complex that it is difficult to arrive at even an approximate idea of its behaviour.

If on the other hand we accept the popular motion of vibrations being "conducted" through the lung tissue, our terminology itself implies that we think of the lungs not as a vibrating system, but as a medium through which the disturbances are propagated as a wave motion just as sound is propagated in the open air.

Now if it could be decided which of these fundamental concepts is correct under any given set of conditions we should be able to correlate completely pathological findings with physical signs.

Let us recall the precise difference between a vibrating system (a body vibrating as a whole) and the transmission of vibrations in a medium.

The case can be well illustrated by considering the organ pipe.

The column of air in the pipe forms a vibrating system. It is a mass of air in a state of vibration as a whole the waves radiating through the surrounding air form an instance propagation in a medium.

In the latter case if we could visualise a circumscribed space and observe the motion of the air particles within its confines, we should note that each successive particle took on the motion of the preceeding one; in other words, if at any given instant we fix our attention on a given particle, the particle in front of it would be a little behind it in the phase of its motion, the particle behind would be a little in advance; so that when the given particle had reached the extreme position in one direction of its oscillation the particle immediately in front of it would have a little way to go to complete its oscillation and the particle behind would have started on its way back in the opposite direction. The amplitude of the oscillations of all the particles would be equal. This can be represented in the usual conventional way by figure (21)

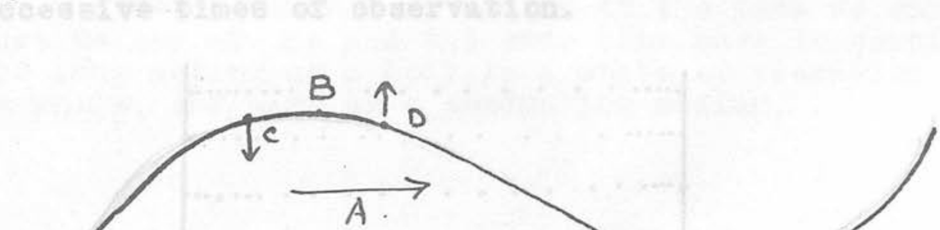


Fig 21.

The arrow A indicates the direction of propagation. Particle B is for the moment at rest C is returning to the undisturbed position, D is moving in the opposite direction.

If we observed a line of particles for a short time we should see the waves of compression and rarefaction move along in the direction of propagation as seen in figure (22)

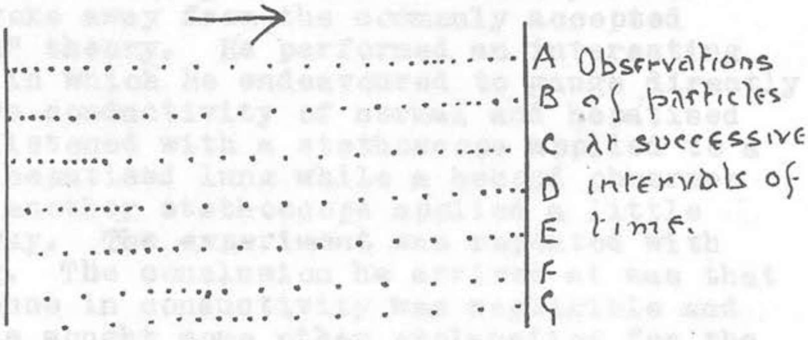


fig 22.

On the other hand in the case of the column of air the waves are stationary, the corresponding adjacent particles are in the same phase at any given instant but their relatife amplitudes differ. By the same convention this motion can be represented by figure (23)

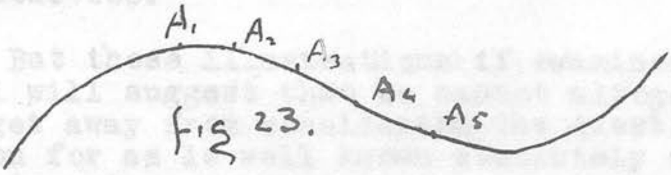


fig 23.

Here the particles A1 A2 A3 A4 A5 have all simultaneously reached their extreme positions, and the compressed and rarefied portions of the media remain stationary forming nodes and antinodes.

This again can be represented by fig. 24 which show s successive times of observation.

fig 24.

Applying the same concepts to the lung tissue (lung parenchyma with its contained air) we see that the essential difference between regarding the lung as vibrating as a whole i.e. assuming ~~not~~ the vibrations not "conducting" them, and as a medium is that adjacent particles in the former case are at any instant in the same phase and in the latter in successive phases.

Skoda in putting forward his theory of "Consonance" broke away from the commonly accepted "conduction" theory. He performed an interesting experiment in which he endeavoured to gauge directly the relative conductivity of normal and hepatised lung. He listened with a stethoscope applied to a portion of hepatised lung while a second observer spoke into another stethoscope applied a little distance away. The experiment was repeated with normal lung. The conclusion he arrived at was that the difference in conductivity was negligible and therefore he sought some other explanation for the increase of vocal resonance in consolidation. (36)

Although many of his illustrations will not bear the construction he puts upon them and this particular experiment is vitiated by the experimental conditions still his work represents a very distinct advance towards the proper understanding of pulmonary acoustics.

But these illustrations if examined in more detail will suggest that we cannot altogether in any case get away from considering the question of conduction for as is well known absolutely stationary waves do not occur in nature. An absolutely stationary wave implies the existence of absolute nodes i.e. places where this is no motion at all of the air particles. As a concomitant of this condition we should have the fact that there would be no radiation of sound, for energy cannot pass a node.

So by a further extension of the idea we surmise that we may at one and the same time have to consider the lung acting as a body in a state of vibration as a whole, and also as a conducting medium.

Let us endeavour to understand the real nature of things by following the sequence of events in vocal resonance.

The voice apparatus has been compared to a reed instrument the lungs taking the part of the bellows and the vocal cords the vibrating reeds.

The vibrations of the cords set up aerial vibrations in the respiratory passages and these as we shall see may be looked upon as the original external physical disturbances which are ultimately perceived as sound sensations.

In tracing the transference of energy from the cords to the surface of the chest two possible means present themselves as the initial step.

(1) Transmission from the larynx by the cartilages and the trachea.
(2) The aerial vibrations in the respiratory passages.

It is not difficult to see that the aerial vibrations in the respiratory passages are by far the more important. The observation that we must have patulous bronchi for the manifestation of vocal resonance is in itself conclusive.

Skoda quotes an observation in support of (37) his theory bearing on this point. He states that cases of consolidation occur in which the vocal resonance varies from one minute to another. When it disappears it can be brought back by coughing and his deduction is that the variation is caused by plugging of the bronchi.

It is not exactly correct to state as some authors have done that the vocal cords set the air in motion and the waves are carried up into the nasal passages and there modified. It is more satisfactory to regard the waves as stationary i.e. to regard the mass of air in the respiratory passages vibrating as a whole and constituting the essential vibrating system.

We have then a mass of air confined within the respiratory passages in a state of vibration. The question now arises, how is the energy transmitted to the body surface? Obviously it must pass to begin with by way of the walls confining this air, but before we turn to consider the behaviour of the boundary walls an interesting point calls for notice.

The upper limit of this mass of air can be considered to be situated in the region of the lips and nares. Where is the lower limit? Must we consider the vibratory motion to be sensible even to the confines of the alveoli? In other words do the alveolar walls form as it were the boundary of the contained mass of air or can the limit be placed in the smaller bronchi?

General principle derived from the study of a similar hydrostatic problem would lead us to conclude that the alveoli and the terminal bronchioles play no part in this stage; that we could in fact ligature them off without affecting the end result. This is simply equivalent to regarding the parenchyma and the minute air chambers as lying external to the bronchi.

In fact we are probably justified in confining the moving mass of air to the larger bronchi, the energy of vibration of the air particles in the smaller bronchi having been transmitted through the walls of the larger bronchi.

The next point to consider is the mode of energy transference from the air in the bronchi to the bronchial walls. If we accept the statement that the walls of the bronchi "conduct" the vibrations to the surrounding tissues we are tacitly assuming that the material of the walls plays the part of a medium in which wave propagation takes place. That is concept must be wrong, as indeed Skoda pointed out, (38) follows at once from the fact that under these circumstances the sound waves would have to be refracted into the material of the walls. But vibrations in air incident on solid material such as the walls are made of, suffer practically complete reflection at the interface even if incident in the line of the normal.

We are therefore obliged to accept the notion of the bronchial walls being set in motion and vibrating bodily not simply subjected to a propagated molecular disturbance in their tissues.

There is however nothing really physically different between bodies in a state of vibration and transmission of vibrations through a medium. The difference is one of degree and circumstance only. The ideas underlying them are in fact complete conceptions which can be severally arrived at from the same starting point of a particle in motion, only in vibrating bodies we have to consider the effects of reflection. But it is more expedient to regard them for a working hypothesis as separate physical facts, and I think I may not unreasonably assert, that even modern teaching regarding pulmonary acoustic phenomena lead us to that concept which should be associated with the transmission through a medium whereas we should get more insight and help towards their comprehension if we were led to construct the other.

We pass now to the consideration of the behaviour of the peribronchial tissue. Suppose that instead of normal lung its place were occupied by air alone then we should have a problem similar to that of a violin in an enclosed room.

This way of looking at the enclosed air amounts to regarding it as a vibrating system itself, which is of course the point of view from which the physicist considers any small enclosed mass of air. Regarded as such it must play a part in modifying the intrathoracic vibrations but that will become more evident after the general treatment of the subject of resonance has been given.

As a step towards approximating to the conditions obtaining in normal lung we might imagine this air space filled with soap suds i.e. we have the air space broken up into small loculi by delicate membranes.

The effect of such a modification can be gauged from the experiment of percussing,

(1) An empty bottle.
(2) The same bottle filled with soapsuds.

It is found that the soap suds lower the fundamental tone. Norris and Landis compare this effect with that obtained by loading a tuning fork. They regard the suds as acting as a load on the vib- (39)

rating system constituted by this enclosed air. The suds might in addition be regarded as an increased resistance to the motion of the air which would further increase the effect of the load.

From one point of view then we may consider the space occupied by normal lung a confined air space modified by the presence of numerous transversing septa, the effect of the septa being to lower the fundamental note that would otherwise obtain in their absence.

If now in place of the air we imagine a perfectly rigid connection between bronchi and chest walls all points of the path to the body surface would move simultaneously. The whole would from a single vibrating structure and there would be a little loss of energy in its interior provided it were free to move.

In normal lung we have a condition intermeiate in properties between this and the former case. In consolidation the properties approximate more to the rigid structure while in pneumothorax and emphysema, the condition is more that of the enclosed mass of air.

Returning to the idea of the rigid connection we can imagine the effect upon the chest wall to be equivalent to a periodic thrust synchronous with the vibrations from the bronchi. The great increase in vocal resonance over consolidation is then explaned by the greater rigidity with consequent less internal loss. In normal lung we have a structure which yields easily. Much of the energy is dissipated in its substance and it cannot so well transmit the thrust to the chest wall. The effect on the area of chest wall over-lying normal lung can then be considered to be made up of two factors. (1) A thrust due to the partial rigidity of the tissue, (2) Forces due to the system formed by the enclosed air. The great increase in consolidation would point to the former being themore important and this is borme out by the reduction of vocal resonance in pheumothorax where factor (1) is removed

The marked reduction of vocal resonance in cases of pleural effusion has been explained as being due to reflection. From one point of view this (40) is readily enough granted but from another it is ~~in~~ a little difficult to understand why such a marked reduction should take place from a thin layer of fluid in contrast to an equal increase in the thickness of the chest wall. Physically following out the idea of reflection one would expect almost as marked a reflection from the inner surface of the chest wall without the presence of fluid. The idea of the lung vibrating as a whole offers a better explanation. When it vibrates against the chest wall it causes an increase in tension parallel with the chest wall just like a blo blow on a drum skin. Hence the wall is easily set in vibration. But in a layer of fluid no such tension is set up, so that it is much more difficult to set the fluid mass in motion. It can only be made to transmit by wave propagation. Now to set up a wave in fluid we require a rigid surface; hence normal lung is not well adapted for such a purpose but consolidated lung would answer the purpose much better, so that in pleural effusion with consolidation we should expect that the vocal resonance would not be correspondingly reduced; a condition that actually obtains.

It is not my purpose to go further into the question of pulmonary acoustic phenomena at present. What I wish to arrive at is the proper conception of the behaviour of the chest wall. It is with the chest wall after all that we are actually concerned in stethoscopy. I think I have said enough to shew that the intrathoracic vibrat~~ing~~ory forces must be considered to set the walls into molar motion. The difference between this concept and that of simple conduction is that in conduction we should be focussing our attention on a line of particles transverse to the chest wall and be mainly interested in their relative compressions and rarefactions, whereas when the chest wall is given molar motions we think of the tensions set up in a line at right angle to the direction of motion. This latter idea explains satisfactorily the better reception of sound from the intercostal spaces. It is not that their tissue 'conducts' sound better than the ribs but that they are so disposed as to be more easily set in motion.

The chest wall must of course be capable of vibrating in an enormous number of natural ways in addition to being forced to vibrate locally or as a whole in unison with any applied periodic force. The complexity of its natural modes of vibration is suggested by the intricate figures for the nodal lines of such simple structures as square plates or discs. (41)

Henry Sewall has written widely on the subject of mural vibrations and the use of pressure in appliying the stethoscope to the chest wall to damp them down, but from the above it will be seen that all vibrations are "mural" though as a rule they are more or less localised depending on the site and nature of the disturbance. His use of the term presumably signifies vibrations effected by a large area or the whole of the chest wall.

Nothing has been said so far regarding the nature of the vibratory disturbances i.e. whether they are to be considered periodic or irregular nor as to what changes in the amplitudes of the component primes arise as a result of the influence of the various vibrating systems. These are matters that will be better treated after the general considerations of the phenomena of Resonance.

It was noted above that we might not in any case be able to get away from the conception of conduction in a medium. The reason for this will be evident when we think of a mass of gelatine disturbed by an impulsive force. Successive portions take up the motion but it is not a simple wave disturbance moving through the medium. The motion is something between a pure wave propagation in which successive particles are in successive phases and a molar vibration in which the particles are in the same phase. There are no actual nodal points but there are localised areas of relatively diminished motion and increased pressure. The lung is to be considered in that way too. **But as regards the chest wall we must consider its motion to be a molar vibration, and even if we think of the lung as a fluid in which waves are propagated we should have to think of the chest wall as a diaphragm suspended in the fluid.**

Two other considerations call for notice before we conclude this article.

Throughout the above we have had in mind vocal resonance in which the source of vibrations is much more or less central. If the source of sound be eccentric it will still under ordinary conditions tend to set up mass vibrations of the whole lung, but the area over which they can be detected will depend on their intensity. Should however the tissues be very briefly and very locally disturbed then instead of a mass vibration of the whole surrounding tissue we get a localised disturbance, gradually spreading to the more distant parts. This condition can be illustrated by considering what happens when a piano wire is sharply struck by a narrow edge in place of the usual broad hammer. The wire does not vibrate according to its natural period determined by the tension and length. The part struck vibrates by itself and the rest of the wire is only slowly set in motion. The effects of these disturbances is to allow the very high unharmonic overtures to predominate and give rise to metallic sounds. This is the explanation offered by Norris and Landis for all the metallic phenomena of auscultation. (42)

Lastly these conceptions must make us hesitate in drawing our conclusions regarding the site of the physical disturbances within the chest. Obviously since we are not dealing with a straightforward wave motion in an isotropic medium we can hardly be justified in simply projecting inwards the area to which the chestpiece is applied.

....

TRANSFERENCE OF SOUND ENERGY TO THE CHEST PIECE AND ITS CONTAINED AIR.

From the brief consideration of the physical disturbances within the chest three possible modes of communication of sound energy fromthe chest walls to the Stethoscope present themselves.

i. By the vibrations of the covered area of skin setting the air of the chest-piece directly in motion.

ii. By the vibrating chest wall setting the walls of the chest piece into molar vibrations.

iii. Conduction in the true sense of the word by the solid parts.

With the common use of rubber conducting tubes the third possibility can be almost immediately ruled out.

Of the other two the first appears to be that most commonly and readily accepted, judging from the design of most instruments, but Dr. Davies in a lecture elsewhere referred to, demonstrated that the mechanism even in the monaural form in large measure consisted in the solid parts of the Stethoscope being set into vibration by the vibrating chest walls.

Direct transference of sound energy from chest wall to air of chest piece:
We may approach this — the common concept — in two stages. Consider first the simple experiment of auscultating the tick of a watch. Let the chest piece approach very close to but not touch the casing. The waves radiated from the vibrating casing are collected more or less completely over the area enclosed by the mouth of the chest piece. Such a wave becomes condensed so to speak and if this were the only mechanism the problem would reduce to determining the optimum solid angle for the cone. This same problem taken on a larger scale has been worked out in connection with gramaphone horns, and the best conditions are known to obtain when the reduction in diameter of the chest piece as it comes nearer to the ear is made as gradual as possible but owing to

the small dimensions of the chest piece in comparison with the length of the received sound waves this becomes a very minor detail.

Consider this experiment in more detail. Using a binaural stethoscope with various types of chest pieces and a watch if we listen with the chest piece closely applied but not touching the casing the sound collecting properties of the various chest-pieces can be compared. It is found for example that an instrument as shown in sketch fig 25 collects the sound as if the watch were held close to the ear and their relative merits are such as we should readily surmise from their contour by a simple application of Huyghens' principle. The same experiment auscultating the chest instead of the watch gives practicably no sound. Even a loud heart can only be faintly heard so long as the chest piece does not make contact with the body surface. The radiation of energy from the body surface comparable to the radiation from the body of a violin is very small so that the mere prevention of laternal radiation does not altogether describe the acoustic properties of the stethoscope. One thing is evident that in direct contact between chest piece and body surface lies the key to the mechanism of the transference of sound energy.

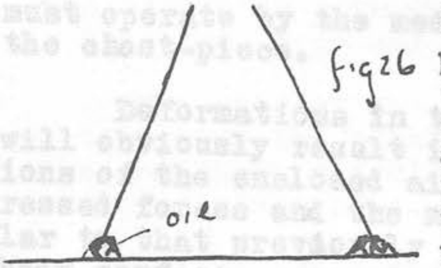
f.g 25.

Two possibilities now become apparent.

i. That the explanation of the mechanism depends on the creation of a closed air chamber by the application of the chest piece to the body surface. The body surface then vibrating causes a rise and fall of pressure in the enclosed air chamber and this results in the transmission of the vibratory notion along the conducting tubes. Working on this concept we cease to try to visualise the wave front advancing from the body surface. I have gone fully into this idea in a subsequent article on "A study of the air enclosed in the chest-piece".

The reason of the necessity for the close application ofthe chest piece to the body surface is then apparent, for so long as there is a free communication with the external atmosphere the variation in pressure will be greatly reduced.

The marked increase in signals by creating such a closed air chamber can be illustrated by the simple experiment of auscultating the tick of a watch with the stethoscope applied close to the casing and the interval closed either by a soap film or by a ring of heavy oil.



The interposition of the film of oil largely cuts out the possibility of the solid parts of the chest-piece being set in vibration (fig. 26). In addition to the increase in intensity in this experiment there is also an increase in what C.J.B. Williams called "reverberations" and others wrongly call 'resonance'. this fact lends support to the theory I have proposed in a later article that this effect is due to the enclosed air acting as a vibrating system. One conclusion from these considerations must be stated here. Since the behaviour of the enclosed air is more properly considered by thinking of the pressure rising and falling with the vibrations of the body surface, and not by thinking of the wave motion advancing through the air from the body surface, the shape of the chest-piece comes to be a matter of much less importance than is usually supposed.

The other possibility, viz. that the chest-piece is directly set vibrating in virtue of its contact with the body surface has been dealt with by various workers e.g. Davies, Williams, Sewall. Sewall perhaps, better then anyone else has given us the best conception of this mechanism but even he does not develop this idea very far.

Though there are many conceivable ways in which the chest piece may be assumed to vibrate some of which were illustrated in a previous article it is plainly impossible to form any correct concept of the motion. As a very simple possibility we might consider the funnel shaped pattern to go through alterations in shape, (illustrated in diagram fig 27).

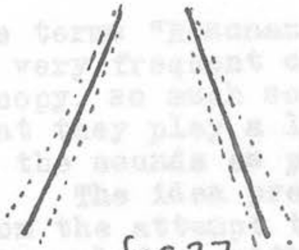


fig 27

Now the vibrations are not communicated by the rubber tubes so that this mechanism to be effective must operate by the medium of the air enclosed in the chest-piece.

Deformations in the contour of the chest-piece will obviously result in compressions and rarefactions of the enclosed air; synchronons with the impressed forces and the mechanism thereafter is similar to that previously described for the vibrating body surface.

If in the experiment of auscultating the tick of a watch with the stethoscope separated from the casing by a film of oil the chest-piece be made subsequently to touch the casing a very marked further increase in intensity results. This and Davies experiments with the monaural stethoscope are sufficient to show how important a factor this is, and we may state at once that it will be correspondingly greater the thinner and lighter and more highly elastic (in the true physical sense) the material of which the walls of the chest-piece are made, i.e. it will be greater in those chest-pieces which are more easily set in vibration.

RESONANCE. INTRODUCTORY.

The terms "Resonance" and "Sympathetic Vibrations"are of very frequent occurrence in the literature of Stethoscopy, so much so that one is apt to form an impression that they play a large part in determining the character of the sounds as perceived by the ear.

The idea presumably arose in the first instance from the attempt to analyse the mechanism of the monaural from with its central contained column of air. The approximate theory of vibrating columns of air has long been widely known,familiar applications being seen in the organ pipe and other wind instuments.

The subject has been constantly discussed in connection with the behaviour of different instruments; some designers claiming magnification by resonance as a special feature of their particular patterns.

Others again without specifying that the principles of resonance are involved have laid the claim for an increased volume of sound cf. the specification of the Phonophore produced by Arnold & Sons. (43)

On the other hand "Resonance"has been considered a disadvantage by other workers who have specially designed their forms to avoid it,claiming that by so doing the sounds are heard more clearly and more naturally.

At a much earlier date what probably amounts to a reference to the same phemonena had been discussed by Dr.C.J.B. Williamsunder the designation "Reverberations". (44)

Lastly let us quote themopinion of Henry Sewall, (45) the distinguished American worker.

"The designer of the stethoscope is happy to make the sounds as loud as possible,yet he may be sure that the loudness is but the result of sympathetic vibrations of the instrument itself.It is always to be suspected that any extraordinary intensity in auscultated sounds is due to Selective Resonance on the part of the instrument used.

These illustrations suffice to suggest the importance of the subject and demonstrate the necessity of inquiring more precisely into the assumptions made in crediting the stethoscope with such behaviour.

....

RESONANCE. GENERAL CONSIDERATION.

In this article I must crave the reader's indulgence. The subject is so important that I have considered it advisable to depart from a merely descriptive treatment and to insert a few mathematical formulae which will demonstrate the truth of the statements.

The arguments however will still be clear even if the mathematical work is not understood and has to be neglected and in any case from the summary given at the end of this article, what is involved will be readily grasped. As regards the authority for the mathematical expressions it will be sufficient to state that it is based on Lord Rayleigh's "Theory of Sound" to which I have closely adhered almost quoting him verbatim.

Consider what happens when a tuning fork is struck and left to itself. The fork gives forth a musical sound but the vibrations gradually die away. The pitch of the note, i.e. the frequency of the vibrations is determined by the properties of the fork (inertia and elasticity). i.e. the fork is not "forced" to perform any unnatural motion. Its vibrations are free.

But if the base of the tuning fork still vibrating be placed in contact say with a suspended bell, the vibrations of the fork are communicated to the bell which after a short interval picks up a motion of the same frequency as the fork. The bell if struck and left to itself may give forth a very different note i.e. its "free vibrations" may differ widely from those impressed upon it by the vibrating fork. The vibrations which it performs are unnatural to it, they are so to speak forced upon it. Such vibrations are termed "forced" vibrations.

The vibrations communicated to the stethoscope are of course of this character. They are forced upon the stethoscope from the body surface.

If however one system (bell) be forced into vibration by the vibrations of a second system (tuning fork) and the natural frequency of the first system be the same as that of the forcing vibrations we have a special case. Here the vibrations of the first system are still "forced" because due to, and maintained by, the external applied force, but are of the same period as its free vibrations. This results in a very marked increase in the amplitude of the vibrations set up. To this phenomenon, the term "Resonance" or "Sympathetic vibrations" is applied. It does not require for its demonstration direct connection between the systems, the intervening air being a sufficient connecting medium.

Everyone is familiar with the terms resonance and sympathetic vibrations, and has at least a general idea of what theyimply during the playing of a piano, we have all observed the phenomenon of a vase or other ornament in the room giving forth a musical sound when a particular note is struck, and we know that the energy of its vibrations must come from the original source. The mechanism is frequently illustrated by referring to the behaviour of a pendulum or a swing. If the pendulum starting from rest (fig 28) receive a gentle blow in the direction indicated by the arrow it will be set in motion with a very small swing. If now every time the pendulum has reached its extreme postion to the right and is on the point of returning to the left a similar gentle blow be applied in the direction of the motion the amplitude is gradually built up until a wide swing is reached.

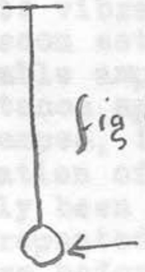


fig 28.

The explanation is that when the second blow is applied the pendulum has not dissipated all the energy derived from the first blow, each successive blow adds a little more energy which goes on accumulating until, when the swing is very large as much enrgy is dissipated in each swing as is applied by each blow.

If however the blows be applied at irregular intervals or at a rate not related to the natural periodic time of the pendulum this large amplitude is not obtained because some of them will tend to stop the motion. The same explanation can be applied to the vibrating vase - The successive sound waves impart to it a certain small amount of energy, and when the frequency of the vibrations of the impinging sound waves is equal to that of the vase accumulation of energy takes place and the vibrations of the vase pick up such an amplitude that it emits an audible sound.

It is not necessary that the two vibrating systems should have exactly the same frequency as that of the exciting note. It will respond to a wider range ifthe damping forces (internal resistance) tending to stop its vibration be relatively large, but if the damping force be small very sharp tuning is required but in this case very marked resonance effects are obtained. The latter can be illustrated by two tuning forks of very accurately adjusted equal periods. If one be made to vibrate, its vibrations, communicated to the air, soon set up vibrations in the other of considerable amplitude even when the forks are some distance apart. If the motion of the first be now damped, it can be set vibrating again from the vibration of the second whose motion had originally been derived from it. The experiment may be repeated several times energy being passed to and fro before the vibrations becomes too feeble to be detected. The periods of the forks have however to be exactly adjusted otherwise for a small deviation a rapid fall in the intensity of the resonance takes place.

We proceed now to the mathematical treatment of the phenomenon.

The chest and the stethosope form together a very complicated vibrating system; therefore we have to make deductions concerning its behaviour by general principles based upon results obtained from analogous simple problems.

A very great deal of valuable information can be derived and applied to more complex problems by considering the case of the simplest mode of vibration of a body, viz. when it is constrained to move only in one way, i.e. having what is known in mathematical language as one degree of freedom.

Consider such a system set in vibration with small amplitude and left to itself. The mathematical expression for the motion of such a case allowing for friction losses, is given by the equation.

$$\ddot{u} + K\dot{u} + n^2u = 0$$

(otherwise written $\frac{d^2u}{dt^2} + \frac{K\,du}{dt} + n^2u = 0$)

where $\ddot{u}$ = acceleration.
K = a constant expressing the effect of friction
$\dot{u}$ = velocity
u = displacement from equilibrium
n is related to periodic time of the vibra- in vacuo by the expression
$\tau = \frac{2\pi}{n}$ where τ is the periodic time.

The solution of the equation is

$$u = Ae^{-\frac{1}{2}Kt}\cos\left\{\sqrt{n^2 - \tfrac{1}{4}K^2}\,t - \alpha\right\}$$

t is time from beginning of motion
e is the base of Naperian logs.
A is an arbitrary constant which can be given special values for special cases.

" From this it is seen that the motion consists of a gradually dying down oscillation provided $n^2 > \frac{1}{4}K^2$ because $e^{-\frac{1}{2}Kt}$ diminishes with the time increasing. If $\frac{1}{4}K^2$ is greater than n^2 es the solution changes form and no longer correspond~~ing~~ to an oscillatory motion, but in all acoustic problems K is small".

This type of vibration is called the"free vibration" i.e. the system having been set in motion by an external applied force, and the force having been removed, is left to itself. Its vibrations depend only on its own properties (elasticity and inertia) and are not subjected to any external applied force.

Now pass from this to the consideration of the case where instead of being set in motion and left to itself the system is subjected to a force varying as a harmonic function of the time. e.g. such a force as is given by the vibrations of a tuning fork.

"Again allowing for, friction losses this motion is represented by the equation.

$$\ddot{u} + K\dot{u} + n^2 u = E\cos pt$$

The solutuion of which is

$$u = \frac{E\sin\varepsilon}{pK}\cos(pt-\varepsilon)$$

where $\tan\varepsilon = \dfrac{pK}{n^2-p^2}$

$\dfrac{2\pi}{p}$ = period of applied force.

"This is called a "forced" vibration. It is the response of the system to a forve impressed upon it from without and is maintained by the continued operation of the force".

"From these solutions certain important deductions can be made viz. thus

1. When n = p the Kinetic energy of the system at the moment of passing through the position of equilibrium is a maximum i.e. the Kinetic energy of the system is a maximum when the period of the applied force is the same as that with which the system would vibrate freely under the influence of its own elasticity and other internal forces without friction.

The vibration is

$$u = \frac{E\sin nt}{nK}$$

and if K be small the amplitude is very great".

This then is the mathematical representation of the phenomenon of resonance.

"To the motions which are the immediate effects of the impressed forces must always be added the term expressing free vibration if it be desired to obtain the most general solution. Thus in the case of one impressed force.

$$u = \frac{E \sin \varepsilon}{pK} \cos(pt - \varepsilon) + Ae^{-\frac{1}{2}Kt} \cos\left\{\sqrt{n^2 - \tfrac{1}{4}K^2}\, t - \alpha\right\} \quad \ldots (1)$$

where A and α are arbitrary

"The distinction between forced and free vibration is very important and must be clearly understood. The period of the former is determined solely by the force what is supposed to act on the system from without while that of the latter depends only on the constitution of the system itself.

Another point of difference is that so long as the external influence continues to operate a forced vibration is permanent being represented strictly by a harmonic function, but a free vibration gradually dies away becoming negligible after a time

Suppose for example the system is at rest when the force E cospt begins to operate. Such finite values must be given to A and α in (1) that both u and $\dot{u}$ are initially zero. At first then there is a free vibration no lessimportant then its rival. "(because for small values of t $e^{-\frac{1}{2}Kt}$ is large)", "but after a time friction reduces it to insignificance and the forced vibration is left in complete possession of the field. This condition of things will continue so long as the force operates.

When the force is removed there is of course no discontinuity in the values of u and $\dot{u}$ but the forced vibration is immediately converted into a free vibration and the period of the force is exchanged for that natural to the system".

Note:- The parts between inverted commas are quoted from Rayleigh.

Summary.

Let us summarise what we have demonstrated here. We have considered the simplest case of a vibrating system. We have seen that when disturbed from its position of equilibrium and left to itself it performs oscillations which gradually dies down in amplitude. These are called "free vibrations" because they depend only on the properties (elasticity and inertia) of the system itself.

Passing on from this we considered the same simple system subjected to a single periodic external force, (e.g. the vibrations of a tuning fork) and we saw that after a time the system vibrates with the same period as that of the applied force, and with an amplitude proportional to the magnitude of the applied force. This vibration is called 'forced' because now the system is forced to fall in with the period of the applied force.

From the expression for the motion in the latter case we saw that the amplitude reached a maximum when the period of the applied force is approximately equal to that of the free vibrations of the systems and may become very great when the resistance is small.

It is to this phenomenon that the term selective resonance or sympathetic vibrations is strictly speaking applied.

Notice here very particularly that sympathetic vibrations are the result of a periodic applied force, that is to say, in the realm of acoustics in order that sympathetic vibrations may be set up we require as the exciting source vibrations which give rise to musical sounds.

Noises which are not periodic vibrations cannot therefore give rise to "sympathetic" vibrations.

Lastly going a step further we get the complete expression for the motion from the beginning considering the system to start from rest.

We saw that the immediate effect of the applied force was to give a motion at first compounded of two terms - a combination of a free vibration and a forced vibration, the former being at first equally as important as the latter, but rapidly dying away depending on the damping of the system. Then after some time the motion is given by the forced vibration alone and finally if the force be removed the motion changes to a free vibration and gradually dies away.

The above case is physically a very simple one. I do not propose to endeavour to approximate more closely to the actual conditions obtaining in stethoscopy. But the conclusions above arrived at are true in a general sense when applied to more complex problems, and lead to certain important concepts and deductions when interpreted in relation to the application of the principle of resonance in the use of the stethoscope.

....

SOME GENERAL POINTS IN AUSCULTATION.

The general consideration of the subject of resonance enables us to grasp the fundamental considerations involved in the problem of stethoscopy. The stethoscope whatever its form, we can consider to be a vibrating system. This is specially true of the binaural form with flexible tubes. This system is subjected to forcing vibrations viz. the vibrations of the chest wall. The purpose of the stethoscope is to enable these vibrations to produce auditory stimili; the problem of the stethoscope is to determine how these auditory stimili depend on the instrument itself. The vibrations of the chest wall are of course related to the original physical disturbances in a very indirect and intricate manner for they have been subjected to modification by the complicated system constituted by the thoracic structures. But the stethoscope is not concerned with the original disturbances. Its purpose is to record the vibrations of the surface tissues to which it is applied. It is the problem of intracorporeal acoustics to interprete these surface vibrations. The vibrations of the chest wall must be very complicated, they may be considered to be composed of a series of superimposed regular and irregular vibrations, the regular vibrations corresponding to tones, the irregular to noises. The relative proportions of these under various conditions has been indicated in the article on resonance in relation to pulmonary acoustics phenomena, where it is seen that the vast majority must be considered to be of the nature ofnoises. This as was pointed out in the article on resonance leads us to modify the common conceptions of sympathetic vibrations in stethoscopy.

Consider in the first case such vibrations as are regular. These applied to the stethoscope systems constitute periodic forcing vibrations.

The vibrations of the stethoscope system willin general follow these forcing vibrations and be proportional to them in intensity. The vibration properties of the instrument will affect the period for a probably inappreciable interval only at the beginning and end of the train of waves. The intensity of the auditory sensations will depend among other things upon the intensity of the forcing vibrations and the ease with which the stethoscope system can be made to vibrate.

For the general case then such vibrations as are periodic will be transmitted to the ear with little modification but in the event of any of the forcing vibrations corresponding in frequency with any of the natural frequencies of the stethoscope system, the auditory stimuli corresponding to these elements will be increased and distortion of the original vibrations takes place. i.e. some of the component elements will be amplified out of proportion to the others. The effects of distortion are well illustrated in the wireless transmission of piano music and to avoid it the instrument required to be so constructed that its natural periods are far removed from the frequences it is called upon to assume.

In the previous article the mechanism by which these increased effects are obtained was explained amd illustrated and for their manifestation it was seen that one necessary condition was that the forcing vibrations should be periodic. Noises not being periodic ~~vibrations~~ cannot give rise to sympathetic vibrations.

But it is an undoubted observation that certain chest-pieces give an increased volume of sound no matter whether we are dealing with tones or with very irregular vibrations, an increased volume of sound which cannot be considered to be a simple magnification of the vibrations impressed upon the chest piece by the vibrating body surface. This effect has been variously referred to by the terms 'resonance''sympathetic vibrations' (H. Sewall) and 'reverberations (Williams).

Objection has already been raised to the term 'sympathetic vibrations' because it implies periodic forcing vibrations. "Resonance" likewise is only permissible in a loose sense.

The explanation of the increased volume of sound is not by any means an easy matter but I think that Williams was not far off the tract when he associated these 'reverberations' with the dimensions of the contained air chamber.

Suppose we endeavour to trace the effect of an irregular series of vibrations applied to a vibrating system. i.e. to determine how a system capable of assuming vibrations would respond to a noise. What precisely a noise is cannot be yet exactly affirmed. Experiments with the siren demonstrated that when a series of air impulses is regular a tone is produced, but the more irregular the impulse becomes the more noise takes the place of the musical sound. It is as already stated, possible that noise in addition to being produced by irregular vibrations may also be produced by periodic vibrations of very short duration. It is known that for the recognition of a tone the vibrations in addition to being regular must be of a certain minimal duration.

In studying the effect of a noise on a vibrating system we should have to consider the effect of a single vibration. This can be done by considering what would happen if in place of one vibration we imagine it to be followed by other similar ones at periodic intervals. We should then have the motion represented by an equation as in previous articles which gives us the immediate effect. From this it is apparent that the character of the vibration is as much dependent on the property of the system as upon the forcing vibration. A similar equation giving the effect when the forcing vibration had been removed would shew that again the motion would towards the end be determined as much by the properties of the system as by the applied force.

So that if we consider the effect of a series of irregular vibrations it seems not unreasonable to suppose that the vibrating system will respond by assuming a corresponding irregular series of vibrations and therefore record or transmit the original noise, but in addition to that the system will tend to be kept continously vibrating according to its own natural period which will give an added element (so called resonance) to the original sound. The volume of the added element will depend on the dimensions and vibrating properties of the system. We can illustrate this by subjecting a violin to a sense of taps--

That I think is in fact the explanation of so called 'resonance' so noticeable for example in Arnold's Phonophore. In general this must be an objectional feature for it gives a constant physical disturbance bearing probably no relation to the physical disturbances within the chest, but a chest piece guilty of adding these "resonance" effects will as a general rule respond with a larger effect to forcing vibrations. So that the increased volume of sound is not entirely to be regarded as extraneous.

....

RESONANCE IN THORACIC ACOUSTIC PHENOMENA.

The previous article on Pulmonary Acoustic Phenomena led us to form the concept of the structures within the chest forming a very complex vibrating system rather than acting as conducting media. To this complex system we may in a general way apply the reasoning and deductions applied and arrived at in the consideration of resonance in general.

Suppose then we had this system set into motion by a periodic force represented by a harmonic function. It would begin to vibrate. The commencement of its vibration would be determined both by the properties of the system and the period of the applied force.

The periodic force continuing to act, very soon - after an inappreciable time it would have complete possession of the field and the vibration of the system would then follow exactly the period of the applied force and be proportioned to it in amphitude.

Now suppose instead of a single applied harmonic force we have several such forces acting simultaneously e.g. singing a note where we have the fundamental tone and all the overtones each capable of being represented by a harmonic function. Then the vibrating system would in due course assume a complex vibration in which each component would correspond to one of the original components of the applied force, and so long as none of the natural modes of vibration of the system approximated to any of the applied frequencies the complex forced vibration would be similar in form to the forcing. Should, however, any of the applied frequencies approximate to one of the natural periods of the vibrating system then the corresponding component will be magnified out of proportion to the others.

It is difficult to estimate the exact part played by sympathetic vibrations in pulmonary acoustic phenomena. I have already stated that one necessary condition for their generation is that the forcing vibrations should be periodic e.g. we should be dealing with the sound having the character of a tone.

In all thoracic phenomena we have a mixture of tones and noises, but only in a few cases can tones be said to predominate. The regular vibrations for the most part arise from periodic disturbances in the bronchi. There is a very definite sense of pitch for instance in bronchial breathing. Such sounds as crepitation, and friction must be considered to be very irregular. Cardiac sounds partake much more of the character of noises than of tones. The murmur in comparison with normal heart sounds must be considered to be the more regular the hissing element representing regular sonorous vibrations of very short wave-length. On account of its short wave-length Rayleigh used a hiss in studying the concentration of sound along the axis of a megaphone. The thoracic wall owing to its contour and its anatomical relations to the contained structures is most easily considered by treating it as an independent vibrating system. It behaves like the body of a violin and responds to any regular vibration in proportion to its intensity. But it is quite impossible to even suggest any of the natural modes of vibrations though it is apparent from the great increase in vocal resonance in the deep male voice, that its gravest natural frequencies are relatively low.

In the case of noise produced within the thorax we may apply a line of argument similar to that put forward in the preceding article. Any physical vibratory disturbance within the thoracic may be considered as an external applied force forcing the complex system into vibration. In noises where we have an irregular series of impulses we should be prepared to anticipate the end result as perceived by the body surface as a more or less tonal mass of sound determined as regards its quality entirely by the vibration characteristics of the thoracic structures superimposed upon an irregular train of vibrations representing the original noise.

In the case of certain phenomena such as the loud booming sound of a hypertrophied heart it is possible that the superimposed mass of sound is due in ~~the~~ to part of primary vibrations of the chest wall, that is to say, the contracting heart exerts a force upon the chest wall, a force comparable to a single blow.

This results in a momentary displacement of the quiescent contour, and the force being removed the wall preforms free vibrations of such frequency as to give an aud~~d~~itory sensation till the derived energy is dissipatated.

In such a case the thoracic wall itself is the source of sound. This is possible in large measure the genesis of Professor Sewall's mural vibrations, and it makes the application of stethoscopic pressure suggested by him for the better auscultation of cardiac sounds both logical and useful.

We see then how difficult must be the ultimate precise interpretation of the mass of sounds conveyed to the ear apart from any modification effected by the stethoscope. Certain elements in the mass of sound might conceivably be sorted out by the principle of selective resonance and be shewn to correspond to regular vibrations, and these may be produced by physical conditions within the thora~~cic~~x the presence of which we are anxious to determine. Others can be considered to represent the vibrations of the chest wall or its contained structures and to give us no information beyond a vague idea of the intensity of the primary physical disturbance.

……………………

A STUDY OF THE MASS OF AIR ENCLOSED IN THE CHESTPIECE.

We have discussed and illustrated some of the conceivable ways in which the air in the chestpiece can be set in vibration. We have also seen that in the case of binaural instruments with rubber tubes the tubes play only a very minor part in conducting the sound. Their main function is simply to prevent lateral radiation. Consequently we can form the concept of a disturbance occuring at the chestpiece end of the stethoscope being transmitted along the tubes to the ear.

Therefore whatever be the means by which transference of sound energy takes place from the chest to the chestpiece it is plain that in the case of the binaural instrument with the rubber tubes the air contained in the chestpiece forms an essential link in the chain of conduction.

Strictly speaking we ought not to separate the consideration of this air from that enclosed in the tubes but we could make no progress at all if we did so and the variation in results obtained in which the dimensions of the chestpiece air chamber appear to be the important factor render such a separate consideration justifiable.

The nearest approach we could make to a combined consideration would be to follow Rayleigh's treatment of vibrations in tubes with expanded ends, i.e. we should have to regard the air in the chestpiece simply as an expansion of the column of air in the tubes.

Rayleigh has shown that the effect of such an expansion depends upon its dimensions. If large, the conditions at the end of the tubes as it opens in to the expansion approximate to the condition s that obtain when the tube opens freely into the atmosphere and therefore can be taken account of by considering the end of the tube as a loop. If small the the conditions approximate to those of a closed end in virtue of which the end of the tube should be regarded as an node.

This mass of air enclosed by the application of the stethoscope to the body surface being subjected to a vibrating force it remains to be seen how its behaviour is influenced by its contour and dimensions

The treatment might conceivable be undertaken in either of two rather different ways. We might on the one hand focussing our attention on the vibrating area of body surface try to trace the course of a train of waves emanating from it. Using Huyghens' principle we should have to endeavour to follow the the subsequent course of the wave front. Now this would be a perfectly legitimate procedure provided we were dealing with waves whose dimensions compared to the size of the instrument were small a condition that does not obtain in the stethoscope; for by the time we had followed a single wave front from the boundary to the opposite side and back again several times, we should still be concerned only with a small part of a single wave and we should be hopelessly lost long before we had formed any conception of what a train of waves would do. This is the fallacy of the only noteworthy attempt at a mathematical investigation I have seen viz. that by Mr. Barnett in 1837. (46)

The other line of treatment is based on the fact that the dimensions of the chestpiece being small in relation to the length of the sound waves it follows that at any particular instance the pressure throughout the enclosed air is paractically uniform and the motion of the air can consequently be deducted from the behaviour of an incompressible fluid.

The idea of the pressure being uniform throughout the chestpiece of any time will be better understood from the diagram below, fig. 29.

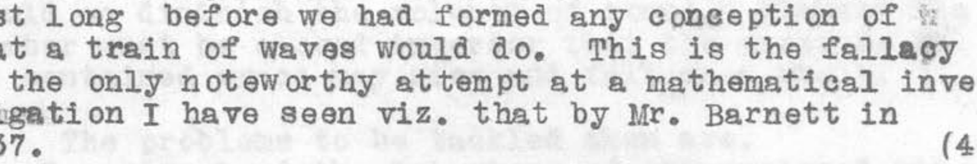


fig 29

The distance x x represents a wave length A is the chestpiece. Where the lines are closely set they indicate compression. It will be seen that in A the air is all in a similar condition. These two conceptions may be illustrated by comparing the former to the ripples set up in a large tank of water when one side is struck, and the other to the motion of water in Higginson's Syringe when the bulb is compressed and relaxed.

That this latter conception is the more logical one follows at once from the experiment of applying the chestpiece ~~to~~ (the ordinary funnel form) to the body surface. Auscultation phenomena are scarcely audible until the chamber is closed. If the chestpiece be tilted so that while part of the rim makes contact with the body surface there is a free communications between the external air and the contained mass of air in the chestpiece very marked reduction takes place though there is no reason why the vibration of The metal parts should be correspondingly reduced, and if we were dealing with a propagated wave motion in a medium there is no reason why an accessory outlet~~s~~ should so diminish the volumes of sound. Plainly the chamber must be closed in order that the pressure in the contained space may rise and fall as a whole.

The problems to be tackled then are.

(1) To understand the behaviour of the enclosed air as regards modification of the component forcing vibrations.

(2) To determine whether or not adventitious elements arise in the nature of free vibrations within the chestpiece such vibrations having no corresponding forcing vibrations.

(3) To determine the behaviour when the forcing vibrations are (a) periodic (b) aperiodic. (4) To determine how the dimensions of the cavity are related to the volume of sound.

At this point the problems can be most readily handled by material derived from the chapter ~~on~~ resonance in Rayleigh's Sound. The mathematical work is very elaborate and advanced, but as he puts the matter so concisely I shall risk quoting him in full in parts with slight adaptations. (47)

"In the organ pipe closed at one end and open at the other we have an example of a mass of air endowed with the property of vibrating in certain definate periods peculiar to itself, in more or less complete independence of the external atmosphere. If the air beyond the open and were entirely without mass the motion within the pipe would have no tendency to escape and the contained column of air would behave like any other complex system not subject to dissipation.

In actual experience the inertia of the external air cannot of course be got rid of, but when the diameter of the pipe is small, the effect produced in the course of a few periods may be insignificant and then vibrations once excited in the pipe have a certain degree of persistence. The narrower the channel of communication between the interior of the vessel and the external medium the greater does this independence become. Such cavities constitute resonators In the presence of an external source of sound the contained air vibrates in unison and with an amplitude dependent on the magnitudes of the natural and forced periods, rising to great intensity in the case of approximate isochronism. When the original sounds cease the resonator yields back the vibtations stored up as it were within it, becoming itself for a short time a secondary source of sound."

The theory of resonators formed by air cavities can be gradually comprehended by considering the case of a stopped cylinder in which a piston moves without friction fig. 30.

"On the further side of the piston the air is supposed to be devoid of inertia so that the pressure is absolutely constant. If now the piston be set into vibration of very long period it is clear that the contained air will be at any time very nearly in the equilibrium condition (of uniform density) corresonding to the momentary position of the piston. If the mass of the piston be very considerable in comparison with that of the included air, the natural vibrations resulting from a displacement will occur really as if the air had no inertia and in deriving the period from the kinetic and potential energies, the former may be calculated without allowance for the inertia of the air, and the latter as if the rarefaction and condensation were uniform.

Under the circumstances the air acts merely as a spring in virtue of its resistance to compression or dilatation; the form of the containing vessel is therefore immaterial; the period of vibration remains the same provided the capacity be not varied."

Rayleigh deals with this hypothetical case mathematically and shows that the periodic time is proportioal to $\sqrt{M.S}$, whem M is the mass of the piston and S the volume of the air.

"Let us now imagine a vessel containing air whose interior communicates with the external atmosphere by a narrow aperture or neck. It is not difficult to see that this system is capable of vibrations similar to these just considered, the air in the neighbourhood of the aperture supplying the place of the piston. By sufficiently increasing S the period of the vibration may be made as long as we please, and we finally obtain a state of things in which the Kinetic energy of motion may be neglected except in the neighbourhood of the aperture and the potential energy may be calculated as if the density in the interior of the vessel were uniform. In flowing through the aperture under the operation of a difference of pressure on the two sides or in virtue of its own inertia after such pressure has ceased the air moves approximately as an uncompressible fluid would do under like circumstances provided that the space through which the kinetic energy is sensible be small in comparison with the lenghth of the wave."

These suppositions become rigorous only when the wave length is indefinitely great in comparison with the dimensions of the vessel.

This simple method of calculating the pitch of resonators is applicable to the gravest mode of vibration only the character of which is quite distinct. The overones of resonators with contracted necks are relatively very high, and the corresponding modes of vibration are by no means independent of the inertia of the air in the interior of the reservoir.

"We shall now examine the forced vibrations due to a source external to the resonator."

The result of this consideration shows that the maximum internal variation of pressure occurs when the natural note of the resonator is the same as that of the generating sound.

The maximum vibration when coincidence of periods is perfect various inversely as S, but if S is small a very slight inequality of the periods is sufficient to cause a marked falling off in the intensity.

We shall owing to the importance of a clear understanding required, go into this subject more fully. Consider the small resonator (Helmholtz) shown in fig. 31.

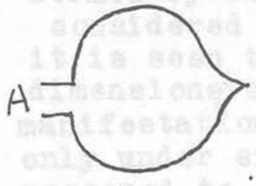


fig 31

Suppose it be exposed to a source of sound. The vibrations arriving at A set the air in the cavity vibrating. Now as this cavity is of small dimensions in comparison with the length of sound waves such as we are concerned with, at any given instant the pressure has practically the same value throughout its dimensions. Under these conditions the motion of the air approximates to that of an incompressible fluid. This is as much as to say that there is practically no motion except in the vincity of A. The air in the vincity of A vibrates more or less violently and the path of vibration would be closely represented by the stream lines followed by fluid in flowing through the neck See fig. 32.

fig 32.

Apart from the vincity of the neck the motion becomes very small, so small that it can be neglected in dealing with the kinetic energy of of the system.

The potential energy of the system can then be calculated by considering the pressure to be constant throughout the cavity at any instant. From these considerations it is possible to deduce the formulae for the frequency of the natural note of the resonater. If the resonator be exposed to a source of sound, following the reasoning of the article on resonance we expect at the very commencement of the vibration, the motion ~~is to be~~ to be made up of two factors one representing free vibrations the other the forced.

In this case however the free vibration is negligible because the mass of the enclosed air is so small that it will practically follow at once the form of theimpressed force. If the frequency of the impressed force be very close to that of the resonator, a sharp rise ~~used~~ in intensity ensues but this sharp increase in intensity only occurs over a very small range of close approximation to the natural note of the resonator.

Further it has been seen from above that the overtunes from such a chamber are very high and we have elsewhere pointed out and that the gravest tones as well as the over tones of the vibrating systems formed by the metal parts of the chestpiece must be considered to be also very high. Also from above it is seen that where the air chamber is of small dimensions/very exact isochronism is demanded for the manifestation of resonance, and in stethoscopy only under exceptional circumstances can this be supposed to occur. The conclusion therefore is that it is extremely unlikely that "Sympathetic vibrations of the instrument itself" is a factor of any importance in stethoscopy.

In stethoscopy we are as has already been stated more interested in irregular vibrations. It will therefore be of interest to consider again what happens in the case of such aper~~noi~~iodic forced vibrations. Here we can only surmise but we may argue thus.

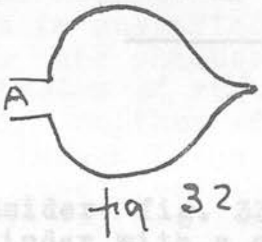


fig 32

A sudden disturbance in A fig. 32 would set the air in motion. Once in motion it tends to persist. The effect of dissipation depends on the diameter of A.

If this be small the dissipation will not be marked at first therefore the energy will not all be dissipated in the single swing corresponding to a singleimpulse impulse. The air in the resonator will continue to vibrate freely until the energy is all dissipated. Now if we exposed the resonator to a rapid succession of irregular impulse e.g. to a maintained noise the effect of these free vibrations would become more marked and the noise as auscultated by the help of such a resonator would have a "resonating" quality.

The "resonating quality" is not related except by way of intensity to the exciting vibrations The ease with which free vibrations are set up is demonstrated by holding a spiral shell to the ear. In this case any external disturbance sets the air vibrating. If this is so it is a very important point because it means that probably the so called resonance in stethoscopy is not sympathetic resonance, i.e. it does not correspond to a vibration derived from the chest It is simply the free vibration natural to the chest piece excited by the disturbance in the air. We can develop the preceding case one stage further in order to approximate very closely to the actual conditions in the chest piece.

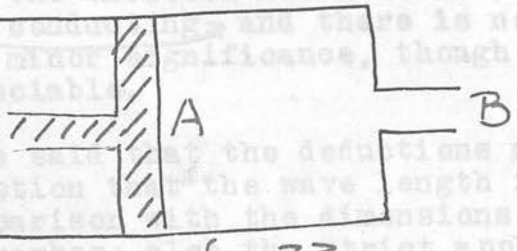


fig 33.

Consider fig. 33. Here we have a large cylinder with a corresponding piston A. and a small outlet B. Extending the above illustration it will be seen that if the piston vibrate through a small amplitude there will be comparatively little motion of the enclosed mass except in the vicinity of B; but there the motion must be very great and will among other things depend on the relative areas of A and B.

In the chest piece, laying aside for the moment the vibration of the solid parts, we can consider the place of the piston A to be represented by the covered body surface and B the leading off tube. It will therefore at once be apparent how the great increase in the kinetic energy transmitted along the tubes is effected and how the chestpiece can be considered to act as a collector.

It is also apparent that the larger the body surface the greater the energy, coeteris paribus.

A further extension enables us to consider the Piston A to represent the total deformities of the contour of the chestpiece i.e. to take account of the motion of the solid parts as well as the body surface.

Lastly the necessity for the chamber being closed by the application of the rim to the body surface all round will be appreciated for if there be a communication to the external air, as may occur in the application of the chestpiece to the parietes of an emaciated subject, there is an alternative path for the escape of the energy, and the amplitude of the pressure variation in the vicinity of the orifice of the conducting tube is greatly reduced.

This argument leads us to neglect entirely the shape of the enclosed air and the point of exit of the tube conducting, and there is no doubt that these are of minor significance, though in some instances appreciable.

We have said that the deductions made depend on the assumption that the wave length is very large in comparison with the dimensions of the chestpiece air chamber; also the strict applications of the theory of resonance demands that the walls be rigid. Neither of these assumptions is exactly true for though large in comparison with the dimensions with chestpiece the ratio is not and infinate number and of coursec the vibrations in the enclosed air are set up by the boundary walls of the chamber, (including the body surface as one wall).

Nevertheless it is apparent that the kinetic energy is relatively sensible only in the vicinity of the outlet.

At the other extreme remote from the above hypothetical case, we should have to consider the whole mass of air performing on appreciable motion. The kinetic energy would then be sensible throughout. We should then have to try and think of the air asa stream of fluid and its behaviour would be analogous to the flow of fluid through orifices and the greater the facility with which the fluid could be forced through the orifice the better the results. For example take the case of the Bowles pattern illustrated below fig. 34

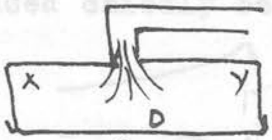


fig 34

The motion of the fluid could be conceived to follow the lines indicated. From this on this conseption it must be evident that the spaces X and Y are of little value.

Cabot points out that the functions of the diagram D is simply to prevent the encroachment of the tissues on the enclosed air space. The real reason I think will now be obvious (48)

Taking away the diaphragm fig. 35 would allow the tissues to encrouch on the air cavity.

The effect of this will be to raise the fundamental note, an insignificant point, but if we could consider the kinetic energy to be sensibly negligible except at A, this would not cause any great change in the pressure amplitude for the vast majority of auxultation vibrations. But on the stream line conception it must be obwious that in fig. 35 as compared with fig. 34 there is a great reduction in the flux at the outlet A.

One other observation lends further support to this later conception. I find that the diaphragm form in which the leading tube enters at the side as in fig. 36.

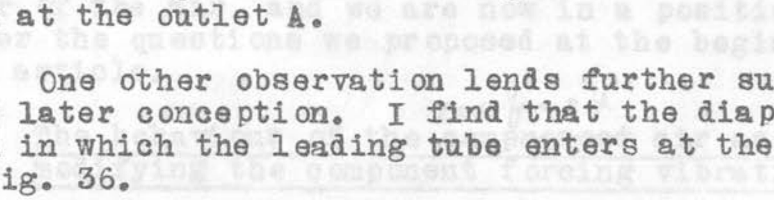


fig 36

is not so efficient in producing a volume of sound as that form illustrated in fig. 34. I think it must be tolerably clear that the motion of the air in A fig. 37 which lies opposite the centre of the diaphragm must be considerably greater than at B.

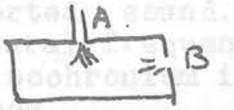


fig 37

The most efficient form of diaphragm pattern would therefore appear to be that designed by Dr. Skinner, fig. 38

The Bowles pattern however was originally introduced chiefly because of its convenience in use in patients who could not sit up. Dr. Skinner however has apparently had the idea that the diaphragm possesses special intrinsic merits. ·X·

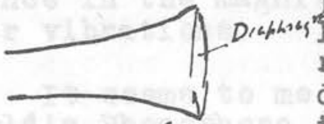


Fig 38

He appears to have formed the concept of theair in motion as indicated by the stream lines in illustration and to have seen that the ordinary mode of insertion of the conducting tube leads to a reduction in intensity.

Summing up then, it appears thatt by accepting in part the fundamental conception on which Rayleigh~~s~~ demonstrates the theory of resonance in air~~,~~ cavities viz. the conception of the kinetic energy of the vibrating mass being sensible only in the vicinity of the communicating channel while the potential energy is calculated without reference to the space variation of pressure in the chamber, combined in part with the idea of the whole mass moving in such a way as to bring the phenomena of stream lines into play, leads us to build up a tolerably notable idea of the behaviour of the air, and we are now in a position to answer the questions we proposed at the beginning of this article.

(1) The behaviour of the ~~compressed~~ confined air as regards modifying the component forcing vibrations:-

The only frequency to be considered is the gravest natural tone of the confined mass of air. The overtones are so high that they do not fall within the range of corporeal vibrations. In the case of an incident regular train of waves coming from the body of frequency very closely approximating to the

·X· This form is made by Bailey. Described as Skinners chestpiece with phonendoscope end. It is not clear that diaphragm is Dr Skinners addition.

gravest natural tone, the phenomenon of resonance will be marked; the particular vibration will be amplified out of proportion to the others and give a distorted sound. Where the air chamber is small its natural frequency is high and in addition very exact isochronism is necessary to elicit sympathetic resonance.

The larger the airchamber the lower its fundamental note and the greater will be the range of frequencies in the vicinity of its own natural frequency to which it will respond.

Apart from these there can be no sensible difference in the magnitude of the response for all other vibrations.

It seems to me that only in such forms as Arnold's Phonophore (where other resonating factors have to be considered) or in the large form of diaphragmatic instruments, can distortion from this cause take place; and further its occurence is circumscribed by the necessity of a regular train of corresponding forcing vibrations, a condition not by any means obviously commonly fulfilled.

(2) <u>The occurence of adventitious elements by way of vibrations having no corresponding forcing vibrations</u>;- This appears to me highly probable and it to be in large measure the explanation of the superimposed elements or as Williams called them "reverberations" attributable to the properties of the chest-piece. The larger the confined air space the lower its fundamental note and the more it is likely to interfere with the forcing vibrations. One can demonstrate this effect by holding a chestpiece such as Arnold's phonophore close to the ear while some external disturbance is coming from the surrounding atmosphere e.g. the rumble of a passing tram-car, or again if with the earpieces in the meatus one listens to the conversation of a friend directing the chestpiece to him, The voice acquires a "resonating" quality which is much more probably due to free vibrations of the Stethoscopy system than to the unequal magnification of the component vibrations of the voice.

This feature must in general be objectionable. It gives one an entirely false conception of the volume of sound coming from the chest. It may lead us to hear quite a volume of sound in one case and appraise the chestpiece accordingly where as with another we hear practically nothing at all, for the deduction we should logically draw would be more accurate in the latter case.

This leads us to lay down the principle that large air chambers in general are to be avoided but if for other considerations they are advisable then the occurence of free vibrations should by guarded against by ~~pervading~~ breaking up the space with perforated diaphragms or some other such device.

(3) The dependance of the behaviour on the periodicity or aperiodicity of the forcing vibrations has now been fully discussed. When the forcing vibrations are periodic we expect a corresponding periodic train of waves transmitted to the tubes. Distortions by the magnifications of one component more than an-other only occurring in the case of very approximate isochronism between the forcing vibrations and the gravest natural frequency of the confined air.

If aperiodic we anticipate a series of irregular impulses along the tubes registering the true character of the original disturbance with a superimposed resonating quality.

(4) To determine how the dimensions of the cavity are related to the volume of sound. The larger the dimensions of the cavity the greater will be the volume of the sound in general. Firstly, because a larger cavity generally implies a greater area of covered body surface. Secondly the larger cavity will general mean greater amplitudes of the boundary, and thirdly on account of both these reasons, The magnitude of the kinetic energy is greater in the vicinity of the outlet.

……

THE BEHAVIOUR OF CHEST PIECES.

The contents of the articles on resonance and the transference of sound energy from the body surface to the chest piece and the behaviour of the enclosed air makes it possible to deal briefly and concisely with chest pieces in general.

Taking the common case of the binaural instrument with rubber tubes we can sum up the action of the chest piece.

1. By considering it simply as the boundary of the enclosed air.

2. By regarding it as a vibrating system.

1. The chest piece as the boundary of the enclosed air. It was seen that much the better way to deal with the vibration of the enclosed air is to adopt the ideas on which the theory of resonators is based. It is quite hopeless to try and visualise a sound wave advancing from the body surface. It follows at once that the actual shape of the chest piece as far as the mould of its internal space is co concerned is a matter of minor importance, and that the only point to be attended to is that the leading off tube should be so placed that the energy of motion of the vibrating air in the vicinity of its commencement is as large as possible.

Arnold's phonophore for example does not collect the sound in the manner commonly supposed viz.inthe bell shaped part and thence reflecting it down the conducting tubes.

2. The chest-piece as a vibrating system. We are only interested in the chest peice as a vibrating system in so far as it is capable of setting up vibrations in the enclosed air.

Now as a vibrating system it is subject to forcing vibrations impressed upon it by the vibrating body surface and its motion of course is determined as already outlined in the general consideration of resonance. To repeat once more.

Suppose it be subjected to a periodic vibration. Its motion at the beginning is determined by two factors, its own properties and the applied force. But very shortly it will be vibrating with the same frequency as the applied force and with an intensity proportioned to the applied force. If a complex periodic vibration be applied we expect all the components to be equally transmitted except in the case of approximate isochronism between any of the natural modes of vibration of the chest piece and the forcing vibration.

I have experimented with a number of different chest pieces and ear specula to try and elicit their natural tones. Now putting them under the most favourable conditions for the gravest tones viz. by suspending them, I found that the natural notes are all very high lying outside the range of normal auscultation sounds. Further the application of the chest piece to the body surface does not permit these tones to be generated because of the damping and the natural vibrations of the metal when applied to the body must probably in all cases be beyond the range of hearing. This leads to the conclusion that the metal parts probably in all cases give an exact replica of the forcing vibrations. There is no distortion only the intensity i.e. the amplitudes of the vibrations will depend on the ease with which the metal parts can be made to vibrate.

The vibration of the metal parts will be greater the thinner, lighter and more highly elastic (in the true physical sense). the material of the chest piece and the smaller its inertia.

Possibly in the case of thin metallic chest pieces the gravest natural note may be low enough to add to the auscultated sounds a superimposed tonal mass of sound of a high ringing quality, the genesis of which may be conceived analogous to the rumbling in some stethoscopes due to the dimensions of the air cavity elsewhere referred to, but I am inclined to think that does not happen in ordinary forms.

RESONANCE IN TUBES.

In the discussion on vibrations in tubes we postponed the question of stationary waves and resonance. We simply thought of the enclosed column of air as a portion of a medium transmitting the waves. But the air in the tubeis an enclosed mass and in consequence it may equally well be treated as a vibrating system.

The behaviour of such a system is well illustrated in the theory of the organ pipe.

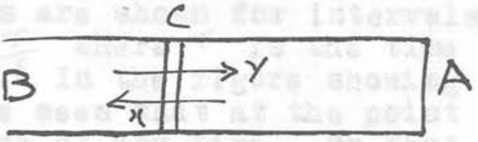
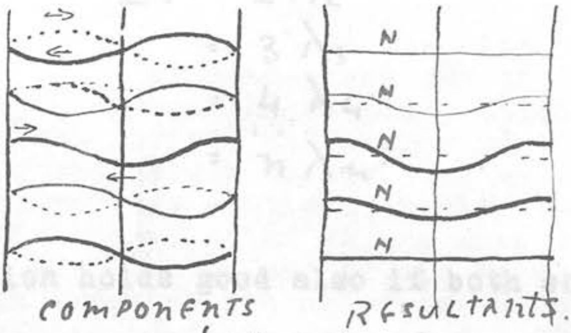


fig 39.

Consider the case of a long narrow cylinder fig. 39 closed at end A and imagine a harmonic vibration incident on the open end B. The waves are propagated along the tube to the closed end A where they suffer complete reflection. So that in thinking of the motion of anymthin lamina C we have to visualise a train of waves passing through it in the direction X Y and an equal and opposite train in the direction Y X. The final result is obtained by combining these two trains which are of course of equal period and sensibility equal amplitude.

Now the combination of such a double set of waves give rise to what are known as stationary waves.

This combination and the resultants are illustrated in fig. 40.



COMPONENTS RESULTANTS.

fig 40

The heavy line indicates the incident waves the dotted line the reflected, while the displacements are shown for intervals of time equal to $\frac{T}{8}$ where T is the time of one vibration. In the figure showing the resultant it will be seen that at the point N no motion takes place at any time. So that there is no propagation of the disturbances. The column of air is now vibrating, in a manner analogous to a vibrating body. It has in fact been forced into vibration by an external applied periodic force.

The natural frequency of vibration of such a column of air is determined by the length of the column and the conditious at the ends. This is the problem of the organ pipe.

When the pipe is open at both ends the lowest natural mode of vibration i.e. the fundamental tone is determine by the relation

$$2l = \lambda$$

Where l is the length of the pipe and λ the wavelength. In addition there is a whole series of overtones natural to the pipe determined by theb relation.

$$
\begin{aligned}
2l &= 2\lambda_2 \\
&= 3\lambda_3 \\
&= 4\lambda_4 \\
&\vdots \\
&= n\lambda_n
\end{aligned}
$$

This relation holds good also if both end are closed.

If one end be closed and one end open the corresponding relation are

$$
\begin{aligned}
4l &= \lambda_1 \\
&= 3\lambda_3 \\
&= 5\lambda_5 \\
&\vdots \\
&= (2n-1)\lambda_n
\end{aligned}
$$

Applying this theory to the binaural stethoscope it is noted that we have two narrow columns of air. The end conditions are difficult to determine definitely. The proximal end being closed by the tympanic membrane probably corresponds to a closed end but it is complicated by the motion of the membrane.

The distal end approximate~~ly~~s perhaps more to an open end the larger the dimensions to the air chamber of the chest piece the more will the commencement of the leading off tubes approximate to an open end.

We are thus led to expect a disproportionate amplification of those vibrations whose period coincides with ons of the natural modes of vibration of the contained air. Also by reasoning similar to that used in the behaviour of the air in the chest piece, it is possible that the irregular disturbances may set the air column vibrating according to its own natural period, without there being any corresponding forcing vibrations. If we auscultate the hiss of a gas fire with a binaural head-piece and tubes of various length without chest piece attached, there is a very obvious difference of pitch according to the length of the tube employed. As the pitch various continously with the length of the tube I think we are more justified in assuming that the column of air is being set in motion in a manner analogous to the operation of an organ pipe or flute, and is not simply reproducing vibrations already representing the complex sound of the burning gas.

But these effects are small in comparison say with those attributable to Arnold's Phonophore. They are small because of the small diameter of the tube. Still, definite claims as regards the utilization of a variable column of air have been made by several experimenters.

....

INSTRUMENTS WITH DIAPHRAGMS.

Instruments such as the Bowles pattern in which a diaphragm or thin circular plate forms an integral part of the chest piece constitute a class by themselves. These diaphragms are generally made of a thin plate of celluloid material. Their function has been much discussed but to very little purpose.

For the most part they are found only in flat types, of chest piece so constructed as to permit, easy examination of the patient without putting him to the exertion of sitting up in bed; but Dr. Skinner apparently ascribing special acoustics merits to the diaphragm itself has introduced it into the funnel form of chest piece.

The current views on the subject are represented by the opinions of Cabot, and Norris and Landis. Cabot is, of opinion that the function of the diaphragm is simply to prevent the soft parts from encroaching upon the closed air space. (49)

He discounts the idea of it acting as a diaphragm in virtue of the fact that he gets equally good results with a diaphragm that is cracked. Norris and Landis ascribe a similar observation to Montgomery but also suggest that the sound waves are amplified by the disc. (50)

Both these atatements illustrate in point the observation previously made as regards the want of scientific precision. The vibrations of a disc (a thin circular plate) depend upon (1) Its intrinsic structure, (2) Its dimensions (3) The manner in which it is held fixed, (4) The nature and mode of application of the applied force, (5) The external physical conditions. By an unqualified reference to the vibrations of a disc it is generally tacitly assumed that the external conditions are represented by air on both sides or at least by a fluid medium, a condition which does not obtain in stethoscopy. on the other hand the fact that the disc is not free to vibrate does not put out of court ~~on~~ consideration of its intrinsic qualities.~~of [illegible]~~. The observation of the crack is besides the point. It simply means we have two or more thin plates of smaller dimensions to consider instead of one, and the only difference would be in the natural modes of vibration none of which as we shall see can be of any importance.

Further in the consideration of the application of the disc against the skin we have to determine whether in addition to the applied forces normal to the disc there is the possibility to a tangential component as such would give rise to extraneous effectshhaving no counterpart in the intracorporal disturbances.

We see then that when a disc is in use we have to consider in addition to its own intrinsic properties, the mode of application of the vibration forces and the external circumstances modifying its behaviour.

There is hardly any question that the diaphragmatic type of instrument yields a greater volume of sound especially in the auscultation of pulmonary sounds. Thisincreased volume of sound has been regarded with suspicion by many clinicians and the use of this form especially by beginners has been strongly condemned.

The increased volume of sound has been variously ascribed to the greater area of body surface generally covered by this type. (2) To the diaphragm preventing the encroachment of the soft tissues on the receiver and to the vibrations of the disc.

Considering these explanations in detail In general the area covered by this form of chest piece is larger than the open type, and for reasons previouly stated this does result in an increase in the volume of sound.

The effect of the encroachment of the parts into the chest piece has already been referred to in the article on the Study of the Enclosed Mass of Air. The problem as in that article has to be viewed in a double light viz. the effect in reducing the volume of the enclosed air, (2) the effect in reducing the effective motion of the air in thevicinity of the leading off tubes.

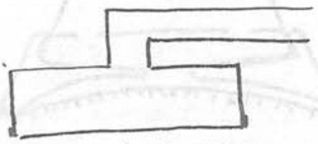


fig 41

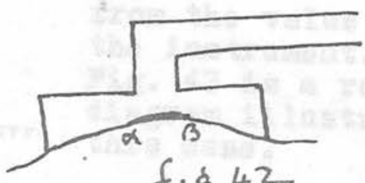
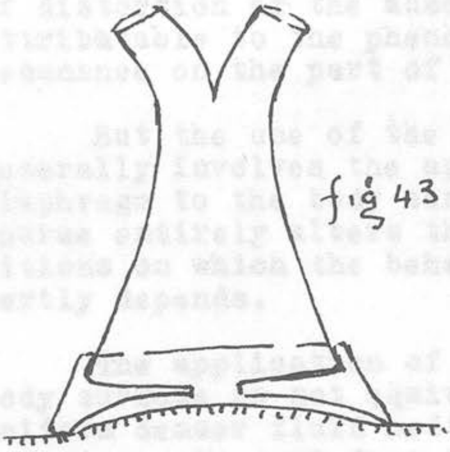


fig 42

Consider the case illustrated in figure 41 and fig. 42. Fig 41 is a common form with diaphragm, fig 42 is the same form in use with diaphragm removed.

In this form of instrument it must be tolerable obvious without further discussion that the part played by the metal parts in the reception and transmission of vibrations is of no account. We are only concerned with the variations in pressure effected by the vibration of the diaphragm, and the value of the Kinetic energy in the vicinity of the leading off tubes. The diagrams and the reasoning of the previous article on the behaviour of the enclosed mass of air indicated how these two function are related. In fig. 41 the motion of any individual part of the diaphragm constitutes something towards the total Kinetic energy in the vinicity of the leading off tube. In fig. 42 where the soft parts have largely obliterated the air chamber only the small area marked ~~aB~~ αβ has any decided importance in setting the air inmthe conducting tube in vibration.

The removal of the diaphragm is tantamount to reducing the area of body surface covered.



I have found the encroachment of the soft tissues into the lumen of that otherwise excellent form introduced recently by Marr, to detract in a similar way from the value of the instrument. Fig. 43 is a rough diagram illustrating this case.

Apart from these considerations there is the problem of the intrinsic behaviour of the diaphragm which I am of opinion is largely responsible for the characteristic increase in sound.

The easiest way is again to regard the diaphragm as a vibrating system subjected to external forcing vibrations. This leads us to deal first with the natural modes in which a diaphragm may vibrate.

The mathematical theory of the vibrations of in plates or discs is extremely complex. It involves the use of some of the fucntions of Higher Analysis, e.g. Bessel functions but as early as 1787 Chladni devised an interesting method of demonstrating the nodal lines by the use of fine sand and the figures so obtained are known as Chladni's figures. Diagrams of which may be seen in any text book of sound e.g. Barton's. (51)
The position of these figures depend upon the points at which the diaphragm is clamped.

In stethoscopy we are usually concerned with a thin plate clamped at the boundary. If this were suspended in a uniform fluid medium e.g. air its natural nodal lines would take the form of a series of ~~conentire~~ concentric circles and a series of diameters. Considering the size of the discs in use these natural frequences must be high and cannot fall within the range of the vibration of auscultation signs so that we may exclude the possibility of distortion of the auscultated sounds attributable to the phenomena of sympathetic resonance on the part of the diaphragm.

But the use of the diaphragmatic pattern generally involves the apposition of the diaphragm to the body surface, and this of course entirely alters the external conditions on which the behaviour of the disc partly depends.

The application of the disc to the body surface is not equivalent to having a uniform denser fluid medium on one side such as water. We must form the concept of the disc making contact with the body surface at a large number of discrete points but not at all points as in the case of a fluid medium. Under these conditions the nodal lines become extremely irregular- so extremely irregular and complicated that neither mathematical analysis nor experimental physics can be of the least service in guiding us to an approximate idea of the behaviour of the disc; but I think we may with fair certainty lay aside any consideration of the question of sympathetic vibrations on the part of the disc. This leaves us to consider in what way the disc in virtue of its intrinsic vibration characteristics is likely to modify in transmitting the forcing vibrations applied to the body surface.

If we try to analyse in sufficient detail any problem of vibrating bodies we come down ultimately to the vibrations and behaviour of the particles of which the bodies are formed.

Try to follow the motions of the particles constituting the chest wall and those of the thin disc applied to it . Think only of the super~~perical~~ficial layer of tissues. These are subjected to a succession of applied forces displacing them outwards while their return motion depends upon their elasticity (in the true physical sense). Now the return motion of a thin disc such as is used in stethoscopy must tend to be more rapid than that of the tissues so that the superficial layer will with the disc in use be restored to its undisturbed position more quickly than if it were dependent only on its own elasticity; so that while the intervals between the successive compression and rarefactions of the air enclosed in the air chamber remain unaltered the character of the waves might be supposed to be altered in a manner from (1) to (2)

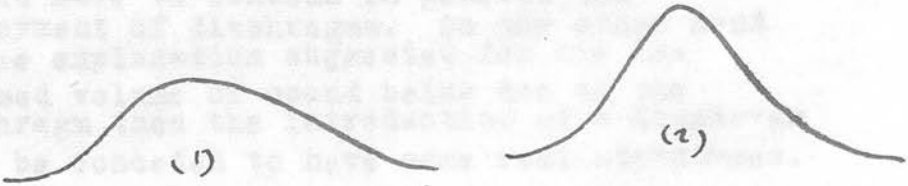


fig 44

illustrated in figure 44 and this would give a more effective pulse along the conducting tubes.

It must be very difficult however to surmise what the realtive effect will be in waves of different frequencies and what the exact result will be in a complex vibration:- In addition instead of having the diaphragm subjected to a uniform variation of pressure we have an impulse applied at a very large number of discrete points.

I think also that the stretching and relaxation of the skin applied against the diaphragm may not altogether be neglected but it is very difficult to arrive at any idea of the importance of these various points.

In summing up the position as regards the desirability of employing a diaphragm against the body surfaces we have to realise first the fact that the vibrating structures pathological or normal are subjected to diverse modifications before they affect the body surface, that we have to frame our deductions as regards the nature of the conditions within the chest from the vibrations of the body surface.

The interposition of a diaphragm means tha addition of another accessory vibrating system likewise responsible for further modifications. It would certainly at first appear to be obvious that the less indirect our deductions require to be the more are they likely to be satisfactory, so that we should have to condemn in general the employment of diaphragms. On the other hand if the explanation suggested for the increased volume of sound being due to the diaphragm then the introduction of a diaphragm must be conceded to have some real advantages.

....

FUTURE OF AUSCULTATION - A.PROSPECT.

Mediate auscultation has now been in common practice for nearly a hundred years, and it is difficult to see how it is likely to be replaced by any other means of physical diagnosis. Skiagraphy it is true has of recent years been brought to such a pitch of perfection as to render it not only a valuable adjuvant but also in some cases to surpass even auscultation in demonstrating a lesion, but for obvious reasons the skiagram can never be of such general applicability and not all the lesions that give auscultating signs can be made manifest by Xrays.

But auscultation cannot be said to be by any means yet a perfect art. The lines along which we could wish and may reasonably hope for development are these:-

(1) Easier detection of faint signs.

(2) Better understanding of the mechanism of the production and transmission of intracorporeal vibrations, and this incidentally implies a more precise knowledge of the macroscopic physiological and pathological conditions associated with auscultation signs.

(3) Further insight into the character of the sounds.

(4) An exact understanding of the properties and behaviour of the instruments employed.

During the past hundred years there has been very little real advance on Laenec's work. Numerous modifications have been devised but beyond the introduction of the binaural form there has been little essentially either new or brilliant. From the study of his work one is almost led to conclude that while his experiments were simple and might easily have been devised and carried out by a physician of ordinary intelligence with equally accurate conclusions,yet he seems by a stroke of genius and to have appreciated how little further improvements he was likely to effect, and so, instead of wasting his time over trivial details of design proceeded to make use of his new instrument,and in a comparatively short life satisfactorily recorded the great majority of auscultation signs.

Side by side since then a double effort has been going on.

(1) the effort to improve the understanding of physical signs and

(2) the effort to improve the instrument.

The outlook at the present day is more focussed on the instrument itself. The general feeling seems to be necessity for instrumental devices to give us more information. Especially so is this the case in small lesions associated with small pathological changes and correspondingly small variations from normal acoustic signs. The certain diagnosis of the early tubercular focus for example is probably the most urgent and difficult work the stethoscope is called upon to perform.

I think it may be safely affirmed that we cannot hope for any effectual augmentation in auscultations signs unless we introduce an accessory intermediate source ofenergy.

From the vibration emitting surface to which we apply the stethoscope we have a certain small amount of energy to make use of and it is idle to talk about amplifying the sonorous vibrations by modifications in the chest piece. As far as one can see at present the accessory source must take the form of an electrical device. We have then the problem (1) To use the vibration energy (kinetic or potential) of the small area of chest wall to control the source of electrical energy and the magnified vibrations in this larger source have again to be made manifest by reconversion to sound. I made memtion in the introductory chapter of the possibilities of the oscillation valve and the advance in phenomena in general sound in consequence of the great interest in Wireless Telephony. Since writing that article the following has appeared in the B.M.J.

France.

(From our Special Correspondment)

"The Electric Stethoscope"

A new and interesting piece of apparatus was presented recently to the Faculty of Medicine.

It is a loud speaker stethoscope, which amplifies the sounds of the heart and lungs, separates them by means of "filters" eliminates all other sounds than that to which the observer wishes to listen. It was brought to France from America by Dr. Le Mée and Dr. Hellé, and seems to be less a medical invention than a contrivance perfected by telephone engineers. The audience which crowded the amphitheatre saw a patent stated to be suffering from Bright's disease, while the disc of the loud speaker, filled the hall with the sound as of a charge of cavalry. It is easy to conceive the value such an invention may have for teaching, but imagination can look forward to a time when the specialist shall sit at his fireside, pipe in mouth, and telephone receiver at ear, examining patient after patient with whom he is successively connected by the telephone exchange. Better still, we can suppose the auscultation sounds registered on photographic discs and collected to form a cardiopathic library. The doctor of to-day must be chemist, tomorrow he will have to be an expert in physics also. It will not be easy for our successors to obtain their medical qualification.

B.M.J. Dec. 5/1925. page 1085.

This article is of course typically French, and characteristically optimistic, and funny, but such a device though probably only a novelty indicates the possibilities. There are two main difficulties in this work. viz.

(1) the sound receiving instrument.

(2) the sound emitter.

Some modification of the carbon microphone has as far as I know been employed so far for the sound receptors but even that is not sufficiently sensitive for the faint sounds we specially want to amplify. The valve circuits do not offer the difficulties that high frequency circuits do in the problem of distortion. The frequencies of auditory vibrations are relatively low and it is comparatively easy to arrange the value of inductance capacity and resistance of the circuits with included walves, so that all the vibrations shall be amplified in proportion giving consequently no distortion effects.

The sound emitter whether it be loud speaker or headphone is another problem. In the latter there is the problem of diaphragms in the former the additional trouble of horns or discs. But these are being very successfully handled.

As regards the value of filters one is chary in passing an opinion. The great difficulty in wireless telegraphy has been the elimination of irregular sounds. Regular vibrations can be amplified or diminished by passing the associated electrical currents though circuits suitably tuned but the principle upon which this is effected depends on the vibrations being regular and in auscultation we are undoubtedly concerned with irregular vibrations probably more so than with regular.

In spite of all this one feels certain that in the oscillation value lies the key to future advance in stethoscopy.

A considerable space in this thesis has been devoted to the phenomenon of selective resonance.

Its importance in auscultation so far is quite unknown. Efforts to make use of the phenomenon have been made on various occasions chiefly in connection with heart murmurs, and the part played by sympathetic vibrations in cardiac and pulmonary acoustics is certainly worth investigating, though selective resonance can hardly be appreciable on the part of the ordinary forms of stethoscopes in use. There are two possible convenient means available at present for such an investigation

(1) By properly constructed resonators as outlined by E.T.Paris in Science Progness Vol.XX No.77 July/25. in which the auscultatory phenomena might be investigated direct.

(2) By an intermediate electrical stage. The phenomenon of resonance in electrical circuits is exactly parallel with resonance in a vibrating system, and has the advantage of being under greater control . The use of tubes of varying length as resonators has been frequently tried.

The autogenous vibratory disturbances which it seems to me may arise within the tubes renders their use of doubtful value. It is possible that by making use of the circular tube, as indicated in

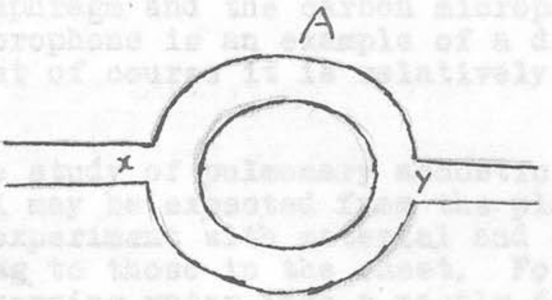


Fig 46.

Rayeigh's Sound would be a more satisfactory and convincing experiment.

In this apparatus one limb A is varible. If both limbs are equal we should get waves diverging at X and travelling round the tubes meeting again at Y in phase.

Now by altering the length of A an amount equal to half the wavelength of the vibration concerned the waves can be made to be in opposite phase at Y and consequently no disturbance is propagated along the tube to C.

The presence or absence of regular vibration will be rendered manifest by the corresponding diminution in volume.

Another possible field for reserch is the location of the origin of the disturbances. The curious phenomenon that if one ear be given a slight advantage over the other e.g. by lengthening one limb of a binaural stethoscope, that ear alone is conscious of the sound, might be made the basis of this investigation. The phenomenon was used in the hydrophone service during the war for direction finding, in sea water.

The measurement of the intensity of the heart sounds and their significance was a subject in which Boek took special interest. He deviced a special instrument by which he sought to compare the intensity of the first sound in different areas but the measurement of the intensity of sound is a field in physics in which nothing has been done.

The rapidity with which physical research is now forging ahead renders it probable that a different detecting device will be introduced to eliminate the diaphragm and the carbon microphone. The hot wire microphone is an example of a different principle but of course it is relatively insensitive.

In the study of pulmonary acoustic phenomena a great deal may be expected from the plan of endeavouring to experiment with material and conditions approximating to those in the chest. For instance Parach by dropping water into a partly filled vessel shewed that the current view as regards the genesis of metallic tinkle obtainable in case of hydropneumothorax was entirely wrong and that the true explanation which can also be demonstrated be experiment is that it is caused by air bubbling through fluid.

……

SUMMARY.

The Thesis begins with a prefactory note explaining the origin of my interest in this unusual subject viz. my early recognition of the importance of diagnostic acoustics the great want of scientific precision in the relevant literature, my previous training in physics and work during the war on the propagation of sound in sea water.

The introduction which follows refers to the enormous variety of instruments on the market indicating the difficulties in determining the principles on which the construction of the stethoscope is based. It discusses the reasons why we ought to aim at understanding the mechanism and not simply lie down to the dictum "Choose your stethoscope and stick to it!" A remark follows on the slow progress during the past 100 years and reasons therefore are given. A brief preliminary reference is made to present day possibilities. The purpose of the thesis is stated with some notes regarding the subject matter.

In the short history no attempt at completeness is made. It is only sufficiently full to give the reader a general outlook on the subject.

The nature of the problem is then discussed with an outline of the points that call for investigation.

The methods and means by which the problem may be tackled are then considered these are,

(1) By Mathematical deduction.

(2) By Experimental Physics.

The limits of each method are discussed. Experimental means are beset with unusual difficulties. A rigorous mathematical treatment is an impossibility, but the results obtained from simple problems can be used to guide us to an idea of the probable behaviour of the instrument.

The article on sound is a preliminary consideration of the phenomena to which reference is made in the course of the work. This and the following article on Sound Sensation and Hearing are included ~~for the textbook~~. to avoid have to refer to a textbook

This latter article is a short consideration of the phychological aspects of hearing to indicate that conclusions regarding the stethoscope cannot be arrived at as if the ear were a recording device.

The article deals with,

(1) Noises and Tones.
(2) Analysis of Complex Sounds.
(3) Attention.
(4) Sound direction.

The Acoustics of the external ear with which in stethoscopy we are specially interested are dealt with. The meatus has no effect in altering the received sounds. It is simply a protective device the auricle acts as a sound collector and assists in determining direction.

The following section on the application of the stethoscope to the ear deals with the problems that arise in connection with the flat and the knob forms of ear pieces and an argument is put forward based on experiment that true bone conduction is an insignificant phenomena in stethoscopy even in the monaural form and that what is usually called bone conduction is really transmission by the meatal walls to the tympanic membrane and apparatus of the middle ear.

The next two sections deal with the transmission of sound by the column of air in tubes and by the tube walls. The conditions obtaining in stethoscopy are seen to complywith those required for the transmission of sounds in tubes without change in character or loss in intensity. In connection with the question of the energy interchange from tube walls to contained air some interesting experiments originally carried out by Davies are described at length with the conclusions derived therefrom.

Having dealt with tubes and ear pieces the work goes on to the chest end. The first consideration here is Pulmonary Acoustic Phenomena.

In this chapter we try to arrive at a true conception of the behaviour of the chest wall and the structures that lie within it when they are disturbed by vibrating forces. Objection is made to the prevailing concept of conduction of sound though the tissues, it being argued that we ought to think of the tissues as bodies in a state of vibration as a whole. An endeavour is made to arrive at the real nature of things by following the sequence of events in vocal resonance. The final conclusion is that in stethoscopy we are really primarily concerned with mass vibrations of localareas of the chest wall. Skoda's theory of consonance and Henry Sewall's of mural vibrations are feferred to.

The manner in which sound energy is transferred from the system constituted by the thorax to the system constituted by the stethoscope and its contained air is then dealt with in detail. In the binaural instrument with open chest-piece it would appear that the air in the chest-piece is a necessary link in the path of conduction and that it is set in motion partly by the vibrating body surface, and partly by the solid parts being made to vibrate directly by the virtue of their contact with the chest wall.

Theterms selective resonance and sympathetic vibrations are of frequent occurrence in stethoscopy. Objection is raised to their use and to show what they actually mean the subject of resonance is dealt with mathematically. This treatment enables us to form a clear idea of how a system subjected to external applied forces will vibrate. A summary is added to this article as an alternative to following the mathematical work. These ideas are applied in the following section to the general physics of stethoscopy we are enabled to state in a broad manner how the stethoscope will respond to forcing vibrations.

The same ideas are again interpreted in relation to Pulmonary Acoustic Phenomena. The behaviour of the enclosed mass of air in the chest piece is then fully considered.

. . . .

After pointing out the great variation in results where the volume of the enclosed air appears to be the deciding factor. The method of trying to understand events by following a wave front from base to apex of chest piece is disposed of. Two other concepts are then framed in its place.

(1) The fundamental concept on which the theory of resonators is built viz. to regard the pressure at any instant throughout the chest piece as being uniform. The energy of motion to be sensible only in the vicinity of the exit to the tubes.

(2) To think in the motion in terms of the flow of fluid through an orifice.

The best idea of the behaviour of the air appears to be arrived at by a combination of these. These ideas are built up gradually by the help of various illustrations. The possibility of resonance is also considered and the only frequencies to be considered seem to be those closely approximating to exact isochronism with the gravest natural tone.

A short following article on the behaviour of chestpieces deals with the solid parts.

Brief consideration is also added regarding resonance in the column of air in the tubes.

Special consideration is given to the behaviour of diaphragms and an argument put forward that they must be considered to have some influence on the sounds besides that of preventing the encroachment on the lumen of the chest-piece.

The final article deals with possible developments in auscultation, in the near furture the lines along which such developments are to be expected and the means by which they may be effected.

A list of references is added and an appendix illustrating a variety of stethoscopes.

....

CONCLUSIONS.

It is submitted that the reasoning, mathematical demonstrations, and experiments of the thesis warrant the following conclusions.

(1) That the appreciation of the exact nature of things with reference to the vibratory behaviour both of the stethoscope and of the tissues is a very complexproblem.

(2) That these articles demonstrate what actually is involved in the problem.

(3) That the few problems treated in more detail, e.g. the subject of resonance point to the hopelessness of anything like an exact mathematical or physical interpretation of the behaviour of the instrument.

(4) That there is a great need for exact physical concepts both as regards the behaviour of the stethoscope and the thoracic structures e.g. that we should drop the term conduction (or at least restrict it to its proper physical connotation) and try to visualise the stethoscope and its contained air, as well as the corporeal structures, as systems or bodies performing molar vibrations and not as media in which wave propagation takes place.

(5) That owing to the variable relationship between sound sensation and the external physical disturbances to which they are due, and owing to the manner in which sound sensation can be modified by education and personal bias in virtue of the subjective phenomena of analysis and attention, the exact comparison of any two instruments cannot be effected; and having so far no experimental means of recording and measuring faint sounds it cannot be done by purely objective means.

(6) That the phenomena of selective resonance especially as attributable to the behaviour of the stethoscope is hardly ever observed. That it is not to be expected, because in the first place, the majority of auscultation sounds cannot be supposed capable of representation by a periodic function, i.e. that they partake more of the character of noises, and in the second place, the only frequency at which selective resonance might occur would be that corresponding to very close isochronism with the gravest natural tone of the air enclosed in the chest piece.

(7) That what is usually designated selective resonance on the part of the instrument is not a magnification of a vibration emenating from the body surface, but that it is an adventitious element- a superimposed tonal mass of sound generated by the enclosed air being set in vibration by irregular disturbances as well as regular and that it is related only in intensity to the forcing vibrations.

(8) That true Bone conduction in stethoscopy even in the monaural pattern is largely a mismomer. That so called bone conduction is really the transmission of a vibratory motion to the apparatus of the middle ear by the meatal walls and hence that the subsequent path, as in normal hearing as via. the stapes and not as in true bone conduction by the vibration of the cochlear walls.

(9) That diaphragms cause a modification in the sound in virtue of their own intrinsic properties and do not merely serve the purpose of preventing the encroachment of the soft parts on the lumen of the chest piece.

(10) That in the binaural instrument with rubber tubes transmission by the column of air is alone important. That the vibrations of the column of air depends on the

variation in pressure in the air in the chest piece. That the variation in pressure in the air in the chest piece is effected both by the vibrations of the body surface and by rapid variations in the configuration of the chest piece, and that the best idea of the behaviour of this mass of air is to be arrived at by combining the fundamental concepts on which the theory of resonators is framed with the theory of stream lines in the motion of fluids.

(11) That the guiding considerations on which a binaural stethoscope should be designed are these.

(a) Consideration should first be given to the acoustics of the instrument, secondly to the ease with which it can be used, thirdly to portability.

(b) The part in contact with the body surface should not be metal but a bad conductor of heat.

(c) The actual shape of the chest piece is not directly a matter of importance.

(d) The interposition of a diaphragm means further modification of the original physical disturbances.

(e) The larger the area of body surface covered the louder the sounds.

(f) The thinner and lightly and more highly elastic (in the physical sense) the walls of the chest piece and the smaller its inertia, the greater will be the contribution to the variation in pressure in the air it encloses.

(g) The adventitious rumbling effect of the air chamber should be eliminated either by making the chamber small or by breaking the space up by perforated diaphragms.

(h) The exit from the chest piece should be placed where the energy of motion is greatest

(i) The air chamber should be deep enough to allow the encroachment of the soft parts within the lumen without producing any appreciable diminution in the energy of motion in the vicinity of the exit.

(j) Rubber conducting tubes are an accepted necessity because of their flexibility. Though flexible metal means louder signals.

(k) The ear pieces must fit exactly and without the slightest discomfort into the meatus and the normal to the exit should be in the direction of the meatus. This can be provided for by the proper curving of the head tubes and their union by a spring of suitable tension.

(12) Finally that advance in stethoscopy depends upon the introduction of an accessory source of energy controlled to act as a relay probably through the medium of the oscillation valve

……………………………………

REFERENCES

1. Diseases of the Chest and the Principles of Physical Diagnosis, 3rd Edition 1924, G. W. Norris & H. R. M. Landis.

2. Magnification of Acoustic Vibrations by Single and Double Resonance, E. T. Paris Science Progress, Vol.XX, No.77 July 1925.

3. Lancet 1828-29 Vol. 11. p. 586.
4. Lancet 1828-29 Vol. 11. p. 721.
5. Lancet 1829-30 Vol. 1. p. 96.
6. Lancet 1829-30 Vol. 1. p. 509.
7. Edinburgh Medicial Journal 1830, Vol. 104, "On the Diagnosis of the Diseases of Lungs and Pleura", J. C. Gregory, Physician to the Royal Infirmary, Edinburgh.

8. Laenec and the Evolution of the Stethoscope, British Medical Journal, 1907, Vol. 11, p. 6.

9. Lancet 1828-29, Vol. 11 p. 684.
10. Medical Gazette, Dec. 11 1840, p. 440.
11. Lancet 1843-44, Vol. 1 p. 267 "Auscultation".
12. Medico Chirurgical Review, Jan. 1841, p. 208.
13. Medical Gazette, Mar. 12th 1841, p. 906.
14. Edinburgh Medical and Surgical Journal 1841, p. 89. "Rectification in the practice of auscultation and percussion."

15. Lancet 1850 Vol. 1 p. 380.
16. Lancet 1856 Vol. 1 p. 389.
17. Lancet 1856 Vol.11 p. 175.
18. Lancet 1856 Vol. 1 p. 398.
19. Lancet 1856 Vol. 1 p. 398.
20. Lancet 1856 Vol. 1 p. 398.
21. Lancet 1857 Vol. 1 p. 256.
22. Lancet 1858 Vol.11.
23. Lancet 1878 Vol.11.

"On the Acoustic Principles and Construction of Stethoscopes and Ear Trumpets, C. J. B. Williams, M.D.F.R.S."

24. Norris and Landis, p. 114.

25. (a) American Journal of Medical Science,
1913 Feb. p. 234.
The Role of the Stethoscope in Physical
Diagnosis, Henry Sewall.
(b) New York Medical Journal, 1897, Vol. LXVl.
The use of Stethoscope pressure in Physical
examination of heart.

26. Rayleigh, Theory of Sound.

27. B. M. J. 1911, Vol. 1 p. 699.
28. Barton's Sound, p. 82.
29. Psyclology of Sound, H. J. Watt.
30. An inquiry into the Analytical mechanism
of the internal ear.
Sir. T. Wrightson & Keith.
31. Lancet 1828-29 Vol. 11.
32. Medical Gazette new series Vol. 1. 1837-38
33. Lancet 1850 Vol. 1. p. 380.
34. Norris and Landis, p. 115.
35. Lancet 1869 Vol. 1.
36. Same as 14.
37. Same as 36.
38. Same as 36.
39. Norris and Landis p. 61.
40. Norris and Landis p. 66, Fig. D
41. Barton's Sound p. 305.
42. Norris and Landis, p. 60
43. B.M.J. Oct. 28/1911. (See appendix).
44. Lancet 1873, Vol 11. Same as 23.
45. Same as 25 (a).
46. Same as 32.
47. Rayleigh's Sound, Vol 11 Chap. XVl.
48. Physical Diagnosis.
49. Cabot Physical Diagnosis.
50. Norris and Landis, p. 115.
51. Barton's Sound, p. 305.

……………………

APPENDIX.

To illustrate at a glance the great variety of instruments, I have collected from various catalogues the sub-joined diagrams.

STETHESCOPES.

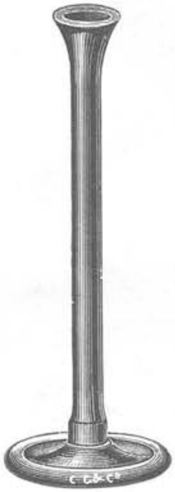
3171

3174

3176

3177

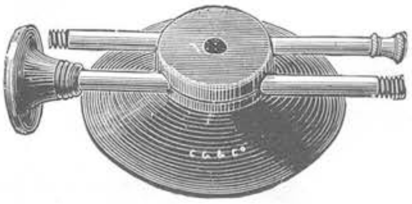
			s.	d.
3171	Celluloid, white concave ear plate, nickel plated stem	each	2	9
3174	Cedar, with screw ear plate or in one piece	,,	1	6
3175-6	Ebony ,, plug ,, ,,	,,	2	0
3177	,, ,, vulcanite screw ear plate	,,	2	0
3179	All glass, in leather case	,,	2	0



3180

3189

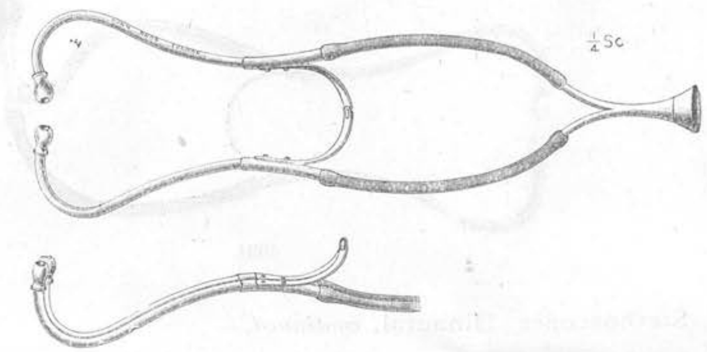
3191



3194

3180	Cedar, with ebony screw ear plate and indiarubber ring for percussion	each	3	0
3181	,, ,, ivory ,, ,, ,,	,,	4	6
3182	Assorted woods, with screw ear plate or in one piece	,,	1	0
3184	Vulcanite or ebony, reversible for pocket	,,	2	6
3189	Wormull's pattern, folding, with vulcanite ear plate and metal stem	,,	3	6
3191	Portable, assorted woods	,,	2	6
3194	Weiss's, vulcanite or white celluloid	,,	4	6
3198	,, all metal, aseptic	,,	3	6
—	Walsham's, with solid stem	,,	2	3
—	,, hollow with vulcanite ear plate	,,	2	6
—	Fergusson's ... cedar or walnut, each 2/6; pine	,,	2	0

No. **Instruments for General Diagnosis,** *continued,*—



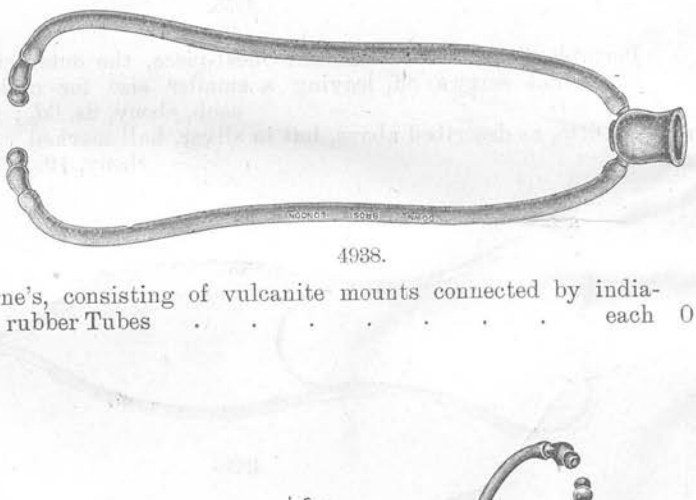
4937.

£ s. d.

Stethoscopes, Binaural, *continued,*—

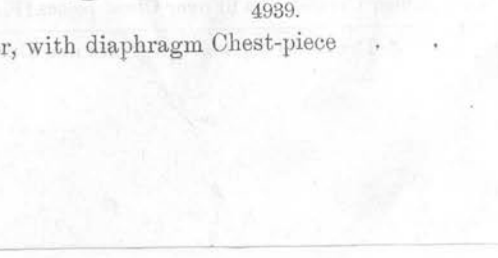
4937 Portable, with jointed spring to fold, with combined Chest-piece . . . . . each, ebony, 8*s.* 6*d.*; ivory 0 10 6

If fitted with Chest-piece as Fig. 4942, 1*s.* extra.



4938.

4938 Sterne's, consisting of vulcanite mounts connected by india-rubber Tubes . . . . each 0 4 3



4939.

4939 India-rubber, with diaphragm Chest-piece . . . each 0 5 0

No.

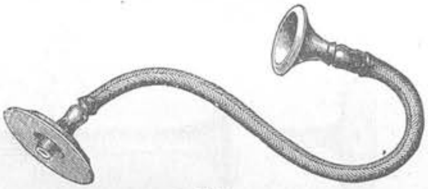
Instruments for General Diagnosis, *continued*,—


4908.

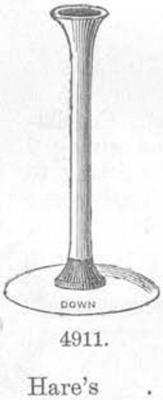

4909.

Stethoscopes, *continued*,—

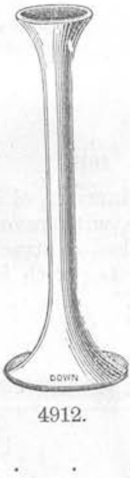
No.			£	*s.*	*d.*
4908	Fergusson's	each	0	2	3
4909	Guy's, in walnut wood, as Fergusson's, but extra light	,,	0	2	6


4910.

No.			£	*s.*	*d.*
4910	Golding-Bird's, flexible	each	0	5	0

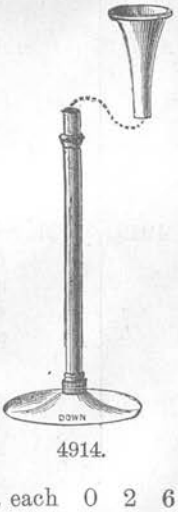


4911.



4912.


4913.



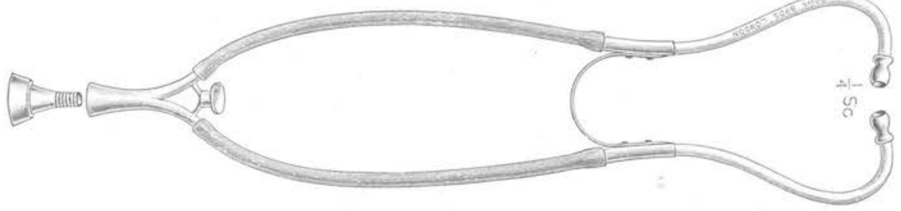
4914.

No.			£	*s.*	*d.*
4911	Hare's	each	0	2	6
4912	Hughes'	,,	0	2	3
4913	Metal, with vulcanite Ear-plate	,,	0	2	0
4914	Ditto, plated, combined with Ear Speculum	,,	0	10	0

Oct 1910

No.

BINAURAL STETHOSCOPES.



9200.

No.			£ s. d.
	Binaural Stethoscopes,—		
9200	Down Bros.' "India" model, with metal ear-pieces, double-ended metal chest-piece and finger rest, fitted with 12-in. india-rubber tubes	each	0 12 6

9201.

No.			£ s. d.
9201	Down Bros.' "Dome" model, with new registered dome-shaped metal chest-piece for readily slipping under the clothing or between patient and bed, fitted with 12-in. india-rubber tubes	each	0 11 6

NEW FORMS OF CHEST-PIECES FOR STETHOSCOPES.

9202.

9203.

9204.

No.			£ s. d.
	Chest-pieces for Stethoscopes,—		
9202	Cup-shaped with ebony end	each	0 2 6
9203	Down Bros.' new registered dome-shaped model, all metal	,,	0 3 6
9204	Mann's, with ivory end, as made for Dr. Corry Mann, Physician to Evelina Hospital	,,	0 3 6

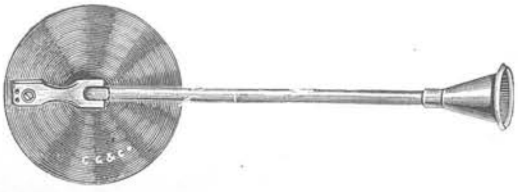
STETHESCOPES—*continued.*

3196

3196 A

			s.	d.
3196	Sir Andrew Clark's, indiarubber, nickel plated ear piece, indiarubber tip, vulcanite chest piece, with diaphragm	each	3	6
3196A	Axtrell's, with patent reversible chest piece	,,	6	6
3199	All metal, with folding ear plate	,,	5	0

3201



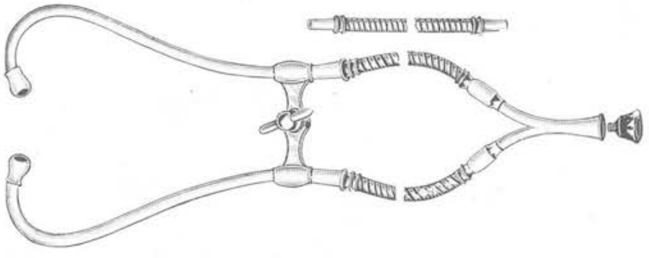
3202

3201	Solid wood	each	3	0

As described by Sir James Sawyer in the Lumleian Lectures on Maladies of the Heart, from which the following is an extract from the *British Medical Journal*:—"Messrs. Cuxson, Gerrard & Co., medical instrument makers, Corporation Street, Birmingham, have followed with much care, my directions as to the making of a Stethescope of this description, and have produced one which is satisfactory in its use, and which I find yields improved auscultatory results in auscultation of the heart." Further particulars on application.

3202	Folding, all metal, nickel plated	each	3	6

Binaural.



3200

3200	Herschell's, tropical, with spiral metal tubes, nickel plated	each	12	6

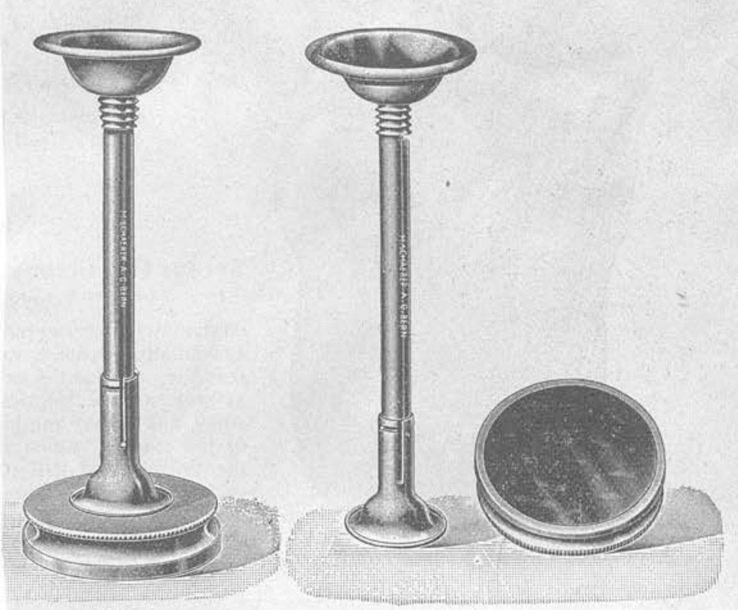


Fig. 1 Fig. 2

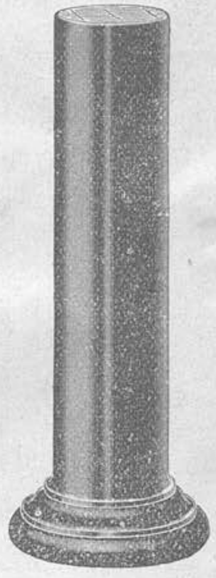
40027

Stethoscope,

Schreiber's,

can be used as a simple or re-inforced stethoscope.

Complete £ 0 12 0



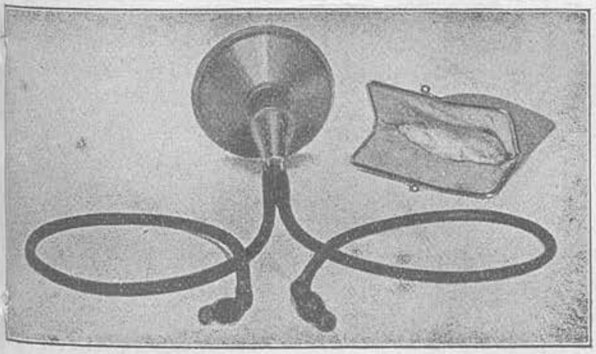
40010

Stethoscope,

Mahillon's,

made of wood, favourite pattern.

£ 0 4 5



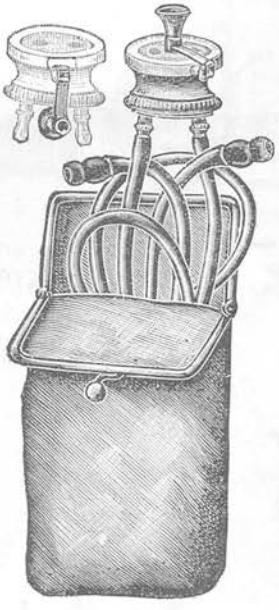
40030

Binaural
Heart and Lung Stethoscope,

Bock's,

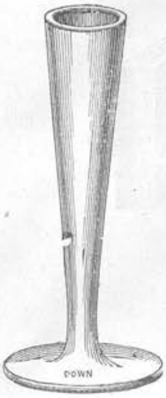
complete in case, with catch

£ 0 9 8

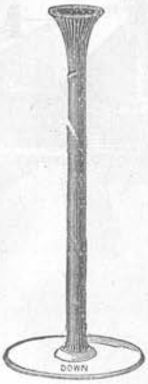


4150

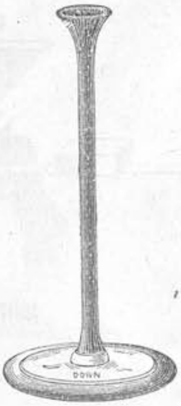
No.	**Instruments for General Diagnosis,** *continued,*—			



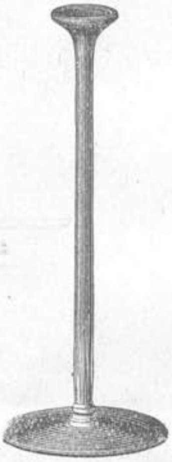
4899.



4901.



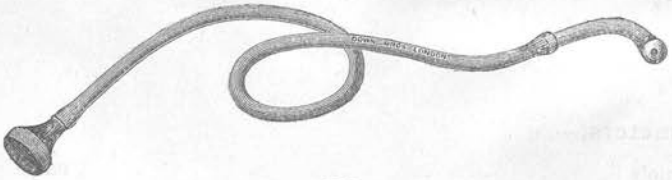
4902.



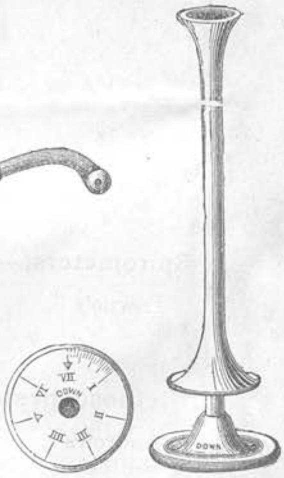
4903.

4904.

No.	**Stethoscopes,** *continued,*—	£	s.	d.
4902	Burrows' ebony, with ivory Ear-plate and india-rubber Ring for Percussion . . . . each	0	5	6
	Ditto, with ebony Ear-plate and india-rubber Ring for Percussion . . . . each	0	3	6
4903	Celluloid throughout . . . . each	0	2	6
4904	Ditto, with metal stems, imitation ivory, or tortoiseshell mountings . . . . each	0	4	0



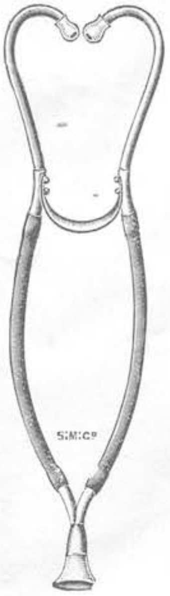
4906.



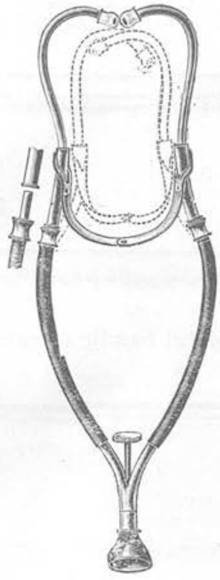
4907.

No.		£	s.	d.
4906	Clark's, Sir Andrew, flexible . . . . each	0	4	9
4907	Dobell's . . . . ,,	0	3	6

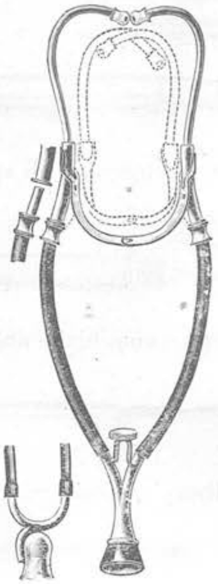
DIAGNOSTIC INSTRUMENTS.



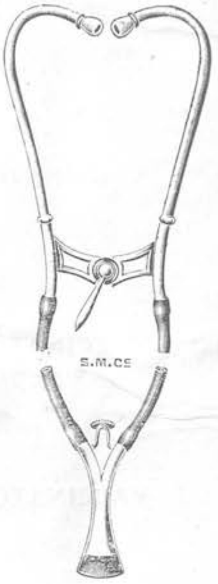
4140



4141

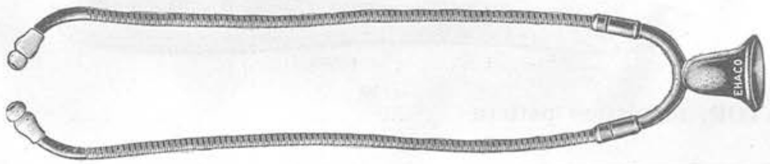


4142



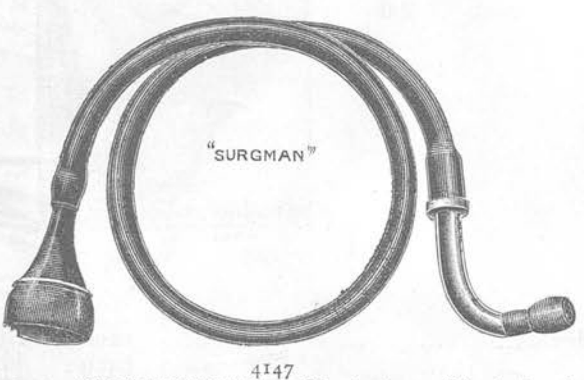
4143

4140	**STETHOSCOPE,** Binaural, nickel plated, with fixed spring and chest piece ...	4/6
4141	Ditto, folding, with chest piece	6/6
4142	Ditto, with improved chest piece	7/6
4143	Ditto, Hirschell's set screw model with any chest piece	10/

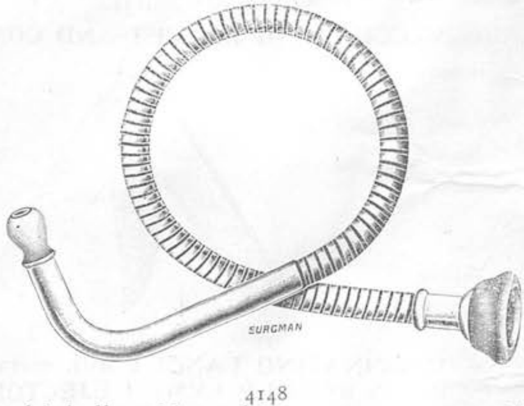


4146

4146	**STETHOSCOPE,** all metal, flexible	6/6



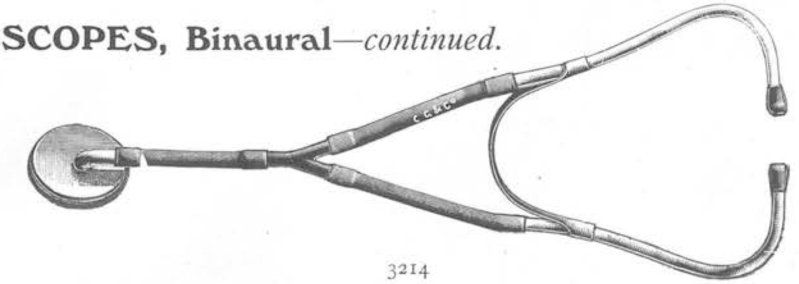
4147



4148

4147	**STETHOSCOPE,** Sir Andrew Clarke's, single, with india rubber tubing	4/6
4148	Ditto, all metal	6/6

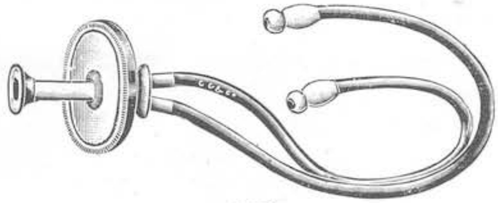
STETHESCOPES, Binaural—*continued.*



3214

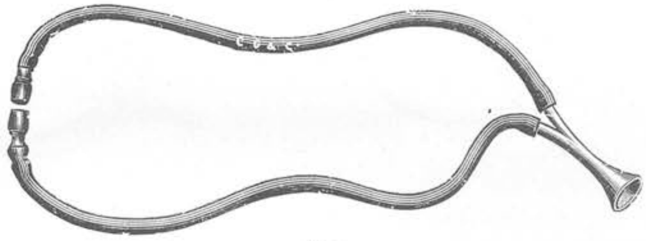
No.	Description		s.	d.
3214	Bowles'	each	12	6

With this Instrument almost all sounds produced within the chest can be heard much more distinctly than in other Stethescopes. For anyone who has difficulty in hearing the ordinary Cardiac or Respiratory sounds, or for one who is partially deaf, this Instrument is invaluable.



3215

3215	Phonendoscope, with celluloid mounts and arabasque tubing, in soft leather pouch complete	each	7	0
3216	,, ,, vulcanite mounts and red tubing	,,	6	0



3217

3217	Simple form, vulcanite chest piece and ear tips, long rubber tubing ...	each	5	0

STETHESCOPE FITTINGS.

3218

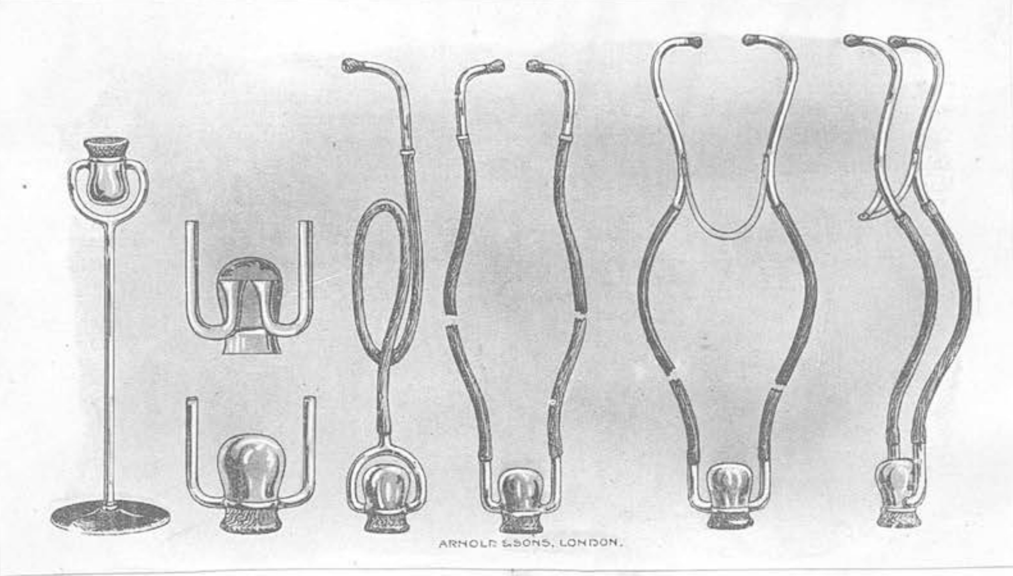
3219

3219A

3219B

3218	Chest-piece, with diaphragm, nickel plated	each	3	0
3219	,, nickel plated, and vulcanite or celluloid	,,	2	6
3219A	,, Skinner's, nickel plated, and vulcanite, with finger rest ...	,,	3	0
3219B	,, Charsley's, with thumb rest and ivory end	,,	5	0
3219C	,, and Phonendoscope combined, angular	,,	6	6
3220	Ear Tips ... ivory, 1/- ; vulcanite, 6d. ; indiarubber, 6d. per pair.			

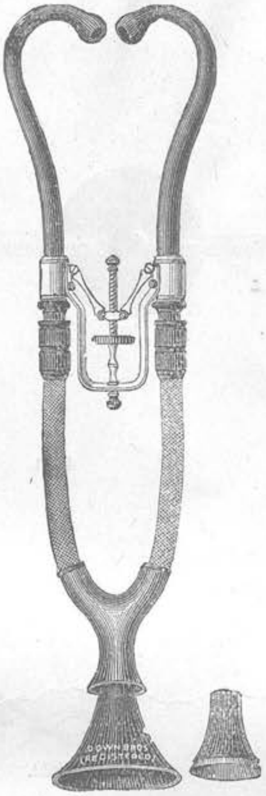
ARNOLD AND SONS, LONDON.



Extract from the "BRITISH MEDICAL JOURNAL," October 28th, 1911.

"Some years ago Messrs. Arnold & Sons, of Giltspur Street, E.C., brought out a stethoscope which they named the 'Phonophore.' Its construction secured a considerably increased volume of sound, and the appliance gained favour among those dissatisfied on general grounds with ordinary stethoscopes, or whose needs, owing to some lack of aural acuity, were not adequately met thereby. Of this appliance the same firm has recently brought out a modification in which the bell-like attachment constituting the chest-piece is provided with two sound tubes instead of one. These tubes are continued upwards, the sound thus being conveyed to each ear direct from the collecting chamber. Each ear, therefore, receives the same amount of sound, although the same amount of sound may not be perceived if there is any difference in the hearing power of the two ears. The gross volume of sound is also greater than supplied even by the original 'Phonophore.' This modification of the 'Phonophore' is worth examination by anyone interested in stethoscopy."

Instruments for General Diagnosis, *continued*,—



4924.

Stethoscopes, Binaural, *continued*,—

No.		£	s.	d.
4924	Denison's . . . . each	2	5	0

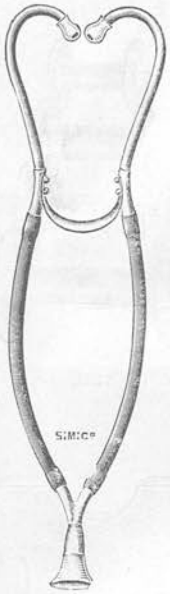
By Charles Denison, A.M., M.D., Denver, Colorado, U.S.A.

I. Quality of Sound.—It is claimed for this Instrument that, being made of vulcanite, the elevated sounds common to metallic Stethoscopes are eliminated.

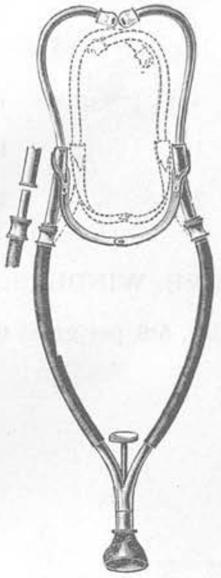
II. Form of the Instrument.—The size of the lumen is largest at its attachment to the bell, gradually decreasing until it reaches the ear-ends, thus concentrating and conducting the waves of sound.

III. The Bell Endings.—These are of four sizes: the smallest or stationary end for use with children; the medium size bell for general use. The india-rubber cup which fits into this is for making pressure against the uneven surface of the chest walls, as in the case of emaciated consumptives. The largest bell (3 inches diameter) is for what Dr. Denison has termed stethoscopic percussion, a process to be made use of when bronchiectasis, excavation, or softening is suspected. It consists in using forcible percussion over and around suspected portions during expiration, while this large bell is held in front of, and one to three inches from, the patient's open mouth.

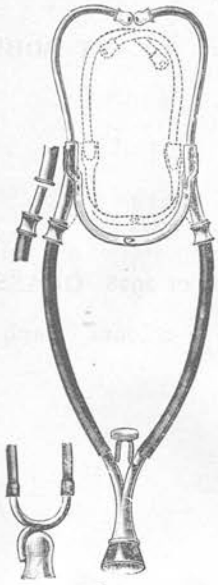
BINAURAL STETHOSCOPES.



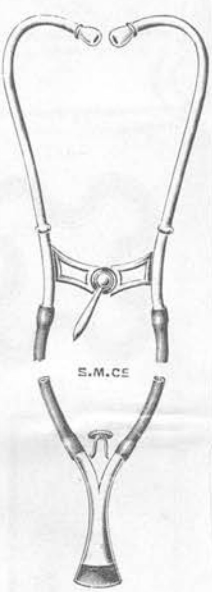
2870



2871



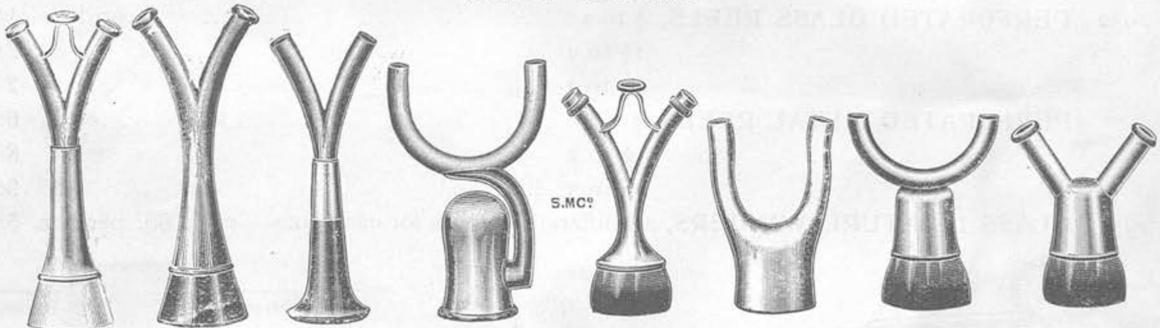
2872



2873

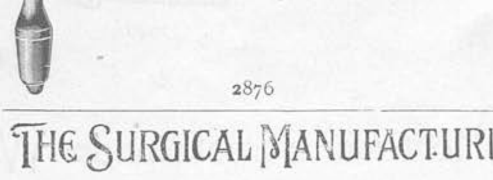
2870	**BINAURAL STETHOSCOPE,** nickel plated, with fixed spring and C pattern chest piece	4/6
2871	Ditto, folding, with B, E, G or H chest piece	6/6
2872	Ditto, with D or Y chest piece	7/6
2873	**HIRSCHELL'S SET SCREW MODEL** with any chest piece	10/6

CHEST PIECES.



2874 A	B	C	D	E	F	G	H
3/0	2/6	1/6	3/6	2/6	3/6	2/6	2/6

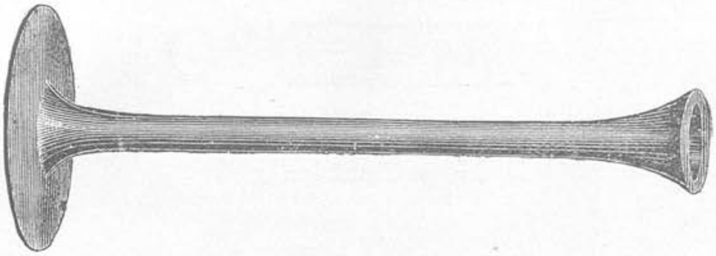
India Rubber caps ... each 1/0



2876

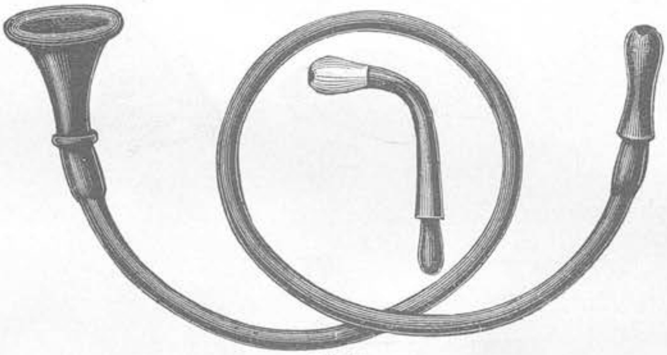
2876 **PERCUSSOR, TRAUBE'S** 2/6

Instruments for General Diagnosis—*Continued.*



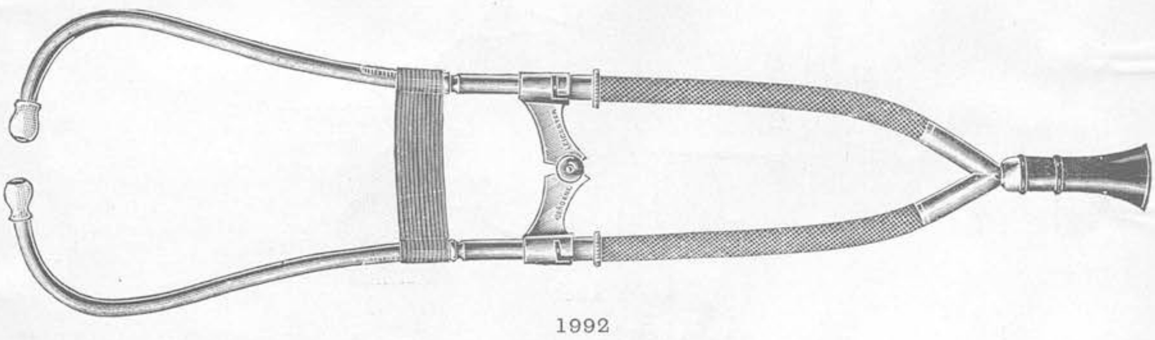
1986

No.			£	s.	d.
1986.	Stethoscope, cedar, ebony, oak, sycamore, or walnut … … …	each	0	2	0
*1987.	,, (Burrow's), ebony, with ivory ear-plate to screw off … …	,,	0	3	6
*1988.	,, ,, ebony, with ivory ear-plate and india-rubber Ring for Percussion … … … … … … … …	,,	0	4	6
*1989.	Stethoscope, all celluloid … … … … … … …	,,	0	2	0
*1990.	,, nickel-plated stem, with vulcanite ear-plate … … …	,,	0	2	6



1991

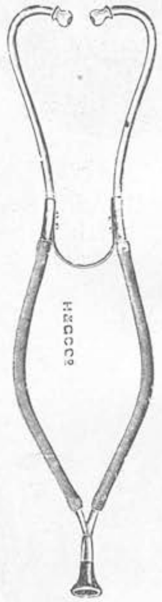
No.			£	s.	d.
1991.	Stethoscope (Sir Andrew Clark's), with soft india-rubber ear-tip, and india-rubber cap on chest piece … … … … … … …	each	0	4	0



1992

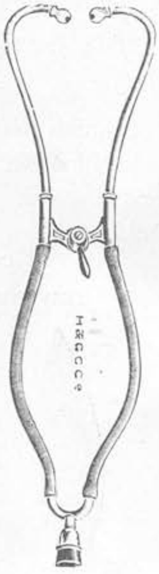
No.			£	s.	d.
1992.	Stethoscope, Binaural, with silk covered tubes and ebony chest piece …	each	0	15	6

CLINICAL INSTRUMENTS.

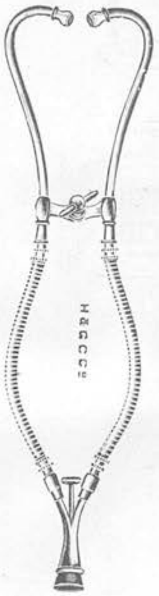


3422

3423

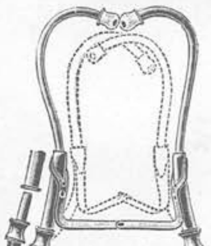


3424

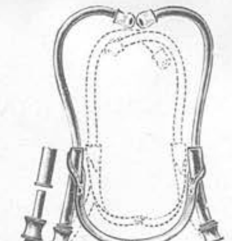


3425

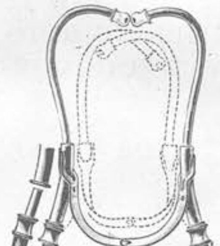
3422.	BINAURAL STETHOSCOPE, complete with red, black or arabesque rubber tubing, black chest piece	4/6
	Ditto, best quality	6/6
3423.	Ditto, with imitation ivory chest piece and finger rest folding spring ... . each	7/6
	Ditto, best quality...	10/–
3424.	Ditto, extra strong, with fixing screw and best quality tubing	10/6
3425.	Ditto, tropical pattern, with special metal tubing	12/6



N 3425A

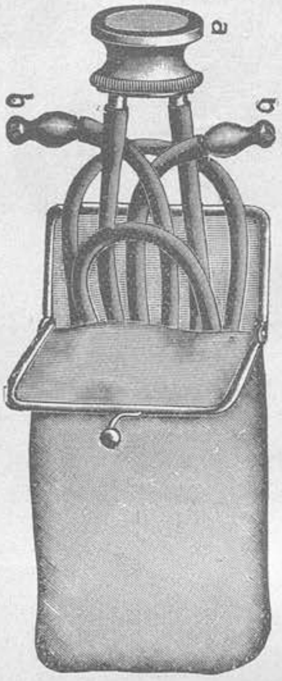


N 3425B



N 3425C

N 3425A, B and C. BINAURAL STETHOSCOPE, new patterns ... ... each complete 12/6



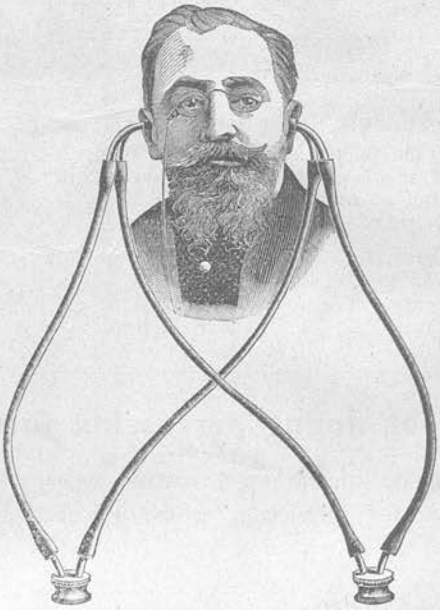
40019

Microphone Endoscope,

complete in case with catch
£ 0 4 10

40020

Ditto, with funnel. — The funnel can be moved and is used for the auscultation of the heart sounds.
(Not illustrated.)
£ 0 5 9



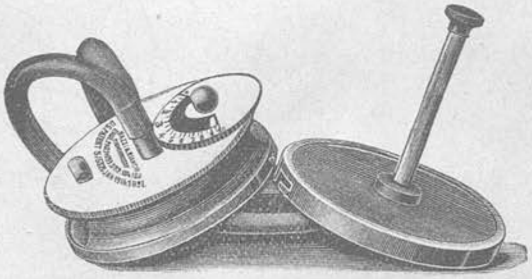
40022

Binaural Stethoscope,

or Double Stethoscope,

according to *von Muralt*, Davos,
complete with tubes and ear pieces, in case with catch £ 0 13 3

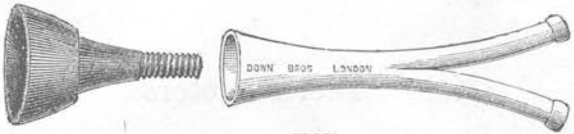
The Stethoscope is specially used for distinguishing autochthone noises from symmetrically continued ones (see Beiträge zur klinischen Tuberkulose Bd. XVI).



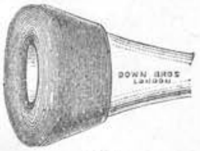
40032—40033

No.

Instruments for General Diagnosis, *continued*,—



4940.



4941.

No.	Chest-pieces for use with Binaural Stethoscopes (*see also page* 1629),—	£	*s.*	*d.*
4940	Combined, the distal end screws off, leaving a small size for children, each, with ebony end, 2*s.* 6*d.*; all metal, 3*s.* 6d.; ivory	0	4	6
4941	India-rubber Cushions (Murray's), to fit over Chest-pieces, each	0	0	9

4942.

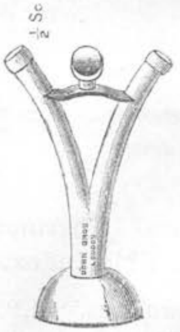
No.		£	*s.*	*d.*
4942	Skinner's, with finger rest, each, ebony, 3*s.* 6*d.*; all metal, 4*s.* 6*d.*; ivory	0	5	6

This will be found a useful and convenient addition to the Binaural Stethoscopes in common use, and is supplied with Figs. 4926, 4935, 4936 and 4937 Stethoscopes at an extra cost of 1*s.*

4943.

4944.

4945.

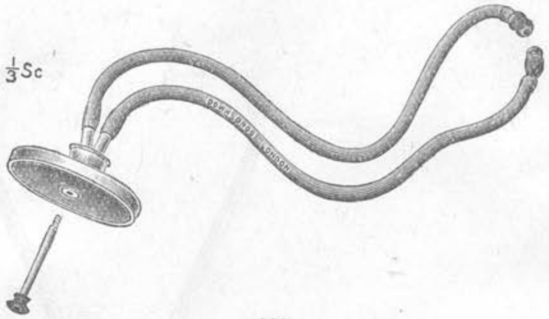


4946.

4947.

No.		£	*s.*	*d.*
4943	Charsley's, for patients lying in bed, with thumb rest and ivory end . . . . each	0	5	0
4944	Hopwood's, for patients lying in bed (suggested by Dr. Hopwood, of London Fever Hospital) . . . . each	0	2	0
4945	Meyer's . . . . each, ebony, 3*s.* 6*d.*; ivory	0	5	6
4946	Schofield's, suggested by Dr. Gerald Schofield, of Bloxham, each	0	3	0
4947	Weatherhead's, ivory . . . . „	0	4	6

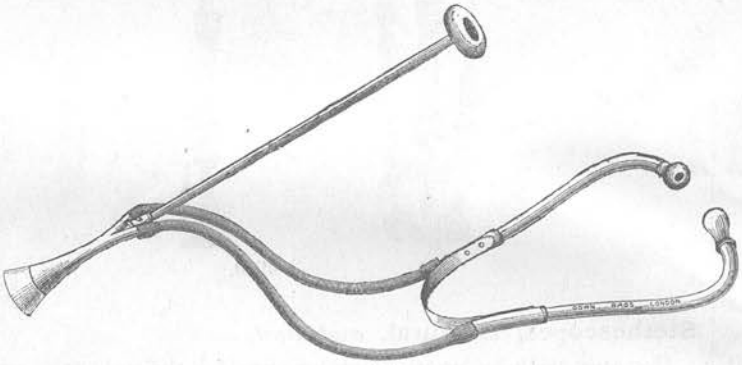
No. **Instruments for General Diagnosis,** *continued,—*



4932.

Stethoscopes, Binaural, *continued,—* £ *s.* *d.*

4932 König's "Gloria" (a modified Phonendoscope) in leather pouch each 0 7 6



4933.

4933 O'Kelly's, with forehead rest for Auscultatory Percussion, each, ebony, 11*s.* 6*d.*; ivory 0 13 6

Extract from "British Medical Journal," April 28, 1894.

The difficulty of performing auscultatory percussion unassisted suggested to Dr. T. O'Kelly, Chipping Norton, the necessity of an addition to the binaural stethoscope which should leave the hands of the auscultator absolutely free, while ensuring at the same time perfect contact of the chest-piece with the patient's body. Messrs. Down Bros., under his instructions, have made this addition, which, as will be seen from the engraving, consists of a metal rod 20 cm. in length, and 5 mm. in diameter, surmounted by a metal disc 25 mm. in diameter, and covered by an india-rubber cushion for the forehead to rest upon when in use. The opposite end of the rod is fixed by a bayonet joint on a metal pin 10 mm. in length and 5 mm. in diameter, substituted for Skinner's finger rest. The india-rubber cushion acts somewhat after the manner of a ball and socket joint when in contact with the auscultator's forehead, allowing considerable movement of the head in every direction, without tilting up any portion of the chest-piece. The smaller chest-piece should be used. The forehead rest can be easily detached and carried in the pocket, while the pin may be utilised as a finger rest. Dr. O'Kelly has had this addition in use for about two years and has found it invaluable.

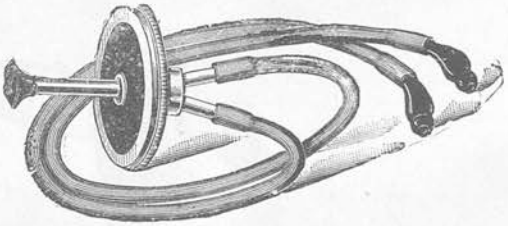
3428

3429

3430

N 3430A

N 3430B



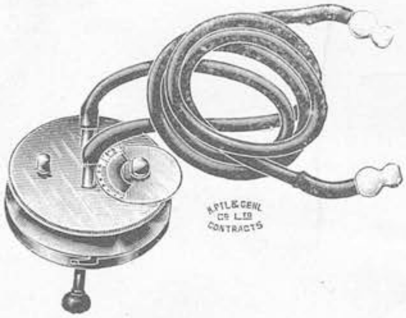
3414

3428.	MONAURAL STETHOSCOPES (SINGLE). Polished wood to plug...		1/-
3429.	Ditto, portable, all metal		3/6
	Ditto, with celluloid ear piece		3/6
3430.	Ditto, improved model, folding ear plate	each	3/6
N 3430A.	Ditto, aluminium, with detachable plate	,,	3/-
N 3430B.	Ditto, adjustable, cedar wood	,,	1/6
	Ditto, ,, ,, best quality	,	3/-

A

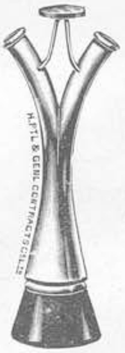
B

C



N 3414A

D



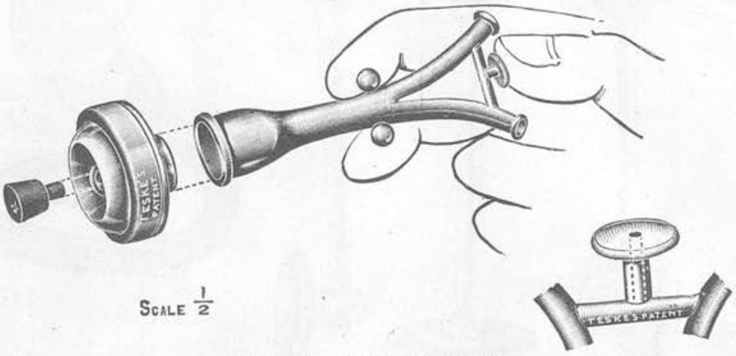
E

F

G

3414.	PHONENDOSCOPE, complete, in leather case		5/6
N 3414A.	Ditto, Biazzi Bianchi, complete in metal or leather case		15/-
	CHESTPIECES FOR BINAURAL STETHOSCOPES, patterns A and B	each	2/-
	,, ,, ,, ,, C, D and E	,,	2/6
	,, ,, ,, ,, F	,,	1/6
	,, ,, ,, ,, G	,,	1/-
	STETHOSCOPE TUBING, extra heavy red india-rubber	per yard	2/6
	,, ,, light ,, ,,	,,	1/6

CLINICAL INSTRUMENTS.



3421 (TESKE'S PATENT).

3421. TESKE'S STETHONOSCOPE.

The instrument comprises in itself three separate instruments—a Stethoscope, as used with a Binaural, a Stethophonoscope, a Phonoscope and Localiser.

Can be carried in the waistcoat pocket.

It renders the different sounds in the body natural, there being no resonance of the instrument.

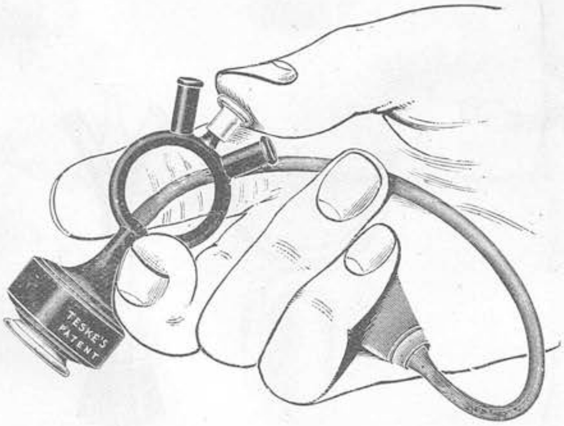
It is provided with an automatic sound regulator, so that the sound reaching the ear can be made more distinct at the user's will, simply by moving the finger on the finger rest.

No undressing required when using the Stethonoscope.

Means are provided to hold the instrument in a firm and comfortable position, so that sounds caused by the friction of the fingers are completely avoided.

The instrument renders the sounds very loud and distinct, and very sensitive.

Made in metal, nickel-plated	each	12/6
Binaural head piece and tubing for above	extra	5/6



N 3421

N 3421. TESKE'S PNEUMATIC STETHONOSCOPE, an improved form of the above

instrument, complete with bellows...	each	16/6
Binaural head piece for above	extra	5/6

TESKE'S UNIVERSAL STETHONOSCOPE, fitted with ivory plugs for intercostal

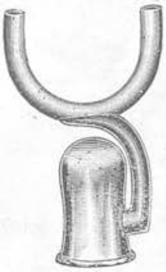
observation and measurement	each	18/6
Binaural head piece for above	extra	5/6

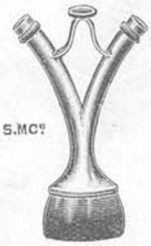
CHEST PIECES.


4164


4165


4166


4167

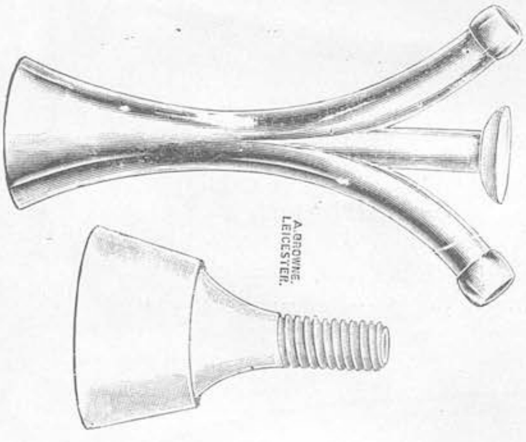


4168

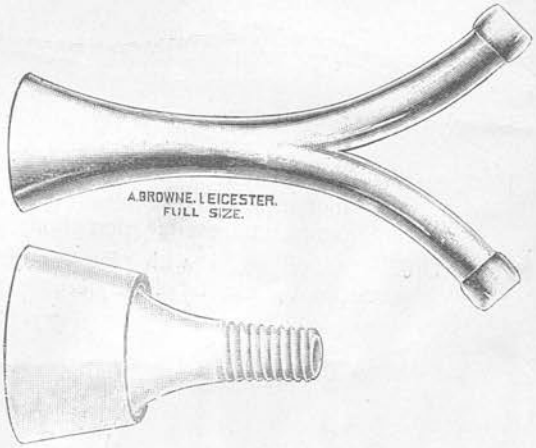

4169


4170


4171

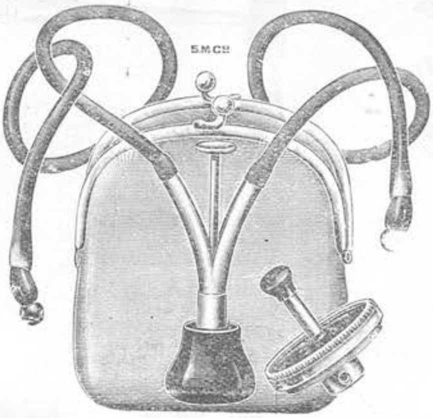


1999



2001

DIAGNOSTIC INSTRUMENTS.

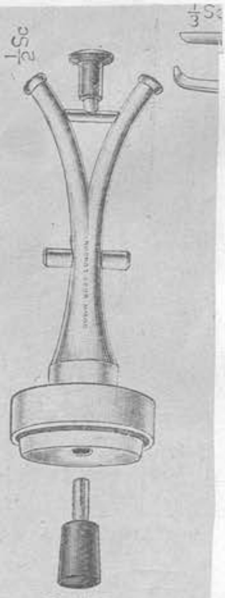


4149

4149	**PHONENDOSCOPE**, "The Surgman," with 2 chest pieces	7/6
4150	Ditto, with heavy chest piece	8/6

9237—**Bazzi Bianchi Phonendoscope.**

In chamois pouch, **12/6**
In round metal box, **12/6**
Ditto, improved form, with valve action, in chamois pouch, **16/6**
In round metal box, **16/6**

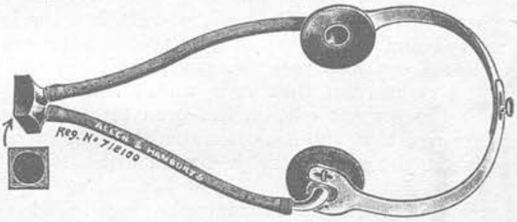


S 468
Stethonoscope Chestpiece

An Improved Stethoscope.

Dr. A. F. G. **Spinks** (Newcastle-on-Tyne) writes: The binaural stethoscope shown in the accompanying figure has been designed to give increased comfort and cleanliness when in use. The present custom of using stethoscopes with penetrating earpieces is not a clean one, nor is it free from the risk of infecting the ear passages, as the occurrence of many painful ears among members of the medical profession has proved.

Briefly, the advantages claimed for this new pattern are: (1) It is much more comfortable in use, and especially in prolonged use, than the present patterns with penetrating earpieces. (2) It cannot affect the ears, and the earpieces do not come into contact with the ear wax, so that it remains always clean. (3) The spring, which is detachable and adjustable, rests on the head, and therefore does not intervene between the eye and the chest-piece, as is the case with most of the present patterns of binaural stethoscopes. (4) The square chestpiece is more comfortable to hold than the prevailing round pattern, and is better adapted for the intercostal spaces.



The stethoscope has been made from my specification by Messrs. Allen and Hanburys, Ltd.