Compressed Air — its physiological and pathological effects

By

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Preface

The cause of any want of completeness which may be judged to characterize some of the observations embodied in the following pages, will be intelligible to those who have a practical acquaintance with the work which afforded the opportunity of this study, and who can appreciate therefore, the difficulties which as a country practitioner, I experienced in pursuing such an inquiry.

- The inaccessible position of the working chambers of the Calicoes, the fact that the workmen were foreigners speaking a different language, having prejudices against being made the objects of scientific observations;
- the constant noise of machinery, or any other professional duties only leaving night as the time available for this special work; these, taken with the interruptions caused by an outbreak of small-pox in my practice were some of the difficulties encountered.

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opportunities of studying the effects of compressed air on the human framework have been infrequent, because under natural conditions of depression, such as exist near the Caspian and Dead Seas, its results are unappreciable; and again because in mines, where the degree of increased pressure may be considerable, its effects are obscured by the altered composition of the atmosphere.

It is only therefore in such processes as diving, working at the preparations for the founding of piers in deep water, and in establishments where the use of compressed air is had recourse to as a remedial agent, that its effects on the healthy and diseased body respectively, may be studied.

In the belief, that one of the main improvements in the Therapeutics of the future, will consist in the application of
Compressed air to the treatment of ailments in which experience and experiment shall have proved its use to be of remedial value. I have resolved that my Thesis shall be an account of some of the symptoms which came under my observation in men engaged at the founding of the deep water piers of the Forth Bridge.

And though happily in a sense it is not part of my duty to chronicle serious accidents, or loss of life; yet opportunity sufficient to compare the leading features produced, with those noted in similar undertakings elsewhere, was frequently presented.

Rarefied air, such as is experienced in ascending high mountains, and in balloon ascents, produces, like compressed air, certain bodily discomforts, to a limited extent compatible with life.
The condition known as Mal-des-Montagnes, being first observed at an altitude about 1700 feet above the Eternal snow line.

The train of symptoms induced both by compressed and by rarefied air, is due to their influence on the blood system.

In the one case, namely, to the tendency to complete saturation of the Oxyhaemoglobin of the arterial blood with Oxygen, and in the other to the diminution of the amount of available Oxygen for the requisite saturation of the arterial blood Oxyhaemoglobin.

And this latter barometric de-oxygenation has such an influence, that, though in healthy people at moderate heights the poverty of Oxygen is not manifestly appreciable; yet when such people are the subjects of disease the anaemic type is readily noticed.
Respiration of attenuated air has also been recommended and tried for the treatment of certain affections, and more than fifty years ago methods for making its application practicable had been used by Jundel, Jundanel, and others; whilst residence in altitudes where rarefied air could be naturally inspired has been frequently and extensively adopted, with marked success in the treatment of Phthisis.

It happened strangely enough about the time the Forth Bridge piers to which reference has been made were being constructed that I had opportunity of witnessing the effects of compressed air as experienced by divers. A diver had gone down to inspect the moorings of the Forth Guard-ship, and, owing it was supposed,
to his life, and other lines having become fouled among the moorings, was lost, in about forty fathoms of strong current water. The day following another diver attempted to descend, to ascertain accurately the cause of the previous day’s disaster. When about half-way down, he felt himself quite unable to guide his movements, the strong currents existing whirled him round and round, and he signalled to be brought to the surface which he reached in a very exhausted condition.

Some minutes afterwards when I saw him he was gasping for breath, his lips were blue, his face livid, and his pulse small, rapid, and feeble.

Around the neck there existed extensive extravasation of blood into the cellular and other tissues, forming a powerful mechanical
impediment to respiratio, and probably acting also on the respiratory centre in the brain. This case which I saw for a short time on transit to the Majesty's Ship Sultan, was recalled to my remembrance by the appearance of a case which has since occurred in my practice.

The case namely of a child who was suffering and evidently recovering from Morbilli, and in whom there suddenly developed subcutaneous Emphysema, which was so extensive as actually to induce a fatal issue.

The compressed air in the case of the diver referred, or more probably, the decompression on his being brought rapidly to the surface, led apparently to rupture of minute blood vessels whose contents extravasated into the area already indicated.
In localities where divers are employed in the pursuit of an industry, means are adopted whereby a comparatively slow return to the pressure of the ordinary atmosphere is secured, and even then the mortality reaches, as in the instance of the pearl divers of the Greek Archipelago, as high as ten per cent.
FORTH BRIDGE.
QUEENSFERRY SOUTH WEST CAISSON.

Figure I

This and the other Engineering plans are very grateful to the kindness of
Mr. A. T. Biggart, C. E., Forth Bridge Works.
I will be needful to describe shortly the construction of a caisson, in order to understand aright the conditions of possible work by means of it.

A caisson is essentially a cylinder devised for carrying out submarine Engineering work through the instrumentality of compressed air. It may vary indefinitely in regard to size.

The idea of a caisson originated so long ago as the year 1647. Since that date it has been improved in various ways according to the experience gained from undertakings in which it had been employed, until now it may be regarded as being in many respects perfect.

A Forth Bridge caisson (Figs. I, II, III) is a huge cylinder having a general appearance not dissimilar to that of a Gaseometer.
The diameter of one of the caissons at its base is 70 feet, but at the top 60 feet. The height is about 70 feet but varying according to the depth to which it was required to be sunk.

Structurally a caisson (Fig. I) may be regarded as consisting of three portions.

1. An Outer (O) and an Inner (I) shell of strong iron plates, and
2. A working chamber (W)

The working chamber forms the lower part of the caisson, and is bounded laterally by the outer shell, and superiority by an air-tight roof, from which the inner shell takes origin and is continued to the top of the caisson.

The roof of the working chamber is securely riveted to cross-girders (G), which form a groundwork for the
FORTH BRIDGE.

AIR LOCK FOR MEN.

Figure IV
Construction of the Caisson.

The lower or cutting edge of the shell forming the wall of the Chamber, constitutes what is known as the Shoe of the Caisson (S).

Opening into the Chamber through its roof are three tubes or shafts (T), each three and a half feet in diameter.

Two being for the outlet of the excavated material, and the third for the ingress and egress of workmen.

These shafts are continued from the working chamber below, to the top of the Caisson, where they are secured at a convenient level to the working platform.

On the summit of each shaft is fixed an Airlock.

With the Airlock used by the men the construction of which is different from that of the
material locks, I shall only in description deal.

It (Fig IV) consists of a double iron cylinder, the inner and longer of the two corresponding to the size of the air shaft on the top of which it rests, and the outer which is double the diameter of the inner, it is separated from it at the base by an enclosed floor. A single plate forms the roof of both cylinders.

The space between the two cylinders is divided by two upright iron diaphragms (A+B seen on section) into two distinct compartments. Each compartment having a strong iron door in the outer cylinder (D.O.) communicating with the outer atmosphere, and another similar door opposite in the inner cylinder (D.I.) opening into the air shaft.
In the roof of each compartment is a small bull's eye light, and also two small tubes with stop-cocks (T, Fig. 7) one for admitting air (compressed) from the air shaft with which to equalize the pressure in the air lock with that of the working chamber, and the other for the escape from the lock of the compressed air in order to allow it to return to the outer world.

When the construction of a caisson had been completed and it had been safely launched and towed into the position where it was desired to found a pier, the part of the caisson above the roof the working chamber (Y Fig. I) and between the outer and inner shells (Fig. IX) was gradually loaded with concrete until the caisson rested firmly on the mud, and could not be moved therefrom either by the
Influence of the rising tide, or by the pumping into the Chamber of compressed air for service in the process of excavation.

Two of the Caicoons (Fig II) did not rest on mud but on the edge of an irregular ledge of rock, which had to be cut away until a level base was reached for the floor of the Caicoon.

In these cases the real Engineering use of compressed air in repelling the surrounding sea was easily observed, for the least fall in the requisite air pressure was at once indicated by an equivalent rise of water within the working chamber.

In these Caicoons there was permitted the opportunity for a free exchange of vitiated atmosphere than was possible in Caicoons embedded in mud. The air vibration produced at
first in consequence of the burning
of lamps so within the Chamber,
was subsequently greatly lessened
by the use of Electric light— the
flame illumination of which at
a depth of ninety feet below the
surface of the wader was in no
small measure wonderful.

Means used for Compressing air

Means of Compressing Air

The essential elements for air com-
pression are an Engine, a Receiver,
and an Air Chamber.

The lower portion of a caisson formed
the Air Chamber.
The receiver was sometimes dis-
patched with; the air being forced
direct from the Condensing Engine
to the Air Chamber.
The Air Pump is driven by an
ordinary Steam Engine.
The piston rod, (accompanying
plane R), is common to both
the cylinders of the pump P,
and of the Steam-Engine (E).

The principle of action is as follows:

At either end of the air-cylinder (A1),
there is an inlet valve (I1), and a discharge valve (D1).

There are thus two inlet and two discharge valves.

Both discharge valves have a common outlet leading either to the Receiver or direct to the Caisson.

On the piston being drawn forwards from either end of the cylinder, the inlet valve opens, owing to a partial vacuum being formed. This continues to the end of the stroke.

So soon as the motion of the piston is reversed, the inlet valve closes, and the discharge valve opens.

The air thus finds its way through the discharge valve on towards the outlet and Receiver.
FORTH BRIDGE.
MODE OF EJECTING MUDD AND SILT.

Figure 11
The same description applies to the action at the other end of the cylinder.

The engine is also provided with two water pumps (W.P.), the object of which is to provide for a spray of water being discharged into each end of the cylinder, to keep the air cool during compression.

In some instances hydraulic power is used in working the Air Compressor, the advantage of it being that the air is not heated or otherwise rendered impure.

The air at the end of the Forth Bridge jetty - a distance of 200 feet from the shore, might be regarded as practically pure.

For therapeutic purposes however, the air may be filtered, by having a box containing cotton-wool through which the inlet-pipe passes, immediately before
Entering the air chamber. This hole in hot weather may be filled with ice and thereby the temperature be suitably reduced.

The compressed air was led in iron pipes from the compressor to a point near the caisson, and afterwards by means of a flexible tube to a check valve in the air shaft, whence it passed into the working chamber.

Similarly water was led from a raised tank, to a pipe on the working platform, from which by smaller pipes it was distributed inside the chamber for the purpose of diluting the compost (Fig IV), which formed the first fifteen feet or so of the material requiring to be removed.
Mode of Entrance into Air Chamber

When a person desires to descend to the Air Chamber, he enters within the outer door of the Air-lock (Fig IV; sectional view D O), securely fastening it behind him.

Thereupon he opens the stop-cock, admitting the Compressed air and when the degree of compression of the Air shaft has been reached in the lock, the inner door (II) of the lock may easily be opened, and descent to the chamber made.

Conversely, when wishing to leave the working chamber a person enters the Air lock from the shaft fastening firmly in this instance the inner door of the lock. He then turns the outlet stop-cock, permitting of the escape of the compressed air in the lock. Once this has been effected, the outer door of the air lock can readily be opened, and exit made.
Physiological Effects of Compressed Air

On entering an air-lock for the first time there is naturally felt a certain amount of excitement, induced by the feeling of in the event of mishap of helpless isolation.

On turning on the stopcock which admits compressed air, a very unpleasant sense of discomfort and pain referred to the neighbourhood of the middle ear is experienced.

This sensation is due to the difficulty of equalizing the pressure on either side of the Membrana Tympani, owing to the unequal calibres on the one hand, of the passage from the outer ear to the Drum Membrane, and of the Eustachian tube on the other. This inequality is frequently rendered greater by the existence of chronic larynx with consequent partial narrowing of the Eustachian tube,
or again, by the entrance being at
-lished whilst a person is suffer-
ing from Coryza with one Throat,
in which case the Continuous
人家なtion of the tube makes
its calibre less, and renders the
Distinctive of its walls less
more difficult and more painful.
The result of this is, that the
Membrane is pressed onwards
to an extent that is associated
with pain more or less severe.
To obviate the sense of suffering,
One has an instinctive desire
to swallow, which act opens the
Cricothyrist tube, and probably
also allows a more abundant
column of air to enter than is
possible by nasal inspiration
alone.
It frequently happens, however,
that just when the effect of
swallowing comes to be most useful,
there is an absolute want of
Saliva, secretion, and consequently,
its repetition (i.e., of swallowing), is
difficult or impossible.
In such cases one finds that
eating a biscuit thereby
stimulating saliva secretion
and necessitating swallowing,
is serviceable.

Another favourite method of
lessening the pain is to prac-
tice frequently Valsalva's method
of middle ear inflation.
This of course acts in a way
similar to swallowing.
Putting cotton wool in the only
ear passage and thus rendering
the column of entering air
smaller and more broken may
also be advantageously used.

In my instance, I was
forcibly struck by the occurrence
of acute suffering in the left
ear tube. None of my friends
experienced this, but on reflection
I recollect something the fact
that years ago, in Vienna, that
found it extremely difficult to pass the smallest size of an Evacuation Catheter along my right nostril, whilst by using the left an instrument of medium size could readily be passed.

The cause of the pain was, in all probability, therefore due to the presence of a stricture in my right nostril, and to the dilatation of it by the passage of a bougie, in the form of an aerial column, which increased in size with the increase of air pressure.

By the time that the requisite amount of pressure had been reached, the ear pain had usually vanished. In exceptional cases, however, the suffering was so excessive that persons could not endure it further.
Bleeding from the ear passage has been reported in the cases of persons in whom granulations near or perforations of the menbrann existed, or when the individual had entered suffering from typhus. The following note illustrates such cases.

Feb. 10, 1885, Desmories, a Frenchman, has worked 14 years in carious, with pressure reaching as high as 39 lbs above the normal pressure, has never had joint pains, to which reference is made beneath. On the 8th Feb he worked under a pressure of 21 lbs, had noene previously. Immediately on entering the carious, he felt severe pain in both nostrils, a little in both ears, and over the frontal sinuses. He remained in the carious but when the trachea, but on leaving, he again suffered severely.
in both nostrils, which was followed and relieved by the occurrence of violent Epistaxis, continuing for some hours.

The discomfort felt on entering the air both was greatly increased by turning on the stopcock, full, which workmen and others who had made the descent frequently were fond of doing. A diminished rapidity of the entering air column always lessened the suffering.

The character of the breathing is altered somewhat. It had always been observed that the inspirations and expirations were carried on more than usually completely, and that consequently the number of respirations per minute was lessened.

I was impressed with the fact that the breathing was in character.
much more than naturally. Abdomino-thoracic the alternation of tension and relaxation of the Abdomino

malar being very striking. It is probable that one can

with more ease control the use of the Abdomino

muscles than the can raise the heavier bony framework of the Thorax.

Observations have found that the

diaphragm ascended lower, that the lungs covered over one

of the heart, the surface anteriorly

screening therefore the area of

auricle dulness, and that

posteriorly with the diaphragmatic, there was also hepatic

lowering, and consequently a

smaller area of dulness.

Owing to the more intimate air

resitors becoming expanded, the

vital capacity of the chest is

very considerably increased.

And it seems to the probable
that in this, as in the greater descent of the diaphragm, the excessive use of the abdominal muscles plays an important part.
The lowering of the number of respirations per minute has been variously stated by different authors.
Dr. Theodore Williams observes, that they (the respirations) have been known to fall from 16 or 20 to 4 or 5 or even 3 or 4 per minute.
Von Ritter remarks, that the frequency may be lessened by from 1 to 4 movements per minute.
I have never met with any case, either a visitor or a constant labourer in prisons, in whom the amount of respiration was such as has been stated by Williams. 12 to 14 respirations per minute being the average of many cases which I carefully observed.
Respiration is very deep and easy. I was difficult for me, owing to the constant noise of machinery, to define accurately the limits of the cardiac dulness, or to ascertain if, as is stated, the posterior hepatic dulness is entirely observed. The diminished sense of resistance on percussion, however, which attempts to prove these facts elicits, gave indication to my mind that certainly both these organs have their usual surface areas, overlapped by the extra lung expansion. Notwithstanding the diminished frequency of respiration, there is a much greater than ordinary absorption of oxygen, and at the same time an increased proportion of carbonic acid formation, that, found by Von Gieson to be, with 3.7 atmospheres, 22 per cent more than at the normal pressure. The compression of the lung during expiration, is also increased.
And a considerable flattening of the convex abdominal wall is produced, owing to the compression of gases existing in the intestinal canal.

Williams, writing of the effect of compressed air on the circulation, says, that the pulse is slower, smaller in volume, but of increased arterial tension. The amount of diminution in frequency varies, from 4 to 20 beats per minute, and if the pulse have been somewhat excited before entering the bath the diminution may be still greater.

Virenet remarks, that the pulse rate diminishes from 14 to 7 beats per minute, the diminution being greater when there has been an abnormal increase.

I can only suppose in regard to these observations that
they have been made some time after the individual has been in the air bath, for I have invariably found that the primary effect of compressed air is to accelerate the heart's action.

My method was to measure the pulse before entering the air-lock, and again whilst in the lock, and, in the latter instance, there was always an increase more or less considerable, which was noticed in those who had entered a caisson for the first time, and in whom excitement may be imagined to have had some effect, as well as in those who had made numerous descents, who had indeed been accustomed to caisson work for years. It is the case, however, that after remaining in the air-chamber for a considerable period, the pulse becomes slower than normal. Thus my own pulse, which is usually about
72 per minute, was generally after
an hour so journ in the Chamber
as low as 27.

But my point is, the primary
acceleration.

Dr. Janineto’s observations on the
men at the construction of the
St. Louis Bridge, tend to confirm
my opinion in this respect. He quotes a series of cases in
which before entering the pulses
were respectively.

81. 78. 78. 79. 79 + 80

At the end of six minutes in the
air both the pulses were.

100. 86. 98. 86. 95 + 90

At the end of two hours in the Air Chamber,
they were: 68. 70. 70. 69. 70 + 72

After climbing the stairs on their
exit from the Journ they were
106. 104. 92. 94. 102 + 99.
On the 27th January 1886, several friends descended No. 4. Laisson with me. When the following freeze records were taken:

Before entering the Air lock:
80  90  88  76  82

In the Air Lock they were:
100  104  100  102  106

After having remained an hour and a half in the Laisson, they were
74  78  76  72  72

After climbing the stairs from the Air Chamber, they were
104  76  88  96  93

The quickened pulse in two of the cases before entering, was attributable to excitement, the descent being their fault.

The temperature of the outer atmosphere was 58 degrees, of the Laisson 18, the Air Chamber 61.5 degrees.
And of the air lock during decompression 50 degrees.

The different degrees of temperature between the air chamber and the air lock during decompression are very striking, and this difference, taken with other features attendant upon decompression, is found to be a powerful factor in the production of certain pathologic states to be referred to hereafter. It was quite a common occurrence for the escape tube to become blocked with ice.

The atmosphere at the same time becomes loaded with moisture, owing to the air being unable to retain in suspension the same quantity held there, during an increased pressure.

The inspiration of this cold mist frequently induces coughing, and to a less degree the Eustachian tube during compression is more also experienced.
Amongst various labourers slow pulse were invariable.

Even in men who had worked for 12 hours under a pressure of 20 lbs and upwards, the average rate was from 50 to 65, the being a number frequently enough met with.

The cause of the primary acceleration of heart's action is probably to be found in the greater amount of oxygen absorption, with increased stimulation of the cardiac motor centre.

The subsequent diminished frequency being principally mechanical. The system having become habituated to the changed circumstances, the true effect of increased resistance to the cardiac systole is appreciable in the slower pulse wave. The pulse is considerably smaller, and there is evidently increased
arterial tension.

The accompanying sphygmographic tracings, taken with Surgeon's instrument, show in degrees of greater or less clearness, the effects of compressed air on different parts of the pulse wave.

*No. 1, 2, 3.* are tracings taken before entering the air lock.

*No. 1.* Harris 4'9-9-08, before going into air lock.

*No. 2.* M. Harrow, 4'9-9-08, 3rd arm.

*No. 3.* M. Harrow; 3rd arm condition was poor.

In *No. 3,* of the same individual in the lavatory, show the influence of a cardo exciting character.
Similar evidence of cardiac excitement in hearts usually quiet and calm, is shown in the following tracings.
The next three tracings show the excited and quickened action of the air, which is succeeded by the quieter and slower rate in the respiring chamber.

The two following tracings of the same individual. Taken the one in my consulting room and the other in a Carsonian consulting chamber.
The two following tracings are intended to illustrate some of the points of difference between the hearts' action under ordinary conditions of life, on the one hand, and during work under compressed air, on the other.

The difference will be noted to exist principally in that part of the pulse wave derived from the commencement of the ventricular systole, to the closure of the aortic valves.

The line of descent though not quite so oblique resembles more the descent line at the closure pressure. First, then, the up stroke is very considerably longer and more pointed, the apex of the tracing being very sharp.

Next, the distance between the apex and the pre-diastolic notch is much longer, and the notch itself is very conspicuous, indicating a degree of arterial tension.
The eminence preceding the pre-dichotic notch is also more clearly defined, and the distance between this and the dichotic notch itself is slightly longer than that shown in the other tracing.

A similar though less striking difference is shown in the following rather inferior tracings.
The next two tracings which are intended to show the difference between the pulse wave during and after compression, suggest the idea that in some instances, the wave is lower in the air bath.

Theodore Williams states, that in the air bath as a nervous agent the pulse is always lowered. The following series of tracings tend in the direction of agreement with this.
The two series above given, however, are tracings of individuals who only made occasional visits, and in whom, the effect of physical effort, could not be calculated upon.

The majority of my tracings confirm Draper's remark, that the curve is above that obtained in normal air.
The interest of the following tracings—in the set of 4 each—lies in the fact that they are those of an Irishman, who did Caesarian labour, though he had no previous experience of it. The Caesian tracings will be seen to differ markedly from those taken at ordinary pressure, the increased length of up-stroke & the pre-diastolic notch—being evident.
I do not think it needful to multiply illustrations of tracings.

The points of difference, to which in the preceding pages I have directed attention, are equally with those included in this paper, shown in some seventy tracings (taken under compressed air), still in my possession.
There is a marked influence of an intrapulmonary character upon the circulatory system. The vessels of the skin and immediately subjacent structures are more or less emptied, and the blood is drawn into closed cavities, such as the skull, joints, as well as into internal solid organs like the liver and spleen.

This consequence is noticed in the much finer calibre of the vessels of the Membrana tympani and of the fundus oculi.

The opportunity of testing this point in the instance of a white rabbit which I took down one of the labyrinths. The markedly lessened fineness of the Ears, of the vessels of the conjunctiva and Iris, being very apparent. Whilst by means of the ophthalmoscope, I was enabled to note the fine, thread-like, loops of the vessels of the fundus,
showing then the intrapulmonary effect in the case of an animal whose circulation was sensitive to increased pressure.
Otherwise the rattie, which was kept alive for fully two hours, under a pressure of 20 lbs, was seemingly uninfluenced and did not sustain injury.

The same intrapulmonary effect of air compression on the circulation, was further noticed in the fact that some people, myself amongst them, suffered from frontal headache for several days after exposure to its influence.

The probable explanation being that during compression there is over-distension of the vessels of the frontal sinuses, and that these vessels do not recover their normal calibre or tone for some time afterwards, the congested state of the sinuses will inducing headache.
Some not able with frequent observation to notice that the vessels of the human fundus ventre much lessened in size. This may have been due, however, partly to the sloping posture necessitated by the nature of the work engaged in.

The increased oxidation in compressed air is supposed to produce an increase in the temperature of the body, and it is stated that this fact can be more correctly estimated when the temperature is taken by the mouth.

Stark frequently the temperature of laborers in the faiseau, as well as of visitors thereto, but my results were by no means uniform.

In some instances pyrexia to the extent of nearly a degree existed, in others there an arrow of health was not reached; and in many there...
one no variation from the normal standard. Dry takings, however, were not oscillatory, still if there were invariably a difference in temperatures taken by the mouth or rectum, one would expect to find it also in auxiliary records.

Mr. Neebeert writes, that the in-
creased oxidation which occurs with animals inspiring con-
densed Oxygen does not, as one would expect, produce an increase of temperature, but is attended on the contrary with marked lessening thereof.

It is possible, therefore, that the increased oxidation consequent upon life and work in compressed air, is influenced by some un-
ascertained cause, similar to that operating in the inspirations of condensed Oxygen, and altering the effects which, a priori,
the writer expected to be produced.
The character of the voice also is changed. One’s sense of hearing is to a small extent lessened, and in speaking the voice is pitched higher than normal.

The tone of the voice is distinctly nasal.

One finds it impossible at first, and always difficult, to whistle, owing to the effort needed to make the dense air vibrate insufficiently. If however the attempt be made kneeling and with the face turned downwards, the result will be more satisfactory.

An obscuring of the special sense smell, taste and touch, has also been observed.

Professor Meigs in a lecture on Evison Disease, states that he found in a patient who came under his care suffering from pressure symptoms, a very small trace of Albumen, which lasted for several days.
Other observers have not remarked this, though one would certainly expect that, in cases in which the efforts of the system to recover from the intrapulmonary effects of the increased pressure were not speedily successful, that temporary renal congestion with albumen should exist.

I found not by any means, not even by money bribes, induce the foreign workmen to collect the whole amount of urine passed by them during 24 hours, so that I cannot speak definitely as to the relative amount passed during that time. I believe, however, that Jaminet and others are correct in their statement, that there is a considerable increase in the daily secretion.

I examined amongst others the following four specimens, especially with regard to the amount of urea excretion.
Paisen work.

By an excessive sojourn in a Paisen, one is conscious of improvement in appetite, and men accustomed to Paisen both are generally thin, indeed Dr. Smith found that men with a tendency to emphysema were unfitted to stand the work.

In the case of the men employed at the Inchgarvie Paisens, where the highest amount of pressure was required, where for a time the hours of work were relatively longer, Anaemia and Swineers were very noticeable features. The Anaemia was in all likelihood due to the want of opportunity of exposure to sun-light, as well as to the influence on the haemopoietic system of the severe pressure.
Pathological Effects of Compressed Air

General Features of the Caisson Work

The sinking of the caissons was carried out by Mr. G. Verne, who employed for the purpose a staff of foreign workmen, French, Belgians, Italians, and Russians. All men who had been accustomed to similar work, who were selected for the work, because of their former proved suitableness.

They were mostly young healthy working men.

Their hours of labour were from 4 to 6 hours, with a like period of rest—except when the Lower Lachine caissons were being sunk. Then 4 hours of work were succeeded by 8 hours of rest, the former method having been found to seriously affect the men's health.

The amount of pressure employed varied from 15 to 340 pounds above the
normal pressure being greatest in the
process of removing the soft mud and rock.
The most dangerous time for caisson work
was early in the morning, whilst the soft soil was
being removed, owing to the excessive dampness as well as perhaps to the
presence of decaying animal matter.
When the process of concreting was
being carried on after a caisson had
reached its proper depth, this being due
partly to the want of a renewed supply
of fresh air, partly to the development
of an excessive amount of carbonic acid
gas. The cases of illness met with during
these two periods were in number out
of all proportion to those occurring
during the excavation of the toes of
clay or of the rock.
For a time the excavation of the clay re-
pelled the men, tired very much the energies
of the men.
The labor implied in cutting through
20 feet of this hard material, of which
it was impossible to dispose with one
stroke of a pick axe a piece larger than ones
hand, must have tried very seriously on their health, & it may be, would have cost many lives, if the Annex had not devised a most ingenious machine termed a hydraulic spade, of which a drawing is annexed.

By means of this machinery the clay was easily dealt with, & labour reduced to a minimum.

Similar ingenuity was shown when, at Invergairnie, compressed air was utilized in drilling the rocks for the insertion of charges of dynamite with which to effect its comminution.

The first case of illness amongst the Caisson workers was not Caisson Disease, but Enteric Fever.

The patient was a young Frenchman, who after days after the commencement of working the first Caisson complained of symptoms of Typhoid, originating, supposed from the decom- position of a vast number of fish, which had become intimated when the Caisson
Symptoms of Caisson Disease

Amongst the earliest of those affected with Caisson symptoms were several Belgians, who had completed the work of one watch under a pressure of 24 pounds, and who had thereafter proceeded to walk on a cold, frothy day, to the tents where they lived. No sooner had they arrived there than several were taken violently ill.

As typical of these cases, I select that of Emmanuel Francis, a tall, well-built, healthy-looking young man who had been accustomed to Caisson work. He complained of most violent pain in the neighbourhood of the knee joint. The pain began in the joint and then extended for a short distance above or below it, quickly darting...
again to its place of origin within the joint itself, having the feeling, as he described it, as if the leg and thigh were stretched as far as possible from each other, and were then allowed quickly to approximate again.

He complained also of pain of a nature similar in character though less severe in his shouder and elbow joints, all of which he was rendered perfectly powerless. In addition, François suffered for two days from retention of urine, a symptom which I noted in one other of the cases which came subsequently under observation. On examination, it was found that François had a very marked mitral regurgitant murmur, on account of which I advised that he should not resume work. Being a valuable workman, however, this advice was disregarded, with the penneth that before
the sinking of all the caissons was concluded, Francis had a very severe attack of Pneumonia. In the course of a week, Francis this fellow suffered were able to resume work, and being now obliged to wear flannel, a precaution which considering their experience of the loss of heat during decompression & the fatigue of walking a considerable distance from the caissons to their dwellings, it seems strange they houses have neglected, they withstood the effects of the work much better than before.

The joint pain is of all the symptoms the most constant and almost invariably it attacks the knee, alone, or with other joints, rendering its poor victims, from its severity, absolutely helpless. One of three men whom I was called to see suffering from this condition, described the pain as being what he could imagine...
Pain

Contd.

Bone of case affected
with knee

Joint pain

Tie of the cases affected, were with joint pains alone, or in combination with other symptoms.

In some instances the pains were milder and of a character not unlike that of Rheumatism.

The following note may be regarded as typical of such cases.

Aug 20, 1885. Angelini Beni, a young Italian engaged as a lascar on a merchant ship, has mitral regurgitant murmur, otherwise healthy looking. Complains of pains in the knee joint, begin ning below the patella, shorting...
upwards to the middle of the joint, then extending some distance above the joint, attaching also to the hip, and left frequently the small of the back.

These pains have existed for some days, becoming aggravated towards evening. He has no rheumatism.

Temp. 99.44, Pulse 88.

He was ordered rest, warm flannel clothing, and to take morning and evening a powder of Salicylic acid in podere powder.

The day following there was little improvement, but on the third day the temperature and pulse were normal, and he gradually improved. This might have been the case of an ordinary case of rheumatic pains.

But there was a careful watch, his pains, though less severe, were similar in character to those of François, a tradesman, occurring always after having been at work in a laissson, and the...
appearing under treatment when such work was temporarily discontinued. This case together with that of Francisco suggested to my mind the possibility that persons with a heart lesion, prone to suffer more severely from fever symptoms. Subsequent observation, however, did not confirm this surmise. At St. Louis, the thirteen workmen were all subjected to repeated medical examinations as to their fitness for the work. Here, however, owing to the contract for the levee work being in the hands of foreigners, with previous service experience of similar work, no such precaution was adopted. Otherwise naturally men physically unfit for such as the two cases noted, prone to have been rejected.

Another prominent symptom met with was epigastric pain accompanied by vomiting.
Frequently soon after leaving the caisson where he had felt well, though a man would suddenly be seized with severe epigastric pain and vomiting, which might be associated or not with the articular pains referred to, or with other symptoms.

The following note illustrates this set of symptoms.

Sept 22, 1884

I saw an old man, a young Belgian named Raymel, who complained of sickness, vomiting, pain in the epigastrum, and deafness. He had been at work in one of the sheet caterpillar caissons till 2 p.m. Then his watch ceased. He was quite near the caisson on the island. And, after having eaten a meal heartily, he had changed his garments with the intention of swimming across to South Headquarry when he suddenly became unsteady and fell. His pulse was weak when I saw him.
was normal, and there was no elevation of temperature.

There were frequent attacks of painful retching, the patient completely unable to steady his movements or to walk.

He had no joint pains, though a week before he had suffered from what he termed "la pression," meaning thereby the articular pains described along with slight retention of urine, which however the application of warmth had sufficed to relieve.

He had rested for two days, after which though feeling somewhat ill, he resumed work. He had had previous cases on experience.

He was ordered to be perfectly still, to take milk and rice. Borax and dilute hydrocyanic acid being also prescribed. Next day his condition has improved, the pain in the epigastrium was less severe, the epigastric had diminished, and he could walk a little though instably.
In the course of a week the symptoms disappeared, and he returned to his home in Belgium, prudently planning to resume Seen work.

Reference has been made in an earlier part of this paper to the occurrence of nasal haemorrhage following a visit to the Caissone. Very different was the haemorrhage in the case of the young Italian, to whom the following note applies.

A. B. has been accustomed to Caissone work, and has already been some time at the Fort Bridge. After leaving work one day he lay down to rest on deck of the ship "Kriegsmont," moored alongside the jetty, about 300 yards from the Caisson. Very soon he was seized with profuse haemoptysis, which I found proceeding from a portion of his right lung, immediately below the clavicle.

The haemorrhage was, after a time, checked, but the pulmonary irritation
set up through its presence, was the case of an acute lobar pneumonia, from which the man nearly died.

On inquiring I found that the patient had suffered some years ago from an emphysema, which then also arose from the same part of the same lung. He had recovered however so sufficiently as to be able to resume caisson work which, no doubt, improved his health. This case may be taken as illustrative of the changes in the circulatory system produced by compression and decompression. The retrograde effect of compression had probably a condensed portion of lung substance of its blood supply, the same vessels, however, becoming over-distended during and after the stage of decompression.

A second slight contraction of cutaneous capillaries, owing to his exposure on the deck of the ship, produced a re-distension of the vessels of the subjacent lung with rupture
of one of the vessels, at a point where from malnutrition, its coats had already been degenerated.

In this case there were no articular pains save those implied in the general malaise associated with a temperature of 103°, which attended the Pneumonia.

I found the Traction of Hamamelis most serviceable in restraining the hemorrhage. The Pneumonia I treated on general principles, and as already indicated, with success.

The next important symptom was Giddiness, frequently accompanied by headache.

The subjoined note illustrates cases in which this was the prominent feature.

Fritz Jacobi, a naturalised German, a tall thin man of about 40 years of age, had been employed for some months as a labourer, but had no previous railway experience.

Thinking to earn larger pay, he
volunteers and was permitted to descend to the working chamber of No. 1. Laverton, where he remained employed during one watch, under a pressure of 20 lbs. above the normal atmosphere. He felt well enough at work and until he reached his lodging in Queenston, about a mile distant from the mine, when he was suddenly seized with giddiness, and severe pain in the head. He reeled and staggered more than a drunken man. He could not stand or walk a step without assistance, his invariable tendency being to stagger to the left. He was assisted to bed, but even then everything seemed to wheel round, and the most uncomfortable sensation of powerful giddiness continued. With the exception of the headache and the complete loss of the power of equilibration, he suffered from no joint or other disturbance. He was ordered perfect quiet and large doses of the Bromides of
Potass and Ammonium were given several times a day.

Under this influence he, to a certain extent improved, and in the course of a few weeks was able, by the aid of a staff to come to my consulting room—a distance of 50 yards or so.

Induced to put him at one end of the room and placing vis-a-vis at the opposite end asked him to walk straight towards me.

His attempts to accomplish this task were interesting, for he always most unwillingly found himself separated from me by the breadth of the apartment, his tendency continuing to incline his movements to the left.

There was no alleviation in the structure of the membrane & beyond some venous fulness, no altered appearance of the fundus oculi.

The patient went to his home at Allora in December 1884, & remained
then till the middle of the March following suffering from vertigo and headache, for which he was blistered and otherwise ineffectually treated. On his return, I found, on testing his progressive power as already described, that he reached a point parallel to me about 3 feet to one side.

Prescribed again Bromide of Potass and combined with it Fluid Extract of Ergot in 20 minims doses to be taken thrice daily.

The effect of this treatment was extraordinary. His headache daily improved, he could walk much more steadily; and in three weeks he had recovered so completely as to be able to resume his former work of a lawyer.

I ordered these things on the assumption that there existed in this man, a congested condition of the vessels at the base of the brain and of the upper part of the spinal cord.
which produce the distressing symptoms recorded.

I hoped the Ergot would contract the vessels of the congested parts, and by partially emptying them relieve the vascular pressure; the pain produced by which, troved, it was believed, be allayed by the Bromide in large doses.

True not 18 months after.

Towards aware of the fact that Dr. A.H. Smith of New York had, on similar grounds, recommended and successfully used Ergot in large doses frequently repeated.

Several other cases of heart's occurred, in all of which, with one exception the tendency was to turn to the left. I am not informed of any reason why this peculiar tendency should have existed and its frequent occurrence may have been merely a coincidence.

None of my cases—one sixth or thereby of the men employed—
proved fatal, and none of the illnesses are likely to lead to permanent disablement.

One man, who suffered severely from joint pains, still complains of what seems like a rheumatic affection of the muscles of his left thigh, which is half an inch less in girth than its fellow and is moreover remarkably sensitive to barometric changes.

Another person, who had vertigo, still complains of deafness in one ear—that to which his tendency was to turn.

At the Bridge of St. Louis, 13 deaths occurred, and the more grave symptoms of Aison disease such as Paralysis, coma, were frequently witnessed. Some of the cases of Paralysis lasted for a year, ending by death, others for a shorter period, resulting in recovery more or less complete.
Post mortem examinations were made in the fatal cases, with the invariable finding of intense congestion of the brain, spinal cord, and their membranes, as well as the existence of some subarachnoid effusion.

There were also found haemorrhages into the kidneys, and injected area, or even patches of Ecchymosis, in the Stomach, Intestines, & Bladder.

After leaving the air chamber (during the earlier part of the work), the men had to climb over 1000 steps of a perpendicular ladder in order to get to the surface. This was terribly exhausting. Following, the wearily effects already undergone of severe labour was no doubt responsible for many of the deaths.

During the later progress of the work an Elevator was used, with marked benefit. At the Forth Bridge the men climbed the stairs, but under the influence of compressed air, the air-lock being at the top of the shaft, part immediately above the working chamber as at St Louis.
Theories as to the Cause of Caisson Symptoms

Various opinions have been held as to the manner in which Caisson symptoms are produced.

Francesco and Paul Bert held, that during compression of considerable degree, the blood absorbs an amount of air or nitrogen, which is set free as bubbles when decompression takes place, interrupting the circulation.

And Bert claims to have discovered such bubbles post mortem, in the vessels of the brain and spinal cord. He is of opinion that the bubbles do not form if the pressure does not exceed 5 atmospheres and that 3 minutes are allowed for decompression.

This explanation cannot be held as always applicable, for at the Forth Bridge as elsewhere, where the pressure did not nearly reach 5 atmospheres, where more than 3 minutes were allowed for the stage of decompression Caisson symptoms have occurred.
As Dr. Smith insists that Bert's theory does not explain why some people escape various symptoms altogether whilst others suffer so severely. He (Dr. Smith) thinks that the cause is to be found in the changed conditions of the circulation. The compression causes all the cutaneous vessels to be emptied, and all the vessels of solid organs and of bony cavities which offer resistance to the compression to be filled to over-distension, the vessels becoming merely passive tubes. When the pressure is removed the emptied vessels are rapidly filled, over-distended and paralyzed. The vessels of the brain and spinal cord being most distended are less able to relieve themselves, the vaso-motor system being in areas paralyzed, owing to the suspension of function in trophic cells in the Cortex or in the anterior horns of the cord.

Professor Bower thinks that with the increased oxygenation and
Tissue waste of organic structures taking place under Compression, the blood necessarily carries with it more lactic acid and other effete material. No harm follows this during Compression, but when decompression occurs the increased oxygenation ceases and the accumulation of waste material acts as a poison to the system.

Dr. Larnot, who had noted the increased amount of urine passed, the excessive amount of urine excreted, as also that the men at St. Louis passed at a lower temperature, is of opinion, that the cause of Larnot's symptoms exists in the increased and rapid tissue waste during Compression. At four atmospheres he found that respiration was more rapid, that each man inspired four times as much oxygen as at ordinary pressure, and that consequently bodily waste went on four times as fast.
Professor Wordward, who wrote the history of the St. Louis bridge, thinks that the symptoms are due to paralysis of vital energies arising to the great loss of heat, due to the expansion of the air in the air-lock whilst coming out. It is to the expansion of free gases and vapors within the body when relieved of the increased pressure. It is to the liberation of the gases held in solution by the liquids of the body during compression. It is to the severe physical effort of climbing the stairs from the working chamber. He noticed the fact that all the men felt cold on coming out of the compressed air, the exhilaration and increased vital energy of the air chamber being replaced on leaving it, by a very low ebb of vitality, and by an all-pervading sense of fagged helplessness.
I think with Professor Veigo that the real explanation is not contained in any one of these theories alone but that it is to be found in a combination of parts of all of them, different theories being account
able for different sets of symptoms.

All the symptoms are produced by decompression. Nothing in the least degree detrimental to health occurring whilst one remains in the working chamber, even under a pressure of four atmospheres.

There is therefore in this stage a degree of increased vital activity proportionate to the degree of increase of pressure.

There is further, for mechanical reasons, an intrapulmonary effect on the cutaneous circulation, with an absorption of gases by the liquids of the body.

The decompression to be effected sufficiently slowly, & with proper precautions, probably little hazard
be heard of laison symptoms. But byavitising methods it takes place with considerable rapidity. There is a great giving out of heat producing an extremely devitalizing effect on the workers. There is a loss in the balance between oxygenation and tissue waste which is held during the increased vitality of compression. And there is a sudden liberation of gases which had been absorbed, and which tend to interrupt the circuluation causing severe pain in the neighborhood of the vascular fringes of joint surfaces. But to me it seems that there is also a nerve element in the production of this severe pain. Dr. Joseph Fargher has pointed out that in cases of verrita he has obtained relief by incising the nerve sheath, releasing thereby a varying quantity of fluid which had accumulated within the
sheath, and, by its painful pressure on the nerve substance proper, has given rise to the condition whose name indicates the locality of that specific neuralgia.

It is quite a possibility then that there occurs in certain areas richly supplied with nerve filaments an absorption of nitrogen during compression, by the intra-perineurial fluid, and that the excessive pain referred to these areas is produced by the attempt at release of bubbles of the gas, when decompression has begun to take place.

**Treatment**

**Preventive.** The rules framed by the managers of the O'Leary Bridge are so in accordance with facts which, in my experience I observed at this Bridge, that, in my opinion, the principles they embody should...
receive the attention of all Directors of Cotton work.

Men showed he healthy and well-fed. They showed eat a meal an hour or so prior to their entering the air-chamber. The period of labour showed be diminished proportionately to the increase of pressure. Perfect rest and warmth showed he had for about an hour after coming out of the chamber. The use of an elevator showed be recommended always, and should be enforced when the air lock is immediate, by elevating the working chamber. The increase and diminution of pressure during compression and recompression respectively should be very gradual. The increase should not be more than six pounds per minute, and the diminution not more than four pounds per minute, and if when in the lock painfully unpleasant sensations continue after
middle-ear infiltration, swallowing re.

Entrance to the working chamber
should not be permitted.

Before leaving the air chamber (after
severe physical labour) each person
should be served with hot tea, coffee
or soup.

There should be separate entrance
and exit locks. The exit lock
being provided with a heating
apparatus to keep up a proper
temperature and to furnish
heat to the men.

On the Continent of Europe and
in America, various workers have
been accustomed to wear, as a
fancied safeguard, Galvanic
bands, composed of alternate
scales of Silver and Zinc.

These bands were worn around
the ankles, wrists and other
parts of the body likely to be
affected with Carcinom symptoms.

It is not clear, however, that any
real benefit was derived from their use.
Active Treatment

In several instances here men who, on coming from work felt certain symptoms threaten, immediately returned to the air chamber when the pains vanished.

Doubtless, were this method of treatment always practicable, it would be found more likely than any other to yield good results. For on again entering the airlock, re-absorption of those gases whose liberation produced the distress, occurs, and care can be taken that on subsequently emerging from the chamber, decompression takes place gradually and with requisite slowness.

It is easy to understand, however, that in many cases it would be impossible to have patients taken back to the air chamber, and the urgent symptoms therefore must be met relieved otherwise.
Treated the severe joint pains by the
application of electric stimuli
us to the area affected, the theory of
treatment being that thereby the
vital activity of the part whose
gas liberation had been interrupt-
ed, owing to the too rapid decom-
position, was temporarily increased.
Subsequent application of
moist warmth to the joint, with
the administration of a sedative
hypodermically or otherwise,
generally afforded relief.

My experience would make me
feel disposed to employ Ergot very
hopefully in the treatment of
the distressing symptom of Giddiness.
Jamines and Smith speak very highly of
the value of Alcoholic Stimulants with
ginger in cases where Epigastric pain
is a prominent symptom. Vomiting
is best treated with Dee. And other
symptoms must be met accord-
ing to the indications of the special
circumstances in which they exist.
Compressed Air as a means of Treatment

I do not propose to enter at any length into the therapeutic uses of compressed air. For, naturally, the activity associated with the construction of a gigantic bridge was not favourable to the testing of its use for medical purposes, and the nature of my present professional duties likewise precludes the possibility of any attempt which I may hope at some future time to make at systematic use of this remedial agent. Establishments where it is employed, however, exist to the number of about fifty at various places on the Continent. But in England they are, I believe, only at Buxted, Shirley, and Brompton. And, with the exception of Dr. Theodore Williams, or more recently of Dr. Sampson, no English physician has recorded any experience of its efficiency or the reverse.
as a Pioneer in Medical Science, cannot
so far as I know, boast of one single
establishment.
The expense of construction of the
establishments and the time
needed to devote to their attention,
have no doubt proved powerful
barriers to their extensive use.
But one is justified in hoping that
with more extended trial the
methods of application will be
come much simplified.
In addition to the Air-baths
for which the Mannon principle
is excited, Compressed Air may be
inspired also through Masks fitting
closely to the mouth.

Of these Masks numerous forms
have been used. The form recom-
mended by Dr. Gamage is that
of Professor Schnitzler. Here-
cuits essentially of two Cylinders,
one for Condensing and the other
for rarefying the Air.
Both are connected by pipes with
the inhaling masks, and are provided with taps which regulate the supply of either for inhalation.

Dr. Williams has found the use of these masks wholesome, he states that many complain of their inducing faintness and headache.

He believes moreover that, with them, it is impossible to keep up a proper supply of fresh air at the needed pressure, and that therefore there is risk of vitiated air being re-breathed. On these grounds he recommends adoption of the air baths.

Dr. Gompee, in a more limited experience has not found those drawbacks to which Dr. Williams refers. His difficulty has lain in the apparatus as used by Schwab, not being so correctly made as to yield results of desirable accuracy. With more extended use however he hopes to remedy the defects and to convince the profession of its therapeutic value.
Therapeutically considered, Compressed air acts in a three-fold manner: (a) mechanically; (b) physiologically; (c) as a vesicant. In virtue of its mechanical effects, its use is indicated in cases where an increased blood determination to certain internal organs, such as, for example as the ovaries is likely to lead to an increased functional activity of these organs. It is contra-indicated on the other hand where as in febrile states, congestion of internal organs already exists. Thus in a pulmonary congestion its use would only be productive of harm, unless to the extent that it actually led to the pulmonary blood supply being driven to more resisting organs. As Williams gives it as a maxim—

that its mechanical effect will be most useful in cases where congestion of the right side of the heart and of the liver exists.

On the pulmonary tissue itself, the mechanical effect of compressed air is most beneficial. In cases namely in which following an overfilling of
the vessels of the bronchial tree are usually a cataract of states of the tubes valvularly has been induced, leaving eventually to their being blocked becoming functionally useless. In such cases the vessels are emptied by its use the bronchial air rendered permanently by the alveoli distended. The secretion is absorbed, the function of the lung restored, and the vital capacity of the chest markedly increased. Owing to the mechanical effect on the intestinal gases, some surgeons have recommended the use in cases of strangulated hernia recommending that these should be resumed after the patient has been for a few minutes in the air bath.

Physiologically, compressed air acts beneficially by introducing more oxygen into the blood, affording thus means of more efficacious saturation of the oxyhemoglobin, producing thereby more rapid tissue change as for instance, in hastening the re-absorption of the cataractous secretion already referred
to, in heating of the action of compressed air mechanically. And by the larger proportion of oxygen leading to increase in the number of red blood corpuscles, improving such conditions therefore, as Anemia and Chlorosis.

Physicians have had difficulty in explaining the cause of the sedative effect of compressed air. It may be that the irritability of certain mucous membranes, the muscle and the vascular spasm common in some pathologic states are due to the supply of the centres regulating the nerve supply of the structures indicated, and that the better nutrition of these centres, consequent upon a more large, oxygenated blood, restores a more healthful peripheric nerve tone.

Dr. Theodore Williams has recorded in most full and interesting detail a series of eight cases of Pneumonia, Bronchitis, Emphysema, Asthma, consolidation of lung following Planes pneumonia, and Phthisis in all of which the use of Compressed air was
reported to with highly beneficial results. Dr. Flameli's experience is entirely confirmatory.

My own experience extends only to one case. Mr. G., aged 25, has been subject to severe attacks of spasmodic asthma since early youth. His emphysematous margins of both lungs anterily.

Has twice been compressed air once in the air lock only, on the other occasion in the working chamber as well. Remained for a considerable period each time. Pressure 18 to 22 lbs. above normal atmospheric pressure. Had not an asthmatic seizure thereafter for eighteen months.