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THE INFLUENCE OF THE ATMOSPHERE ON OUR HEALTH AND COMFORT IN CONFINED AND CROWDED PLACES

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(From the Physiological Laboratory of the London Hospital Medical College)

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By LEONARD HILL, MARTIN FLACK,[1] JAMES McINTOSH, R. A. ROWLANDS, H. B. WALKER

(From the Physiological Laboratory of the London Hospital Medical College —London Hospital Research Fund)

INTRODUCTION

It is generally thought and taught that the ill effects which arise from ill-ventilated houses, factories, workshops, theaters,—from stuffy and crowded rooms where many people congregate together—are due to alterations in the chemical quality of the air. The purpose of this paper is to demonstrate that no evidence has yet been brought forward which shows that the chemical quality of the air has anything to do with these ill effects, and that, apart from the influence of infecting bacteria, the ventilation problem is essentially one of the temperature, relative humidity, and movement of the air. In Germany this point of view has been upheld by that distinguished hygienist, Flügge, and he and his co-workers have contributed a series of papers in which convincing evidence is adduced. In England, Haldane and Lorrain Smith have advanced the same view, and we find it expressed in the evidence given to the Departmental Committee of the Home Office on the Humidity and Ventilation of Cotton Weaving Sheds. (Haldane, Pembrey, Leonard Hill, etc.) Confirmatory evidence has been brought forward in America by Billings, Weir Mitchell, and Bergey.

In all the elementary text-books of hygiene, and in most of the standard works, the chemical aspect of the question is treated as if it were the fundamental factor, and this opinion, widely reiterated in the daily press and in daily conversation, has become accepted as an article of faith.

[1] Working during the tenure of the Eliza Ann Alston Research Scholarship.

Everyone thinks that he suffers in an ill-ventilated room owing to some change in the chemical quality of the air, be it want of oxygen, or excess of carbon dioxide, the addition of some exhaled organic poison, or the destruction of some subtle property of the air by its passage over steam coils, or other heating or conducting apparatus. We hear of "devitalized" or "dead" air and "tinned" or "potted" air of the battleship. The good effects of open-air treatment, of sea and mountain air, are no less generally ascribed to the chemical purity of the air. We maintain that the health-giving properties are primarily those of temperature, light, movement, and relative moisture of the circumambient atmosphere, and, leaving on one side those gross chemical impurities which arise in mines and in some manufacturing processes, that the alterations in chemical composition of the air in buildings where people crowd together and suffer from the effects of ill ventilation, have nothing to do with the causation of these effects.

Satisfied with the maintenance of a specious standard of chemical purity, the public has acquiesced in the elevation of sky-scrapers and the sinking of cavernous places of business. Many have thus become cave-dwellers, confined for most of their waking and sleeping hours in windless places, artificially lighted, monotonously warmed. The sun is cut off by the shadow of tall buildings and by smoke—the sun, the energizer of the world, the giver of all things which bring joy to the heart of man, the fitting object of worship of our forefathers.

The ventilating and heating engineer hitherto has followed a great illusion in thinking that the main objects to be attained in our dwellings and places of business are chemical purity of the air and a uniform, draughtless, summer temperature.

Life is the reaction of the living substance to the ceaseless play of the environment. Biotic energy arises from the transformation of those other forms of energy—heat, light, sound, etc.—which beat upon the transformer, the living substance. Thus, when all the avenues of sense are closed, the central nervous system is no longer aroused and consciousness lapses. Laura Bridgeman, paralyzed in almost all her avenues of sense, fell asleep whenever her remaining eye was closed. The patient who lost one labyrinth by disease and, to escape unendurable vertigo, had the other removed by operation, was quite unable to guide his movement or realize his position in the dark. Rising from bed one night, he collapsed on the floor and remained there helpless till succor arrived.

Sherrington points out that a sense organ—the receptor apparatus—is not stimulated unless there is a change of rate in the transference of energy; and that a change of rate, to be effectual, must occur in most cases with considerable quickness; "otherwise there is a mere unperceived shift in the stationary equilibrium which forms the resting zero of the sensual apparatus." "Both for sensation and for reflex action a function in the threshold value of stimulus is time as well as intensity and quantity. If a weak agent is to stimulate, its application must be abrupt."

Thus the slow changes of barometric pressure on the body surface originate no skin sensations, though such changes of pressure, if applied suddenly, are much above the threshold value for touch. A touch excited by constant mechanical pressure of slight intensity fades quickly below the threshold of sensation. Thus the almost unbearable discomfort which a child feels on putting on for the first time a "natural" wool vest fades away and is no longer noticed with continued wear. Thomas à Becket soon must have become oblivious to his hair shirt and its harbingers. It is not the wind which God tempers to the shorn lamb, but the skin of the lamb to the wind.

"There streams constantly from the body through the skin a current of thermal energy much above the threshold value of stimuli for warmth sensations; yet this current evokes—under ordinary circumstances—no sensation. It is the stationary condition, the fact that the transference of energy continues at constant speed, which makes it unperceived." The inflow of sensations keeps us active and alive, and all the organs working in their appointed functions. Those from the great cutaneous field are of the highest importance. The salt and sand of wind-driven sea air and sea baths act on the skin and brace up the body. The changing play of wind, of light, of cold and warmth, stimulate the activity and health of mind and body. Monotony of occupation and external conditions for long hours destroy vigor and happiness and bring about the atrophy of disuse. Daily observation shows us that a drayman, navvy, or policeman can live in London or any other big city strong and vigorous, and no less so than in the country: the brain worker, too, can keep himself perfectly fit if his hours of sedentary employment are not too long and he balances these by open air exercise. The horses stabled, worked, and fed in London are as fine as any in the world: regular open-air exercise and proper feeding and housing ensure the health and fitness of a horse, and no less of a man.

The hardy men of the north were evolved to stand the vagaries of climate—cold and warmth, a starved or full belly, have been their changing lot. The full belly and the warm sun have expanded them in lazy comfort; the cold and the starvation have braced them to action. Modern civilization has withdrawn many of us from the struggle with the rigors of nature; we seek for and mostly obtain the comfort of a full belly and expand all the time in the warm atmosphere afforded us by clothes, wind-protected dwellings, and artificial heat—particularly so in the winter, when the health of the business man deteriorates.

Cold is not comfortable, neither is hunger; therefore we are led to ascribe many of our ills to exposure to cold, and seek to make ourselves strong by what is termed good living. In reality the bracing effect of cold is of supreme importance to health and happiness; we become soft and flabby and less resistant to the attacks of infecting bacteria in the winter not because of the cold, but because of our excessive precautions to preserve ourselves from cold; the prime cause of " cold " or " chill " is not really exposure to cold, but exposure to the overheated and confined air of rooms, factories, and meeting-places.

Seven hundred and eleven survivors were saved from the *Titanic* after hours of exposure to cold. Many were insufficiently clad and others were wet to the skin. Only one died after reaching the *Carpathia*, and he three hours after being picked up. Those who died perished from actual cooling of the body. Exposure to cold did not cause in the survivors the diseases commonly attributed to cold.

Conditions of city and factory life diminish the physical and nervous energy, and reduce many from the vigorous health and perfectness of bodily functions which a wild animal possesses to a more secure, but poorer and far less happy, form of existence. The ill-chosen diet, the monotony and sedentary nature of daily work, the windless uniformity of atmosphere, above all, the neglect of vigorous muscular exercise in the open air and of exposure to the winds and light of heaven—all these, together with the difficulties in the way of living a normal sexual life, go to make the pale, undeveloped, neurotic, and joyless citizen. Nurture in unnatural surroundings, not nature's birth-mark, moulds the criminal and the wastrel. The environment of childhood and youth is at fault rather than the stock; the children who are taken away and trained to be sailors, those sent to agricultural pursuits in the Colonies, those who become soldiers, may develop a physique and bodily health and vigor in striking contrast to their brothers who become clerks, shop assistants, and compositors.

Too much stress cannot be put on the importance of muscular exercise in regard to health, beauty, and happiness. Each muscle fills with blood as it relaxes, and expels this blood on past the venous valves during contraction. Each muscle together with the venous valves forms a pump to the circulatory system. It is the function of the heart to deliver the blood to the capillaries, and the function of the muscles—visceral, respiratory, and skeletal—to bring it back to the heart. The circulation is contrived for a restless mobile animal; every vessel is arranged so that muscular movement furthers the flow of blood.

The pressure of the blood in the veins and arteries, under the influence of gravity, varies with every change of posture. The respiratory pump, too, has a profound influence on the circulation. Active exercise, such as is taken in a game of football, entails endless changes of posture, varying compressive actions—one with another struggling in the rough and tumble of the game—forcible contractions and relaxations of the muscles, and a vastly increased pulmonary ventilation; at the same time the heart's action is accelerated and augmented and the arterial supply controlled by the vaso-motor system. The influence of gravity, which tends to cause the fluids of the body to sink into the lower parts, is counteracted; the liver is rhythmically squeezed like a sponge by the powerful respiratory movements which not only pump the blood through the abdominal viscera, but thoroughly massage these organs, and, kneading these with the omentum, clean the peritoneal cavity, and prevent constipation. At the same time the surplus food products, such as sugar and fat stored in the liver, are consumed in the production of energy, and the organs are swept with a rapid stream of blood containing other products of muscular metabolism which are necessary to the inter-relation of chemical action. The output of energy is increased very greatly; a resting man may expend two thousand calories per diem; one bicycling hard for most of the day expended eight thousand calories, of which only four thousand were covered by the food eaten.

Such figures show how fat is taken off from the body by exercise, for the other four thousand calories came from the consumption of surplus food products stored in the tissues. While resting, a man breathes some 7 liters of air, and uses 300 cc. of oxygen per minute, against 140 liters and 3,000 cc. while doing very hard labor. The call of the muscles is for more oxygen, and their waste products stimulate the formation of hæmoglobin, and in other not fully defined ways influence the metabolism.

Exposure to cold, cold baths, and cold winds has a like effect, accelerating the heart and increasing the heat production, the activity of the muscles, the output of energy, the pulmonary ventilation, and the intake of oxygen and food. In contrast with the soft, pot-bellied, overfed city man, the hard, wiry fisherman trained to endurance has no superfluity of fat or tissue fluid. His blood volume has a high relative value in proportion to the mass of his body. His superficial veins are confined between a taut skin and muscles hard as in a race-horse trained to perfection. Thus the adequacy of the cutaneous circulation and loss of heat by radiation rather than by sweating are assured. His fat is of a higher melting point, hardened by exposure to cold. In him less blood is contained in adipose tissue and skin, and the circulation through the brain muscles and viscera is more active. He uses up the oxygen in the arterial blood more completely and with greater efficiency; for the output of each unit of energy his heart has to circulate much less blood (Krogh); his blood is sent in full volume by the well-balanced activity of his vaso-motor system to the moving parts. Owing to the perfect coördination of his muscles, trained to the work, and the efficient action of his skin and cutaneous circulation—the radiator of the body—he performs the work with far greater economy and less fatigue. The untrained man may obtain 12 per cent of his energy output as work, against 30 per cent or perhaps even 50 per cent obtained by the trained athlete. Hence the failure and risk suffered by the city man who rushes straight from his office to climb the Alps. On the other hand, the energetic man of business or brain worker is kept by his work in a state of nervous tension. He considers alternative lines of action, but scarcely moves. He may be intensely excited, but the natural muscular response does not follow. His heart is accelerated and his blood-pressure raised, but neither muscular movements, and accompanying changes of posture, nor the respiratory pump materially aid the circulation. The activity of his brain demands a rapid flow of blood, and his heart has to do the circulatory work, as he sits still or stands at his desk, against the influence of gravity. Hence a high blood-pressure is maintained for long periods at a time by vaso-constriction of the arteries in the lower parts of the body and increased action of the heart. Hence, perhaps, arise those degenerative changes in the circulatory system which affect some men tireless in their mental activity. We know that the bench-worker, who stands on one leg for long hours a day, may suffer from degeneration and varicosity of the veins in that leg. Long-continued, high, arterial pressure, with systolic and diastolic pressures approximately the same, entails a stretched arterial wall, and this must impede the circulation in the vaso-vasorum, the flow of tissue lymph in and nutrition of, the wall. Since his sedentary occupation reduces the metabolism and heat production of his body very greatly, the business man requires a warmer atmosphere to work in. If the atmosphere is too warm it reduces his metabolism and pulmonary ventilation still further; thus he works in a vicious circle. Exhausting work causes the consumption of certain active principles, for example, adrenalin, and the reparation of these must be from the food. To acquire certain of the rarer principles expended in the manifestation of nervous energy more food may have to be eaten by the sedentary worker than can be digested and metabolized. His digestive organs lack the kneading and massage, the rapid circulation and oxidation of food-stuffs which are given by muscular exercise. Hence arise the digestive and metabolic ailments so common to brain workers.

Mr. Robert Milne informs us that of the thousands of children who have passed through Barnardo's Homes—there are 9,000 in the homes at any one time—not one after entering the institution and passing under its regimen and the care of his father, Dr. Milne, has developed appendicitis. Daily exercise and play, adequate rest, and a regular simple diet have ensured their immunity to this infection. It pays to keep a horse healthy and efficient; it no less pays to keep men healthy. One of us (L. H.) recently investigated the case of clerks employed in a great place of business, whose working hours are from 9 to 6 on three days, and 7 to 9 on the other three days of each week, and, working such overtime, they make from $5 to $10 a week. These clerks worked in a confined space—forty to fifty of them in 8,200 cubic feet, lighted by thirty electric lamps, cramped for room, and overheated in warm summer days. It is not with the chemical purity of the air of such an office that fault is to be found, for fans and large openings ensured this sufficiently. These clerks suffered from their long hours of monotonous and sedentary occupation, and from the artificial light, and the windless, overwarm and moist atmosphere. Many a girl cashier has worked from 8 to 8.30, and on Saturdays from 8 to 10, and then has had to balance her books and leave perhaps after midnight on Sunday morning. (The Shop Act has given a littlè relief to these hours.) Her office is away in the background—confined, windless, artificially lighted. What is the use of the State spending a million a year on sanatoria and tuberculin dispensaries, when those very conditions of work continue which lessen the immunity and increase the infection of the workers?

Isolation hospitals, sputum-pots, and anti-spitting regulations will not stamp out tuberculosis. Such means are like shutting the door of the stable when the horse has escaped. Flügge has shown that tubercle bacilli are spread by the droplets of saliva which are spread yards around as an invisible spray when we speak, sing, cough, sneeze. Sputum-pots cannot control this. The saliva of incipient cases of phthisis may teem with the bacilli. The tuberculin reaction tests carried out by Hamburger and Monti in Vienna show that 94 per cent of all children aged eleven to fourteen have been infected with tubercle. In most the infection is a mere temporary indisposition. We believe that the conditions of exhausting work and amusement in confined and overheated atmospheres, together with ill-regulated feeding, determine largely whether the infection, which almost none can escape, becomes serious or not. Karl Pearson suggests that the death statistics afford no proof of the utility of sanatoria or tuberculin dispensaries, for during the very years in which such treatment has been in vogue, the fall in the mortality from tuberculosis has become less relatively to the fall in general mortality. He opines that the race is gradually becoming immune to tubercle, and hence the declination in the mortality curve is becoming flattened out—that nature is paramount as the determinant of tuberculosis, not nurture. From a statistical inquiry into the incidence of tuberculosis in husband and wife and parent and child, Pearson concludes that exposure to infection as in married couples is of little importance, while inborn immunity or diathesis is a chief determinant. Admitting the value of his critical enquiries and the importance of diathesis, we would point out that in the last few years the rush and excitement of modern city life has increased, together with the confinement of workers to sedentary occupations in artificially lighted, warm, windless atmospheres. The same conditions pertain to places of amusement, eating-houses, tube railways, etc. Central heating, gas-radiators, and other contrivances are now displacing the old open fire and chimney. This change greatly improves the economical consumption of coal and the light and cleanliness of the atmosphere. But in so far as it promotes monotonous, windless, warm atmospheres, it is wholly against the health and vigor of the nation. The open fire and wide chimney ensure ventilation, the indrawing of cold outside air, streaky air—restless currents at different temperatures, which strike the sensory nerves in the skin and prevent monotony and weariness of spirit. By the old open fires we were heated with radiant heat. The air in the rooms was drawn in cool and variable in temperature. The radiator and hot-air system give us a deadly uniformly heated air—the very conditions we find most unsupportable on a close summer's day.

In Labrador and Newfoundland, Dr. Wakefield tells us, the mortality of the fisher folk from tuberculosis is very heavy. It is generally acknowledged to be four per 1,000 of the population per annum, against 1.52 for England and Wales. Some of the Labrador doctors talk of seven and even eight per 1,000 in certain districts. The general death-rate is a low one. The fishermen fish off shore, work for many hours a day in the fishing season, and live with their families on shore in one-roomed shanties. These shanties are built of wood, the crannies are "stogged" with moss, and the windows nailed up, so that ventilation is very imperfect. They are heated by stoves and kept at a very high temperature, for example, 80° F. Outside in the winter the temperature may be 30° below freezing. The women stay inside the shanties almost all their time, and the tuberculosis rate is somewhat higher in them. The main food is white bread, tea stewed in the pot till black, fish occasionally, a little margarine and molasses. The fish is boiled and the water thrown away. Game has become scarce in recent years; old, dark-colored flour—spoken of with disfavor—has been replaced by white flour. In consequence of this diet beri-beri has become rife to a most serious extent, and the hospitals are full of cases. We (M. F. and L. H.) have found by our feeding experiments that rats, mice, and pigeons cannot be maintained on white bread and water, but can live on whole meal or on white bread in which we incorporate an extract of the sharps and bran in sufficient amount. Recent work has shown the vital importance of certain active principles present in the outer layers of wheat, rice, etc., and in milk, meat, etc., which are destroyed by heating to 120° C. A diet of white bread or polished rice and tinned food sterilized by heat is the cause of beri-beri. The metabolism is endangered by the artificial methods of treating foods now in vogue. As to the prevalency of tuberculosis in Labrador, we have to consider the inter-marriage, the bad diet, the over-rigorous work of the fishermen, the over-heating of, and the infection in, the shanties.

Dr. Wakefield has slept with four other travelers in a shanty with father, mother and ten children. In some there is scarce room on the floor to lie down. The shanties are heated with a stove on which pots boil all the time; water runs down the windows. The patients are ignorant, and spit everywhere, on bed, floor, and walls. In the schools the heat and smell are most marked to one coming in from the outside air. In one school 50 cubic feet per child is the allowance of space. The children are eating all day long, and are kept in close, hot confinement. They suffer very badly from decay of the teeth. Whole families are swept off with tuberculosis, and the child who leaves home early may escape, while the rest of a family die. Here, then, we have people living in the wildest and least populated of lands, with the purest atmosphere, suffering from all those ill results which are found in the worst city slums—tuberculosis, beri-beri, and decayed teeth.

The bad diet probably impels the people to conserve their body heat and live in the overwarm, confined atmosphere, just as our pigeons fed on white bread sit, with their feathers out, huddled together to keep each other warm.

The metabolism, circulation, respiration, and expansion of the lung are all reduced. The warm, moist atmosphere lessens the evaporation from the respiratory tract, and therefore the transudation of tissue lymph and activity of the ciliated epithelium. The unexpanded parts of the lung are not swept with blood. Everything favors a lodgment of the bacilli, and lessens the defences on which immunity depends. In the mouth, too, the immune properties of the saliva are neutralized by the continual presence of food, and the temperature of the mouth is kept at a higher level, which favors bacterial growth. Lieutenant Sein (Norwegian navy) informs us that recently in northern Norway there has been the same notable increase in tuberculosis. The old cottage fireplaces with wide chimneys have been replaced with American stoves. In former days most of the heat went up the chimney, and the people were warmed by radiant heat. Now the room is heated to a uniform moist heat. The Norwegians nail up the windows and never open them during the winter. At Lofoten, the great fishing center, oil motor-boats have replaced the old open sailing boats and rowboats. The cabin in the motor-boat is very confined, covered in with a watertight deck, heated by the engine, crowded with a dozen workers. When in harbor the fishermen used to occupy ill-fitted shanties, through which the wind blew freely; now, to save rent, they sleep in the motor-boat cabins. Here, again, we have massive infection, and the reduction of the defensive mechanisms by the influence of the warm, moist atmosphere.

The Norwegian fishermen feed on brown bread, boiled fish, salt mutton, and margarine, and drink, when in money, beer and schnapps; there is no gross deficiency in diet, as in Labrador, and beri-beri does not attack them. They return home to their villages and longshore fishing when the season is over. The one new condition which is common to the two districts is confinement in stove-heated, windless atmospheres. In old days the men were crowded together, but in open boats or in draughty shanties, and had nothing but little cooking-stoves.

The conditions of great cities tend to confine the worker in the office all day, and to the heated atmosphere of club, cinema show, or music-hall in the evening. The height of houses prevents the town dweller from being blown upon by the wind, and, missing the exhilarating stimulus of the cool, moving air, he repels the dull uniformity of existence by tobacco and by alcohol, or by indulgence in food, for example, sweets, which are everywhere to his hand, and by the nervous excitement of business and amusement. He works, he eats, and is amused in warm, windless atmospheres, and suffers from a feeble circulation, a shallow respiration, a disordered digestion, and a slow rate of metabolism.

Many of the employments of modern days are detestable in their long hours of confinement and monotony. Men go up and down in a lift all day, and girls in the bloom of youth are set down in tobacco stalls in underground stations, and their health and beauty there fade while even the blow-flies are free to bask in the sun. In factories the operatives feed machines, or reproduce the same small piece of an article day after day. There is no art, no change, no pleasure in contrivance and accomplishment. The miner, the fisherman, even the sewerman, face difficulties, changing risks, and are developed as men of character and strength. Contrast the sailor with the steward on a steamer, the drayman outside with the clerk inside who checks the goods delivered at some city office, the butcher and the tailor, the seamstress and the market woman, and one sees the enormous difference which a confined occupation makes. Monotonous sedentary employment makes for unhappiness because the inherited functional needs of the human body are neglected, and education—when the outside field of interest is narrowed—intensifies the sensitivity to the bodily conditions. The sensations arising within the body—

proprioceptive sensations—come to have too large a share in consciousness in comparison with exteroceptive. In place of considering the lilies how they grow, or musing on the beauty and motions of the heavenly bodies, the sedentary worker in the smoke-befouled atmosphere with the limited activity and horizon of an office and a disturbed digestion, tends to become confined to the inward consideration of his own viscera and their motions.

Many of the educated daughters of the well-to-do are no less confined at home; they are the flotsam and jetsam cast up from the tide in which all others struggle for existence—their lives are no less monotonous than those of the sweated seamstress or clerk. They become filled with " vapors " and some seek excitement not in the cannon's mouth, but in breaking windows, playing with fire, and hunger strikes. The dull monotony of idle social functions, shopping, and amusement, equally with that of sedentary work and an asexual life, impels them to a simulated struggle—a theatrical performance, the parts of which are studied from the historical romances of revolution.

Each man, woman, and child in the world must find the wherewithal for living, food, raiment, warmth, and housing, or must die or get some other to find it for him. It seems to us as if the world is conducted as if ten men were on an island—a microcosm—and five sought for the necessaries of life, hunted for food, built shelters and fires, and made clothes of skins, while the other five strung necklaces of shells, made loin cloths of butterfly wings, gambled with knuckle bones, drew comic pictures in the sand, or carved out of clay frightening demons, and so beguiled from the first five the larger share of their wealth. In this land of factories, while the many are confined to mean streets and wretched houses, possessing no sufficiency of baths and clean clothing, and are ill-fed, they work all day long, not to fashion for themselves better houses and clothing, but to make those unnecessaries such as " the fluff " of women's apparel, and a thousand trifles which relieve the monotony of the idle and bemuse their own minds.

The discovery of radium and its disintegration as a source of energy has enabled the physicist to extend Lord Kelvin's estimate of the world's age from some thirty to a thousand million years. Arthur Keith does not hesitate to give a million of these years to man's evolution. Karl Pearson speaks of hundreds of thousands of years. The form of the human skull, the brain capacity of man, his skill as evidenced by stone implements and cave drawings of animals in action, was the same tens of thousands of years ago as now. For ages primitive man lived as a wild animal in tropical climes; he discovered how to make fire, clothe himself in skins, build shelters, and so enable himself to wander over the temperate and arctic zones. Finally, in the last few score of years, he has made houses draughtless with glass windows, fitted them with stoves and radiators, and every kind of device to protect himself from cold, while he occupies himself in the sedentary pursuits and amusements of a city life. How much better, to those who know the boundless horizon of life, to be a frontiersman and enjoy the struggle, with body hardened, perfectly fit, attuned to nature, than to be a cashier condemned to the occupation of a sunless, windless pay-box. The city child, however, nurtured and educated in confinement, knows not the largeness and wonders of nature, is used to the streets with their ceaseless movement and romantic play of artificial light after dark, and does not need the commiseration of the country mouse any more than the beetle that lives in the dark and animated burrows of his heap. But while outdoor work disciplines the body of the countryman into health, the town man needs the conscious attention and acquired educated control of his life to give him any full measure of health and happiness.

CHEMICAL PURITY OF THE AIR

THE OXYGEN

Experimental evidence is strongly in favor of our argument that the chemical purity of the air is of no importance.

Russell[1] gives the average percentage of oxygen as follows:

In the open country or sea	20.95
In the streets of London	20.888
Backs of houses	20.70
Mines	20-18.2
Pit of a theater, 11.30 p. m.	20.74
Court of Queen's Bench	20.65
Chemical Theater (Sorbonne) (before and after lecture)	20.28-19.86
Cow house	20.75

Analyses show that the oxygen in the worst-ventilated schoolroom, chapel, or theater is never lessened by more than 1 per cent of an atmosphere; the ventilation through chink and cranny, chimney, door and window, and the porous brick wall, suffices to prevent a

[1] F. A. R. Russell: The Atmosphere in Relation to Human Life and Health. Smithsonian Miscellaneous Collections, Vol. 39, 1896. Pub. No. 1072.

greater diminution. So long as there is present a partial pressure of oxygen sufficient to change most of the hæmoglobin of the venous blood into oxyhæmoglobin during its passage through the lungs, there can arise no lack of oxygen.

At sea-level the pressure of oxygen in the pulmonary alveolar air is about 100 mm. Hg. Exposed to only half this pressure, the hæmoglobin is more than 80 per cent saturated with oxygen.

In noted health-resorts of the Swiss mountains the barometer stands at such a height that the concentration of oxygen is far less than in the most ill-ventilated room. On the high plateau of the Andes there are great cities; Potosi, with a hundred thousand inhabitants, is at 4,165 meters, and the partial pressure of oxygen there is about 13 per cent of an atmosphere in place of 21 per cent at sea-level. Railways and mines have been worked up to altitudes of 14,000 to 15,000 feet. At Potosi girls dance half the night, and toreadors display their skill in the ring. On the slopes of the Himalayas shepherds take their flocks to altitudes of 18,000 feet. No disturbance is felt by the inhabitants or by those who reach these great altitudes slowly and by easy stages. The only disability to a normal man is diminished power for severe exertion, but a greater risk arises from want of oxygen to cases of heart disease, pneumonia, and in chloroform anæsthesia at these high altitudes. The newcomer who is carried by the railway in a few hours to the top of Pike's Peak or the Andes may suffer severely from mountain sickness, especially on exertion, and the cause of this is want of oxygen. Acclimatization is brought about in a few days' time. The pulmonary ventilation increases, the bronchial tubes dilate, the circulation becomes more rapid. The increased pulmonary ventilation lowers the partial pressure of carbon dioxide in the blood and pulmonary air, and this contributes to the maintenance of an adequate partial pressure of oxygen. Haldane and Douglas[1] maintain that the oxygen is actively secreted by the lung into the blood, and find that the number of red corpuscles and total quantity of the hæmoglobin increase, but the method by which their determinations have been made has not met with unqualified acceptance.[2] Owing to the combining power of hæmoglobin the respiratory exchange and metabolism of an animal within wide limits is independent of the partial pressure of oxygen. On the other hand the process of combustion is dependent on the

[1] Phil. Trans. Roy. Soc. B., Vol. 203, p. 185, 1912; and Fitzgerald, ditto, p. 351.

[2] Cf. Dreyer, Ray & Walker, Skand. Arch. für Physiologie, Bd. 28, p. 299, 1913.

percentage of oxygen. Thus the aëroplanist may become seized with altitude sickness from oxygen want, while his gas-engine continues to carry him to loftier heights.

The partial pressure of oxygen in a mine at a depth of 3,000 feet is considerably higher than at sea-level, and if the percentage is reduced to 17, while the firing of fire-damp and coal dust is impossible, there need be in the alveolar air of the lungs no lower pressure of oxygen than at sea-level. Thus the simplest method of preventing explosions in coal mines is that proposed by J. Harger,[1] viz., to ventilate them with air containing 17 per cent of oxygen. There is little doubt that all the great mine explosions have been caused by the enforcement of a high degree of chemical purity of the air. In old days when ventilation was bad there were no great dust explosions. Mr. W. H. Chambers, general manager of the Cadeby mine, where a recent disastrous explosion occurred, with the authority of his great and long practical experience of fiery mines, told us that the spontaneous combustion of coal and the danger of explosion can be wholly met by adequate diminution in ventilation. The gob-fires can be choked out while the miners can still breathe and work. The Coal Mines Regulation Act enforces that a place shall not be in a fit state for working or passing therein, if the air contains either less than 19 per cent of oxygen, or more than 1.25 per cent of carbon dioxide. A mine liable to spontaneous combustion of coal may be exempted from this regulation by order of the Secretary of State. It is also provided that any intake airway shall not be deemed to be fit for persons travelling thereon, if the average percentage of inflammable gas found in six samples of air, taken at intervals of not less than a fortnight, exceeds 1.25 per cent. Workmen must be withdrawn from any working place, if worked with safety-lamps, if the percentage of inflammable gas is found to be 2.5 per cent or upward, or if worked with naked lights, 1.25 per cent or upward.

These regulations impel the provision of such a ventilation current that the percentage of oxygen is sufficient for the spread of dust explosions along the intake airways, with the disastrous results so frequently recorded. If the mine were ventilated with air containing 17.5 per cent of oxygen in sufficient volume to keep the miners cool and fresh, not only would explosions be prevented but the mines could be safely illuminated with electric or acetylene lamps, and

[1] Coal, and the Prevention of Explosions. Longmans, Green & Co., London, 1913.

miners' nystagmus be prevented, for this is due to the dim light of the safety-lamp. The comfort and the working power of the miners would be greatly augmented in a well-lighted mine. To show how little the proposed diminution in the oxygen percentage affects the men, Harger cites a report of Cadman and Whalley concerning a place where there was a quantity of black damp given off, and where "a light would not burn 1 foot 6 inches from the floor, or in the waste, but the men had no fault to find with the atmosphere." The foreman said it was "better than usual."

Analyses of samples taken (1) at the floor, and (2) at the coal face showed:

		Per cent		Per cent		Per cent
(1)	CO_2	4.56	O_2	13.13	N_2	82.28
(2)	CO_2	1.21	O_2	18.97	N_2	79.80

The problem perhaps may be solved by purifying and cooling furnace air, and mixing and circulating this with a sufficiency of fresh air.

All the experimental evidence which we detail later goes to show that it is only when the partial pressure of oxygen is lowered very considerably that signs of oxygen want arise. The athlete suffers from oxygen want in the performance of any rapidly executed and strenuous effort because he uses up oxygen in his muscles more rapidly than it can be supplied by the respiration and circulation. The rapid contraction of the muscles impedes the circulation of blood through the muscles. The blood can flow through them only during the relaxations, not during the contractions. Douglas and Haldane have found that a man doing the hard exercise of pushing a motor-cycle up a steep hill may use up 3,000 cc. of oxygen per minute against 300 cc. when resting. The heart called upon to circulate blood ten times as fast—a strenuous effort—may suffer from want of oxygen, because the circulation of blood through the coronary vessels is impeded by the contraction of the heart muscle during the height of systole, and the total period spent in systole is increased when the heart beats quickly. To start with the lungs full of pure oxygen benefits the athelete; so, too, the breathing of oxygen helps him when cycling and exhausted, or in the intervals of boxing. The strength of the pulse and the fulness of the artery are increased and the frequency of the heart diminished thereby. The athlete in these conditions is like the mountain-sick person. So, too, the pneumonic patient is benefited by oxygen-inhalation. Apart from the influence of high concentrations of oxygen in conditions of extraordinary exertion or in disease, the evidence shows that a diminution of oxygen by 1 per cent at sea-level has not the slightest effect on health and comfort, and that none of the effects of ill-ventilated rooms can be ascribed to want of oxygen.

By breathing over 70 per cent of oxygen the frequency of the heart is diminished four or five beats per minute in the normal resting individual. (J. Parkinson, Journ. Physiol., 1912; also Benedict and Higgins, Amer. Journ. Physiol., Vol. 28, 1911.) In cases of pneumonia with failing heart, the regularity, strength and fulness of the pulse are notably restored by oxygen-inhalation. G. N. Stewart has found that the rate of blood-flow in the arm of one particular cyanosed patient was increased four or five times by oxygen-inhalation—not so in the other cases tested or in the resting, normal man. Cases of pneumonia and heart disease are sent down to the sea-level from high altitudes such as Mexico City, for this is recognized as giving the best chance of recovery. Chloroform, too, is a more dangerous anæsthetic at high altitudes (Johannesburg) and is made safe when given with oxygen.

THE CARBON DIOXIDE

Owing to the fact that the percentage of CO_2 is the usual test of ventilation and that only a very few parts per 10,000 in excess of fresh air are permitted by the English Factory Acts, it is generally supposed that CO_2 is a poison and that any considerable excess has a deleterious effect on the human body. No supposition could be further from the truth.

Reiset[1] gave the percentage of CO_2 as 0.0294 four miles from Dieppe, 0.02898 in a trefoil field, 0.03178 near a flock of sheep. In London a summer average is 0.0379, and a winter average 0.0422. In fog it was 0.072 and once as high as 0.141. In a Court of Chancery, 0.20; in a workshop, 0.30; in the pit of a theater, 0.32; in a crowded meeting, 0.365; in badly ventilated barracks, 0.1242 to 0.195; in the general hospital, Madrid, 0.32 to 0.43; in a girls' school (70 girls and 10,400 cubic feet), 0.73. We see, then, that the percentage of CO_2 in the worst-ventilated room assuredly does not rise above 0.5 per cent or, at the outside, 1 per cent. It is impossible that any excess of CO_2 should enter into our bodies when we breathe such air, for whatever the percentage of CO_2 in the atmosphere may be, that in the pulmonary air is kept constant at about 5 per cent of an atmosphere by the action of the respiratory center. It is the con-

[1] Cited after Russell. Vide supra.

centration of CO_2 which rules the respiratory center, and to such purpose as to keep the concentration both in the lungs and in the blood uniform. (J. S. Haldane.) The only result from breathing such a slight excess of CO_2 as 0.5 per cent (slight to the physiologists, but regarded as enormous by the hygienist) is an unnoticeable increase in the ventilation of the lungs. The increased ventilation is exactly adjusted so as to keep the concentration of CO_2 in the lungs always at the normal 5 to 6 per cent of an atmosphere. The very same thing happens when we take gentle exercise and produce more CO_2 in our bodies; the pulmonary ventilation is slightly increased, and thus the concentration of CO_2 in the blood and lungs is kept the same.

We turn to the evidence of former researchers. Leblanc[1] found that an animal could survive exposure to an atmosphere containing 30 per cent of carbon dioxide, provided the percentage of oxygen was 70 per cent, and recover quickly from the depression produced by this mixture. So, too, Regnault and Reiset[2] found that an animal could survive exposure to an atmosphere containing a relatively high concentration of CO_2 so long as sufficient oxygen was supplied.

Pettenkofer[3] demonstrated clearly that the symptoms produced in crowded ventilated places were due neither to excess of CO_2 nor deficiency of O_2. He found that 1 per cent of CO_2 could be breathed for hours with no discomfort. Pettenkofer did not regard the impure air of dwellings as directly capable of originating specific disease, or as a poison in the ordinary sense of the term, but concluded that the capability of withstanding the influence of disease-producing agencies was diminished in those who continually breathed such air. He laid down the doctrine accepted by sanitarians, that the percentage of CO_2 is a guide to the other deleterious properties of the atmosphere.

It is manifest, however, in regard to the heat, moisture, and movement of a confined atmosphere, that the CO_2 percentage may give no indication, and fails wholly as an adequate test.

R. A. Smith[4] enclosed men in a chamber and found that the pulse frequently fell from 73 to 57, while the frequency of respiration rose from 15 to 24, in an atmosphere in which the CO_2 increased

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[1] Ann. de Chim. et Phys. Paris, 1842, (3), v, 223.

[2] Ann. de Chim. et Phys. Paris, 1849, (3), XXVI, p. 299.

[3] Ann. de Chem. u. Pharm. Leipzig u. Heidelberg, 1862-3, 2. Suppl. Bd. p. 1-52.

[4] Air and Rain. London, 1872.

in four hours' time from 0.04 to 1.73. He found the circulation was weak and the respiration difficult when the CO_2 rose to 3 per cent, but attributed these results to other conditions than the excess of CO_2. The air in his chamber must have become overwarm and moist.[1]

J. T. F. Hermans[2] employed a tin chamber 1.8 meters high, 1.75 meters broad, and 1.2 meters deep. Observations were made on the body temperature, frequency of pulse, and respiration. In some experiments the CO_2 was absorbed, in others not. The air of the chamber was also analyzed for combustible gases by passing over glowing copper oxide, but none could be detected even with two people in the chamber. No organic products could be traced by drawing the air of the chamber through H_2SO_4.

The following figures show the effect of absorption or non-absorption of CO_2.

	CO_2	O_2	Pulse	Respiration
	Per cent	*Per cent*		
1 person in chamber......	3.3	12.7	70–72	24
1 person in chamber......	0.87	....	75–72	16–18
2 persons in chamber.....	5.13	14.4	(a) 80–84 (b) 68–72	34 30

When, with two people in the chamber, the CO_2 percentage reached 5.13, they suffered from dyspnœa and headache.

Haldane and Lorraine Smith confirmed the results of Hermans. With 3.9 per cent there were hyperpnœa and slight headache, which disappeared on leaving the chamber. On breathing 5.5 to 6 per cent there was great hyperpnœa, which was very exhausting. By breathing in and out of a bag they found that distress became very severe when CO_2 reached 10 per cent and the oxygen was correspondingly decreased. If the bag was filled with oxygen to start with, they endured the inhalation until the percentage of CO_2 reached 10.4, the oxygen being 58.6 per cent. Hill and Flack have confirmed this.

By breathing oxygen for two or three minutes, and then holding the breath with the lungs full of oxygen, the breath can be held for astonishingly long periods of time, for example, for 5 to 6 minutes and even for 8 to 9 minutes.[3]

[1] Above authorities cited after Billings, Weir Mitchell, and Bergey. Smithsonian Contributions to Knowledge, Vol. 39, 1895.

[2] Arch. f. Hygiene. München u. Leipzig, 1883, Vol. 1, p. 1.

[3] Cf. Vernon, Journ. Physiol. Proc., XVIII, Vol. 38, 1909.

Sweating and slight headache are the only abnormal results of the short exposure to such percentages of CO_2.

If the CO_2 be removed from the blood and tissues by a preliminary period of increased ventilation of the lungs, analyses of the pulmonary alveolar air taken at the breaking point, show that when the partial pressure of CO_2 is lower, a lower partial pressure of oxygen can be borne, and vice versa; for example, the breaking point occurred with 6.6 to 6.9 per cent CO_2, and 11.1 to 9.1 per cent O_2; with 5.5 to 5.9 per cent CO_2 and 5.8 to 3.7 per cent O_2; with 8 to 10 per cent CO_2 and 30 to 50 per cent O_2.

Oxygen-inhalation notably increased the power to do work with the breath held, and the partial pressure of CO_2 in some cases rose to 11 per cent of an atmosphere before the breaking point occurred.[1]

One subject, with the breath held, ran 113 yards in 79⅗ seconds after ordinary breathing, 150 yards in 35⅔ seconds after deep breathing, and 256 yards in 62⅗ seconds after deeply breathing oxygen.

As some reserve of energy must be kept for collecting the sample of pulmonary air, it is clear that the percentage of CO_2 must rise higher than 11 per cent in those who run to the utmost limit of endurance with the breath held.

These experiments make it quite clear that while the lungs normally contain 5 to 6 per cent of CO_2, at sea-level pressure, it is no less certain that they may contain more than this amount when the breath is held during any effort, and such temporary exposures have no ill effect.

Speck found that the inhalation of 7 per cent CO_2 produced great hyperpnœa, but he managed to endure it for 2.5 minutes. On breathing an atmosphere containing 11.5 per cent he found that the first breath was uncomfortable—there resulted headache, sweating, dimness of vision, and tremors. He could hardly endure the inhalation for a period of one minute. On inhaling 5.4 per cent CO_2 he exhaled 6 per cent and still maintained a respiratory exchange by the intensity of his breathing; with 7 to 8 per cent CO_2 inspired, 7 to 8 per cent was expired, and the output of CO_2 from the body was checked. The symptoms of poisoning begin when this happens; the lower percentages, which cause no retention of CO_2 in the body, have no effect other than the production of hyperpnœa. Löwy found with 6 per cent CO_2 considerable dyspnœa and with 8 per cent very great dyspnœa. Emmerich recorded that the inhalation of 8.4 per cent CO_2 caused dyspnœa, a flushed face and headache in 10

[1] Hill and Flack, Journ. Phys., Vol. 40, 1910, p. 347.

minutes. We can confirm these findings. High percentages of CO_2, for example, 30 to 50 per cent cause spasm of the glottis and cannot be inhaled by the normal individual.

At each breath we rebreathe into our lungs the air in the nose and large air-tubes (the dead-space air), and about one-third of the air which is breathed in is dead-space air when we are resting. Thus, no man breathes in pure outside air into his lungs, but air contaminated perhaps by one-third or (on deep breathing during muscular work) by one-tenth with his own expired air. When a child goes to sleep with its head partly buried under the bed clothes, and in a cradle confined by curtains, it rebreathes the expired air to a still greater extent; and so with all animals that snuggle together for warmth's sake. Not only the new-born babe sleeping against its mother's breast, but pigs in a sty, young rabbits, rats and mice clustered together in their nests, and young chicks under the brooding hen, all alike breathe a far higher percentage than that allowed by the Factory Acts. Cattle in ill-ventilated stalls may breathe 10 times the normal percentage[1] of CO_2.

When the air of a room is still, the expired air may not be blown away and hangs round a person recumbent therein. Thus B. Heymann[2] found 0.44 per cent in the inspired air, against 0.0318 in the air of the room. On putting an electric fan to blow across his face at a rate of 3.3 meters per second the CO_2 in the inspired air fell to 0.0307 per cent.

To rebreathe one's own breath is a natural and inevitable performance, and to breathe some of the air exhaled by another is the common lot of men who, like animals, have to crowd together and husband their heat in fighting the inclemency of the weather.

Lehmann found in a brewery 1.5 to 2.5 per cent CO_2 in the air of the fermentation rooms. This was breathed by 5 to 8 workers for hours long with no ill effects. All were strong, healthy young men, some having done the work for years. Weak men with affections of the lungs are not allowed to do this form of work. With 11.6 to 14.7 per cent most were constrained to leave the room in two minutes, but two strong young men endured it for 5 minutes and were all right afterwards.

An experiment was made of breathing for three-fourths of an hour 1.8 to 3.5 per cent CO_2, rising finally to 10 per cent, when the

[1] Schultze u. Maercker. Neben den CO_2 Gehalt der Stallfult. Göttingen, 1869. Cited after B. Heymann.

[2] Ztschr. f. Hygiene, Vol. 49, 1905, p. 403.

subjects were compelled to go out. The workers stood 8 to 14 per cent no better than the experimenters.

In the Albion Brewery, Whitechapel (Mann, Crossman & Co.), we analyzed on three different days the air of the room where the CO_2, generated in the vats, is compressed and bottled as liquid carbonic acid. Work goes on night and day; 18 tons of liquid CO_2 are sold per week; three men work per shift. We found from 0.14 to 0.93 per cent of CO_2 in the atmosphere of that room. The men who were filling the cylinders and turning the taps on and off to allow escape of air must often breathe more than this. The men engaged in this occupation worked twelve-hour shifts, having their meals in the room. Some had followed the same employment for eighteen years, and without detriment to their health. It is only when the higher concentrations of CO_2 are breathed, such as 3 to 4 per cent of an atmosphere, that the respiration is increased so that it is noticeable to the individual himself; such percentages diminish the power to do muscular work, for the excess of CO_2 produced by the work adds its effect to that of the excess in the air, and the limit of panting is soon reached.

ALBION BREWERY

CO_2 Compression Room

	Sample taken	Per cent CO_2
Jan. 10, 1912, morning	At breathing level	0.3
	Near cylinder from which air (and CO_2) was escaping during filling process	1.48
	At another part of the room	0.44
Jan. 10, afternoon	At breathing level	0.54
	Near cylinders in foreman's office	0.39
	In center of room about 20 minutes after blowing off cylinders	0.79
	Ditto a few minutes after blowing off cylinders	0.93
Jan. 12	In the middle of the room, no taps open for some time	0.196
	Near cylinders	0.345
	In foreman's office	0.142
	In middle of room after blowing off cylinders, at breathing level	0.533

Haldane and Priestley found that with a pressure of 2 per cent of an atmosphere of CO_2 in the inspired air the pulmonary ventilation was increased 50 per cent; with 3 per cent, about 100 per cent; with 4 per cent, about 200 per cent; with 5 per cent, about 300 per cent; and with 6 per cent, about 500 per cent. With the last, panting is severe; while with 3 per cent it is unnoticed until muscular work is done, when the panting is increased 100 per cent more than usual. With more than 6 per cent the distress is very great, and headache, flushing, and sweating occur. With more than 10 per cent there occurs loss of consciousness after a time, but no immediate danger to life. Even exposure to 25 per cent may not kill an animal within an hour or two.

Such high concentrations, when sufficient O_2 is supplied, poison the heart and lower the blood-pressure (Hill and Flack).

It is only when the higher concentrations of CO_2 are breathed, such as 3 to 4 per cent of an atmosphere, that the respiration is increased so that it is noticeable to the resting individual; but percentages over 1 per cent diminish the power to do muscular work, for the excess of CO_2 produced by the work adds its effect to that of the excess in the air, and the difficulty of coördinating the breathing to the work in hand is increased. Nevertheless, divers who work in diving dress and men at work in compressed-air caissons constantly do heavy and continuous labor in concentrations of CO_2 higher than 1 per cent of an atmosphere, and so long as the CO_2 is kept below 2 to 3 per cent they are capable of carrying out efficient work. The excess of oxygen helps them. In the case of workers in compressed air it is important to bear in mind that the effect of the CO_2 on the breathing depends on the partial pressure and not on the percentage of this gas in the air breathed.[1] Thus the volume of air breathed was increased 2 to 2.5 times by inhaling 5 per cent CO_2 at 1 atmosphere, and to the same extent by inhaling 1.6 per cent at 3.7 atmospheres. The partial pressure in the two cases was approximately the same. It follows from this that whatever the pressure a diver is under he requires the same volume of air for ventilation, measured at that pressure. Thus at 2 atmospheres (33 feet depth of water) the air supply, measured at atmospheric pressure where the pump is, must be doubled; at 3 atmospheres, trebled; and so on.

In the boring of the St. Gothard tunnel the laborers carried out the work in an atmosphere containing 0.3 to 0.96 per cent CO_2. At the altitude of the tunnel the partial pressure was considerably less, but yet far above that set as the limit in factories. In the compressed-air caisson at Nussdorf the CO_2 percentage varied from .04 to 0.5, and the partial pressure was about three times this amount, that is, equivalent to 0.12 to 1.5 per cent at sea-level.

[1] Haldane and Priestley, Journ. of Physiol., Vol. 32, 1905, p. 225, and Report of Admiralty Committee on Deep-sea Diving, 1905.

In these tunnels the temperature is often very high (21° to 30.2° C. in the St. Gothard) and almost saturated with moisture. The discomfort, weariness, excessive sweating, loss of appetite, and pallor, which may affect tunnel workers, are, we believe, due to the excessive heat and moistness of the atmosphere. That this is so is shown by the experiments of L. Paul and Ercklentz. (See later, p. 53 of this paper.)

RATS AND CO_2.

By a series of observations made on rats confined in cages fitted with small, ill-ventilated sleeping chambers, we (M. F. and L. H.)

EXPERIMENTS ON RATS

Animals	Temperature	CO_2	O_2	Remarks
	Degrees C.	*Per cent.*	*Per cent*	
8 Rats.....	19	4.69	.....	In sleeping chamber.
Do.....	....	4.95	14.90	Do.
Do.....	19	3.39	16.95	6 in, 1 out.
Do.....	23	....	.....	Put over stove, the rats kept coming out.
Do.....	....	3.01	18.00	After putting outside window in cold air, all went in.
7 Rats.....	21	4.23	16.19	All inside sleeping chamber.
Do.....	24	2.90	17.24	Put on stove, all inside still.
Do.....	23.5	....	.....	Later, 3 or 4 outside.
Do.....	22	2.24	17.74	Off stove, all inside.
Do.....	....	3.07	.....	Little later, all inside.
Do.....	23	3.18	17.66	All inside.
Do.....	23	2.33	.....	Do.
Do.....	23	5.8	13.06	Chamber put out in the cold and opening in it made smaller, all inside.
Do.....	34½	5.70	.....	Put on stove, all inside. No moist bread inside.
Do.....	25	....	.....	Much moist bread put inside sleeping chamber.
Do.....	31	....	.....	Noses at hole.
Do.....	32	....	.....	2 out.
Do.....	32.5	3.36	16.28	3 out.
				4 out.
Do.....	27	5.61	.....	Put out in the cold again, 1 out.
18 Rats.....	30	5.51	.....	All in.
7 Rats.....	35	5.56	.....	Dry sleeping place, all in.
Do.....	31½	3.80	.....	Moist bread in sleeping place, all gradually came out.

have found that the temperature and humidity of the air—not the percentage of carbon dioxide or oxygen—determine whether the animals stay inside the sleeping room or come outside. When the air is cold, they like to stay inside, even when the carbon dioxide rises to 4 to 5 per cent of an atmosphere. When the sleeping chamber is made too hot and moist, they come outside.

We cite the view expressed by Benjamin Moore,[1] that the living cell fat and carbohydrate are elaborated with protein into molecular union, the whole forming the water-clear bioplasm in which both fat and carbohydrate are lost to ordinary chemical tests. As a preliminary step to oxidation, the sugar or fat molecule must be built in as an intrinsic part of the bioplasm. Oxygen is likewise taken up, and there exists in the cell a delicately balanced equilibrium between the bioplasm, which acts as a catalyst, the carbohydrate (or fat) in labile union, the oxygen, and the carbon dioxide formed in the reaction. Variations of the concentrations, or osmotic pressures of any member of the system, may lead to corresponding alterations in rate of oxidation.

In regard to osmotic pressure of the dissolved oxygen, there is a very large factor of safety, for Edie, Moore, and Roaf's experiments on cats, rats, and rabbits show that, provided the carbon dioxide formed in respiration is not allowed to accumulate to a poisonous extent, the animals can be kept for over 40 hours on 5 to 6 per cent of oxygen (rabbits) and 9 to 10 per cent of oxygen (cats) without any evil after-effects, and with no glycosuria. On the other hand, "in accordance with the general fundamental principles of chemical equilibrium, and kinetics of chemical reactions, any accumulation of the products of reaction causing an increase in osmotic pressure, and hence an increased chemical potential of these produced constituents, will act as a resistance upon the reaction, and with further increase will finally bring it to a standstill."

Thus when the CO_2 in the air breathed was allowed to exceed 13 per cent (7 per cent sufficed in the case of a cat), sugar always appeared in the urine, even though the oxygen percentage was kept up to 25 per cent or more. These experiments also show how very great must be the accumulation of CO_2 in the air to produce such an effect as a temporary slight glycosuria. The CO_2 percentage must exceed that in the pulmonary air; viz., 5 to 6 per cent. The increase in badly ventilated rooms, at the outside 0.5 per cent, can cause no accumulation of CO_2 in the body. The experiments also confirm all the other evidences which demonstrate how very greatly the O_2 percentage can be reduced (at sea-level) without endangering the life of the resting animal.

[1] Cf. Edie, B. Moore, and Roaf, Biochem. Journ., Vol. 5, p. 325. Liverpool. 1911.

THE SUPPOSED EXISTENCE OF A CHEMICAL ORGANIC POISON IN EXHALED AIR

In a paper published by the Smithsonian Institution, F. A. R. Russell[1] says:

"Organic matter is given off from the lungs and skin, of which neither the exact amount nor the composition has been hitherto ascertained. The quantity is certainly very small, but of its importance there can be no doubt. It darkens sulphuric acid, decolorizes permanganate of potash, and makes pure water offensive when drawn through it.... Since this organic matter has been proved to be highly poisonous, even apart from carbon dioxide and vapor, we may safely infer that much of the mischief resulting from the inspiration of rebreathed air is due to the special poisons exhaled from the body, their fatal effect being accelerated by the depression of vitality caused by the gaseous products of respiration and by the want of oxygen.... *As to the frequent emission of a deadly particulate poison, no doubt whatever can exist.* It is a dangerous and pernicious element in all aggregations, and, combined with carbon dioxide, produces, when in moderate quantity, depression, headache, sickness, and other ailments; when in large quantity, as in the Black Hole of Calcutta,..... rapid death in the majority. .... Much of the mortality of infant and adult life may be due to the rebreathing of poison excreted by breath and skin."

This passage expresses the popular view.

We shall show that there is no evidence to justify these statements. The deaths in the Black Hole of Calcutta, the depression, headache, etc., in close rooms, are alike due to heat stagnation; the victims of the Black Hole died from heat-stroke.

From what has gone before, it is evident that neither the diminution of oxygen nor the increase in carbon dioxide has any influence in crowded rooms, and we shall now show that there is no evidence of the existence of any organic chemical poison in exhaled air.

The sanitarian says it is necessary to keep the CO_2 below 0.01 per cent, so that the organic poisons may not collect to a harmful extent. The evil smell of crowded rooms is accepted as unequivocal evidence of the existence of such. He pays much attention to this and little or none to the heat and moisture of the air. The smell arises from the secretions of the skin—sweat, spray from the mouth;

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[1] F. A. R. Russell: The Atmosphere in Relation to Human Life and Health. Smithsonian Miscellaneous Collections, Vol. 39, 1896, p. 44. Pub. No. 1072.

from food eaten, such as onions, garlic; from carious teeth; from the bad breath of dyspepsia, due to regurgitation of food particles and their decay on the unhealthy, flabby mucous membrane of the tongue; from the passage of wind from the alimentary canal; from dirty clothes soiled with body secretions—sweat, menstrual discharge, etc. The clothes, too, absorb smells such as those of the stable, tobacco, etc., and give these out. The air may also be contaminated by smells of cooking, or smells arising from urinals, latrines, stables, etc., or by trade smells, many of which are most offensive to the newcomer. The smell is only sensed by, and excites disgust in, one who comes to it from the outside air. He who is inside, and helps to make the "fugg," is both wholly unaware of and unaffected by it. Flügge[1] points out, with justice, that while we naturally avoid any smell that excites disgust and puts us off our appetite, yet the offensive quality of the smell does not prove its poisonous nature. For the smell of the trade or food of one man may be horrible and loathsome to another.

The sight of a slaughterer and the smell of dead meat may be loathsome to the sensitive poet, but the slaughterer is none the less healthy. The clang and jar of an engineer's workshop may be unendurable to a highly-strung artist or author, but the artificers miss the stoppage of the noisy clatter. The stench of glue-works, fried-fish shops, soap and bone-manure works, middens, sewers, becomes as nothing to those engaged in such; and the lives of the workers are in no wise shortened by the stench they endure. The nose ceases to respond to the uniformity of the impulse, and the stench clearly does not betoken in any of these cases the existence of a chemical organic poison. On descending into a sewer, after the first ten minutes, the nose ceases to smell the stench; the air therein is usually found to be far freer from bacteria than the air in a schoolroom or tenement (Haldane).

If we turn to foodstuffs, we recognize that the smell of alcohol and of stilton or camembert cheese is horrible to a child, while the smell of putrid fish—the meal of the Siberian native—excites no less disgust in an epicure who welcomes the cheese. Among the hardiest and healthiest of men are the North Sea fishermen, who sleep in the cabins of trawlers reeking with fish and oil, and for the sake of warmth shut themselves up until the lamp may go out from want of oxygen. The stench of such surroundings may effectually put the sensitive, untrained brain-worker off his appetite, but the robust

[1] Ztschr. f. Hygiene, Vol. 49, 1905, p. 433.

health of the fisherman proves that this effect is nervous in origin, and not due to a chemical organic poison in the air.

Studying the ventilation of sleeping-cars, T. R. Crowder[1] finds that in those cars called "close" or "stuffy" the temperature invariably is high. There has sometimes been an unpleasant odor. A high temperature renders this more noticeable. The most marked offensiveness noticed was in a day coach, where "the air was of such a degree of chemical purity as to indicate ideal ventilation by any standard that has ever been proposed. The car was hot and had many filthy people in it." Perfect comfort has been found associated with the highest chemical impurity in other cars.

Ventilation cannot get rid of the source of a smell, while it may easily distribute the evil smell through a house.

As Pettenkofer said, "if there is a dungheap in a room, it must be removed. It is no good trying to blow away the smell." Houses and people and their clothes and bodies must be made clean, and latrines and kitchens must be placed on the top of houses, or outside them, and on the least windy side.

The right way of dealing with an offensive smell is to remove its cause. By opening the window and letting the wind blow in we may only drive the smell elsewhere. In schools, hospitals, or houses an open window in a latrine may cause the impulsion of the smell into the house. Aspiration by fans may be employed or deodorization by ozone; the latter is one of the simplest methods of dealing with an offensive trade odor. Schoolrooms may be cleared at short intervals, and all the windows and doors thrown open for five minutes, while the children take a "breather" in the form of active exercise in the open air.

Flügge and his school, Beu, Lehmann, Jessen, Paul, and Ercklentz controvert the supposition that there is an organic poison, and bring convincing evidence to show that a stuffy atmosphere is stuffy owing to heat stagnation, and that the smell has nothing to do with the origin of the discomfort felt by those who endure it.

Flügge points out that the inhabitants of reeking hovels in the country do not suffer from chronic ill health, unless want of nourishment, open-air exercise, or sleep come into play. Town workers are pale, anæmic, listless, who take no exercise in the fresh air. Sheltered by houses they are far less exposed to winds, and live day and night in a warm, confined atmosphere.

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[1] Arch. of Internal Medicine, 1911, Vol. 7, pp. 85-133.

We will now summarize the evidence for and against the existence of an organic chemical poison in expired air.

Hammond[1] arranged an experiment in which a mouse was enclosed in a large jar with sponges soaked in baryta to absorb the exhaled CO_2, etc., and he attributed the death of the mouse to organic poison. His method undoubtedly was at fault, the mouse dying of suffocation.

Ransome[2] condensed the aqueous vapor of human breath and found that "in ordinary respiration about 0.2 of a gramme or 3 grs. of organic matter is given off from a man's lungs in 24 hours," and that this amount varies greatly in certain diseases; for example, it is greatest in a case of phthisis complicated with Bright's disease.

Seegen and Nowak[3] demonstrated, as they thought, the presence of poisonous organic matter in the expired air, but the quantity obtained was so small that its nature and properties could not be determined.

Hermans[4] was unable to detect any organic matter in the atmosphere of the small chamber in which he confined persons for many hours.

The widespread belief in the presence of organic poisons in the expired air is mainly based on the statements of Brown-Séquard and D'Arsonval, almost wholly unsubstantiated by other workers. These statements have done very great mischief to the cause of hygiene, for they have led ventilating engineers to seek after chemical purity, and neglect the attainment of adequate coolness and movement of the air.

In their first series of experiments Brown-Séquard and D'Arsonval injected into the blood-vessels of a rabbit water with which they had repeatedly washed out the air-tubes of a dog. In a second series they injected the water condensed from the exhaled breath of man; in a third series, the water condensed from the exhaled breath of a tracheotomized dog.

The symptoms recorded[5] were dilatation of the pupil, acceleration of the heart, slowing of the respiration; there usually occurred diarrhœa and paralysis of the posterior limbs. The larger doses caused, as a rule, labored breathing, retching, and contracted pupils.

[1] A Treatise on Hygiene. Philadelphia, 1863. Cited after Billings, etc.

[2] Journ. Anat. and Physiol. London, 1870, Vol. 4, p. 209.

[3] Arch. d. ges. Physiol. Bonn, 1879, Vol. 19, p. 347.

[4] Cited supra.

[5] Compt. Rend. Soc. de Biol., 1887 (8), iv, 814; 1888 (8), v, 33, 54, 94, 108, 121; Compt. Rend. Acad. d. Sc., Paris, Vol. 106, 1888, p. 106.

They attributed the results to a volatile organic poison of the nature of an alkaloid or ptomaine. The poison, they said, is reduced by ammoniacal nitrate of silver or chloride of gold solution. Boiling made no difference to the toxic action of the trachea washings. The condensed liquid turned concentrated sulphuric acid yellow.

The boiled trachea washings might kill even when injected into the rectum or stomach. Intraperitoneal injection killed a guinea-pig in 12 hours. Injection of the liquid into the lungs produced inflammation. Some of these results may be attributed to bacterial infection, others to the toxic effect which is known to follow injection of foreign protein or water containing bacteria, and others to the large doses of water injected at room temperature.

An experiment with two dogs was so arranged that one breathed the air exhaled from the lungs of the other. The experiment continued for nearly seven hours and no untoward results followed.

Dastre and Loye[1] repeated these experiments, but with no result. They inoculated animals with the condensation water of the breath and obtained no effect when 33 to 75 cc. of the fluid was injected into each of five rabbits and two dogs, and 5.7 cc. into each of two guinea-pigs. Two rabbits were killed by the injection of 50 to 190 cc. (60 cc. per kilo) and one puppy by the injection of 30 cc. of distilled water (25 cc. per kilo). The marvel is that all the animals were not rendered severely ill by the injection of such large amounts of water. An equivalent injection for a man would be 2 to 4 liters. Russo-Gilberti and Alessi[2] confirmed the negative findings of Dastre and Loye. They obtained the condensation water from a crowded schoolroom which was sealed up for 2 hours. The air produced headache and was offensive.

von Hofmann Wellenhof[3] obtained the symptoms noted by Brown-Séquard and D'Arsonval when he injected not only large quantities of condensation liquid, but also distilled water at the temperature of the laboratory. There occurred muscular weakness, slowing of respiration, fall of temperature, and dilatation of the pupils. When he injected 10 rabbits with 6 to 30 cc. of the condensation fluid warmed to body temperature, the results were negative.

Lehmann and Jensen[4] likewise obtained wholly negative results

[1] Compt. Rend. Soc. de Biol. Paris, 1888 (8), v, 91.

[2] Bull. Soc. d'Igiene di Palermo, Vol. 3, 1888, p. 331.

[3] Wien. Klin. Wochenschr., 1888, I, p. 753.

[4] Archiv. f. Hygiene, 1890, Vol. 10, p. 367.

with the condensation water of human breath. The fluid was obtained by breathing through a glass spiral surrounded with ice. It was clear, odorless, and neutral in reaction, contained traces of ammonia, and yielded a small sediment on evaporation which they believe originated from the glass vessel. There was no trace of an alkaloid, and ammoniacal silver solution gave no reaction. The reducing power as tested by permanganate of potash was given as 3 to 4 milligrams of O_2 for the oxidation of 1 liter. They confined a man in a metal box for half an hour and then allowed a boy and a girl to inhale the air from the box. No effects resulted excepting slight hyperpnœa. Lipari and Crisafulli[1] also reported results directly contrary to those of Brown-Séquard and D'Arsonval.

J. S. Haldane and Lorrain Smith[2] found that hæmaturia was produced when more than 100 cc. of boiled distilled water was injected subcutaneously into rabbits weighing 1,800 grams. They injected therefore 80 cc. of condensation liquid (human), and without result, an amount corresponding to a dose of 3 liters in a man.

Beu[3] collected the condensation water after cleansing his apparatus with potassium permanganate and distilled water and sterilizing it. The saliva was collected in a Woulfe bottle attached before the condenser. From 3,000 liters, expired in 8 hours, 100 cc. of fluid were collected. This gave a distinct ammonia reaction with Nessler's reagent. Its reducing power with permanganate of potash solution indicated that 50 milligrams of O_2 were required to oxidize 1 liter. The reactions for alkaloid were negative.

He expired 500 liters through 150 cc. of a 1 per cent solution of KHO and evaporated the solution to dryness. The deposit, dissolved in distilled water, formed a fatty layer on the surface of the water which was tinged slightly yellow.

The fluid had a distinctive smell. It was warm to body temperature, and the whole of it was injected under the skin of a mouse without producing any sign of disturbance—a most conclusive experiment and complete refutation of Brown-Séquard and D'Arsonval's statements.

Billings, Weir Mitchell, and Bergey[4] have published the results of a very thorough investigation. They found that in ordinary quiet

[1] Sicilia med. Palermo, 1889, Vol. 1, p. 229; Abstr. Arch. de Physiol. norm. et path., Paris, 5 s., Vol. 2, p. 679.

[2] Journ. Path. and Bact. Edinburgh and London, 1892-3, I, 168.

[3] Ztschr. f. Hygiene. Leipzig, 1893, Vol. 14, p. 64.

[4] Smithsonian Contributions to Knowledge, Vol. 29, 1895. Pub. No. 989.

respiration no bacteria, epithelial scales, or particles of dead tissue are exhaled.

Flügge has shown that in the act of coughing, sneezing, or speaking, such organisms or particles may be thrown out (droplet contagion). The minute quantity of ammonia or other oxidizable matter in the condensed moisture of human breath appears to be due to the decomposition of organic matter in the mouth and pharynx. Thus the reducing power is greater 4 hours after eating than ½ hour after, and far less if the mouth is cleansed; for example, equivalent to 12 milligrams of O_2 per liter against 3 milligrams. Experiments on the air of the hospital ward, and the moisture condensed therefrom, showed that the greater part of the ammonia is connected with dust particles, microorganisms, etc., which can be filtered off. The bacteria are probably the only really dangerous elements in the air.

The fluid condensed from the pulmonary exhalations of man has no toxic or specially injurious effect when injected into animals, and there is no evidence that such fluid contains an organic poison. The fluid was collected with great care in sterilized apparatus, and was proved to be sterile; it was warmed to body temperature, and was injected in doses in some instances less, in others greater, than the smallest quantities which were used by Brown-Séquard and D'Arsonval with fatal effects.

Peters tested the condensation fluid obtained from human breath on the frog's heart. It had no poisonous effect. In the last year or two Weichardt[1] claims to have found traces of "kenotoxin" in expired air. This, he says, is a protein decomposition product of high molecular weight obtainable in the juice expressed from fatigued muscles. He obtained the condensation fluid from the expired air of a fatigued man of 60 years who breathed through wadding for 2 hours. The fluid was expressed from the wadding. He claims to have obtained it also from blotting paper exposed in a room crowded with sleepers. The fluid was concentrated by evaporation and 1 cc. or more was injected into a mouse.

Inaba[2] carried out similar experiments and reached the conclusion that the mice were poisoned no less by an equally large dose of distilled water. Thus 0.3 to 0.7 cc. gave no result, while 1 to 1.5 cc. made the mice ill. So, too, with distilled water; to put 1 or 1.5 cc. of water into a 13-gram mouse is the same as injecting 5 liters into a 60-kilogram man.

[1] Arch. f. Hygiene, Vol. 74, p. 185, 1911.

[2] Ztschr. f. Hygiene, Vol. 68, p. 1, 1911.

Weichardt[1] rejoined that the respiratory condensation fluid gives the guiac reaction and so must contain some trace of protein. He also said the mouse was not affected by 1 cc. of the concentrated condensation water, if heated to dryness and redissolved, while it was affected by the same dose of unheated condensation water.

He gives details of only one or two such experiments. We now know that either distilled water or isotonic saline solution, when kept in the laboratory, may produce toxic symptoms, especially when large doses are injected. The solution or water becomes infected with bacteria and although sterilized by boiling, when injected intravenously into men, may produce febrile and other disturbances, such as have been observed after the injection of salvarsan. These mischances have been altogether prevented by the use of freshly prepared, pure, sterile, salt solution.[2]

The toxic effect is due to the dosage of dead bacteria injected with the water. The symptoms are shivering, fever, and cyanosis, vomiting, headache, and pain in the back lasting about four hours. The only conclusion which can be drawn from the above is that the evidence in favor of the existence of poison in the condensation water is entirely unsubstantiated. The negative results obtained by so many capable workers are convincing, while the few positive results cannot be accepted in the absence of proper controls. To inject one-thirteenth of its body weight into a mouse, and expect it not to be ill, is about the limit of absurd experiment. Recently Rosenau and Amoss[3] have brought forward evidence of another kind which seems to show that traces of protein may pass away in the expired air, at any rate under their experimental conditions. They breathed through a Drechsel flask, interposing a plug of cotton wool, for 6 to 10 hours; 10 to 20 cc. of condensation fluid was so obtained; 5 to 10 cc. of this fluid was injected into guinea-pigs; and a month later 0.2 cc. of human serum was injected either into the heart or into the brain. Symptoms of anaphylactic shock occurred in many of the animals; but, be it noted, several of the experiments gave negative results, and in particular some in which a double plug of glass wool was employed. It seems to us that in breathing through a tube droplets of saliva will be carried away from the mouth and the glass wool in time will become wet through. When this hap-

[1] Weichardt and Stötter, Arch. f. Hygiene, Vol. 75, p. 265, 1912.

[2] McIntosh and Fildes: Syphilis, pp. 200, 207. Arnold, London, 1911; Lancet, March 9, 1912.

[3] Journ. Med. Research, Boston, 1911, Vol. 25, p. 35.

pens, droplets may be carried on from the farther side of the wool into the condensation water. Breathing through a tube leads to an expulsion of saliva which does not occur in natural breathing. Dust of white lead may be carried through four wash bottles by a current of air.[1]

The guinea-pigs, as we might expect, therefore became sensitized to human protein by the injection of the condensation water containing traces of salivary protein.

Rosenau and Amoss do not take this view, and think that their results afford evidence in favor of the exhalation of a volatile protein —an organic chemical poison. They say they " have always felt that a vitiated air must contain substances which are harmful, even though not demonstrable to science," and suggest that the sensitivity of some adults to a first injection of horse serum may be due to such adults having worked with horses and breathed their breath. Horse dung and horse hairs seem to us far more likely to produce anaphylactic sensitivity in a groom than the breath of ten thousand horses. The authors say " there is a growing tendency to regard the ill effects of vitiated air as due to increased temperature and moisture; it is now apparent that there are other factors which must be taken into account." But the question is—Do men breathe out a substance poisonous to man? If there were anything in these claims, we should expect to find guinea-pigs which dwell in the same confined cage, and breathe each other's breath, sensitive to the injection of a trace of each other's protein. All those who study the phenomena of anaphylaxis know that no such sensitivity can be shown. Anaphylaxis can be produced only by the injection of a foreign protein. No one has ever demonstrated that it is possible to produce anaphylactic sensitivity by the assimilation of protein from the alimentary tract; in fact all the evidence of daily experience is against such a possibility. There is no more likelihood that a foreign protein should have such an effect when absorbed from the respiratory tract. We (M. F. and L. H.) have put the matter to the test, and in this part of the research Dr. James McIntosh coöperated with us. The method we have adopted is one which places the animals in a condition similar to that of men living in a crowded, confined atmosphere. Rats and guinea-pigs lived together at the bottom of boxes, the lids of which were only so far opened as to give imperfect ventilation. Thus, the animals lived in obscurity, and in an atmosphere containing 0.5 to 1.5 per cent CO_2. The

[1] Legge and Goadly: Lead Poisoning; Arnold, 1912.

boxes were cleaned out daily and the animals were well fed. They not only must have inhaled each other's breath, but must have eaten food contaminated with each other's fur and excreta. After so living for weeks, we injected rat's serum into the guinea-pigs and guinea-pig's serum into the rats. In neither case was there any evidence of anaphylaxis.

We made the injections into the veins of the ear of most of the guinea-pigs, using a fine needle. In others, and in the rats, we made the injections into the heart. A month later we gave a second dose of rat's serum to the guinea-pigs, and each one died within a minute or so with all the symptoms of anaphylactic shock. The rats, on the other hand, did not become sensitized to guinea-pig's serum. It is recognized that rats are immune to anaphylaxis.

We sensitized more guinea-pigs by an injection of rat's serum and a month later injected into these the condensation water we obtained from the air drawn through a vessel containing rats—a father, mother and seven young rats. The result was nil. 0.5 and 0.75 cc. were the doses of condensation water injected. While entirely unaffected by the condensation water, these *sensitized* guinea-pigs suffered from anaphylactic shock when a dose of rat's serum (of the minutest volume) was injected three hours later. We are driven to conclude, then, that Amoss and Rosenau's positive results were due to contamination of the condensation water by saliva, and that when the experiments are conducted under the conditions which pertain in a crowded room, there is no evidence of the exhalation of any volatile protein.

Brown-Séquard and D'Arsonval [1] sought to substantiate their results obtained with condensation water by another form of experiment. They confined a rabbit in each of a series of four metallic cages connected by means of rubber tubing through which a continuous current of air was aspirated. The animal in the last cage breathes the air which has passed through all the previous cages and which is contaminated with the other rabbits' breath. This animal after a time dies, then after a time the rabbit in cage 3 succumbs, while rabbits in cages 1 and 2 usually survive. They could not attribute the deaths to CO_2 poisoning, because they rarely found in the last cage more than 3 per cent with small animals, and 6 per cent with larger animals. On interposing between the last two cages (3 and 4) absorption tubes containing concentrated H_2SO_4,

[1] Compt. Rend. Acad. de Sc. Paris, 1889, Vol. 108, 267-272.

the animal in cage 4 remained alive, while the one in cage 3 was the first to die. They concluded that the deaths were due to a volatile poison which was absorbed by H_2SO_4.

Such were their statements, definite and precise and apparently backed up by well-contrived experiments.

As it turns out, no one except Merkel has claimed to have obtained similar results.

Haldane and Lorrain Smith constructed an air-tight wooden chamber containing 70 cu. ft., measuring 6 ft. 2 in. by 2 ft. 11 in. by 3 ft. 11 in., and fitted with a large window. One of them stayed 4 hours within the chamber with no renewal of the air until the CO_2 reached 3.9 per cent. The subject had slight hyperpnœa and slight headache. Both disappeared as soon as he left the chamber. In another experiment they varied the conditions by placing a large tray of soda lime in the roof of the chamber. There were very much less hyperpnœa and no headache on this occasion. Slight hyperpnœa occurred when the deficiency of oxygen in the chamber air became greater than 5.5 per cent. In yet another experiment they charged the air of the chamber with 5.4 per cent CO_2 at the beginning, and at the same time kept the oxygen percentage up to 19.8 per cent. There was great hyperpnœa, with great relief on coming out, but frontal headache followed the experiment. In other experiments they breathed the same air over and over again, in and out of a bag; they found the distress became unbearable when the CO_2 reached 10 per cent. On breathing 5 per cent of CO_2, hyperpnœa and headache occurred equally whether there was 14 per cent or 70 per cent of oxygen in the bag, so they concluded that with air vitiated by respiration up to the extreme limit which we can tolerate, the diminution in the percentage of O_2 is practically without effect on the hyperpnœa. Brown-Séquard and D'Arsonval stated that they had breathed air containing 20 per cent of *pure* CO_2 for 2 hours without hurt and with no marked distress, and drew a distinction between the chemically pure CO_2 and impure exhaled CO_2. This is a wholly erroneous statement. Haldane and Lorrain Smith breathed air containing 18.6 per cent pure CO_2. After 15 seconds there was hyperpnœa; in 60 seconds this was severe; at the end of 90 seconds the subject turned blue and had to stop; in the 134th second the hyperpnœa ceased. They next breathed in and out of the bag of air through a Woulfe bottle containing soda lime. The subject stopped after 2 hours because he was getting blue in the face and felt abnormal. There was no headache, throbbing, flushing or marked hyperpnœa. At the end of the experiment the bag contained 0.0 per cent CO_2 and 8.7 per cent O_2; in another experiment only 6.7 per cent O_2. They blindfolded the subject and let him breathe alternately air containing 7 per cent CO_2 and 11.3 per cent O_2 and air containing almost no CO_2 and 9.5 per cent O_2. The first caused hyperpnœa and the second relieved it.

In another experiment the subject breathed from a bag filled with hydrogen. At 30″ he was getting blue; at 40″ he was blue and hyperpnœic; at 50″ he lost his senses and fell down in his chair, but recovered at once without headache or any other symptoms.

They placed two large rabbits in a chamber, and drew a current of air through this, and through a chamber in which were two small rabbits. No effect was produced. They took five bottles, each of a capacity of 1 to 1.5 liters, and connected these by tubes and, placing a mouse in each, drew a current of air through the whole series. The mice were exposed to this for 53 hours without harm.

In another experiment, lasting 3 days, the mice remained normal, and yet the percentage of CO_2 in the last bottle varied from 2.4 to 5.2 per cent, averaging about 3 per cent, during the whole period.

Beu also repeated the Brown-Séquard experiments and attributed the death of their animals to accumulation of moisture and change of temperature. His animals became wet and cold, and the protection afforded by the H_2SO_4 absorption tube Beu attributed to the removal of moisture.

Bauer carried out the same kind of experiment but inserted between the fourth and fifth cages an H_2SO_4 absorption tube, and between the fifth and sixth cages soda-lime absorption tubes. The sixth animal remained alive, while the fifth died, proving that excess of carbonic acid was the cause of death.

Lubbert and Peters reached the same conclusion. Between the third and fourth flasks they placed a tube containing red-hot cupric oxide to remove the organic matter, and other tubes for cooling the air and drying it. The animal in the fifth jar died when the CO_2 increased to 11 to 12 per cent. When a soda-lime tube was interposed between the fourth and fifth cages, the animal in the fifth lived. None of these researches yielded any evidence of organic poison in the exhaled air.

Billings, Weir Mitchell, and Bergey investigated the duration of life of mice in closed jars of about 2 liters' capacity and found as a general rule that the animals died when the CO_2 increased to 12 to 13 per cent and the oxygen diminished to 5 to 6 per cent.

The death of animals confined in a small chamber is due to deficiency of oxygen, which has its effect before the CO_2 rises to a poisonous level. "The duration of life in such conditions is very perceptibly shortened through the influence of a higher as well as a lower temperature than 18° to 20° C." If the oxygen be kept above 6 per cent, animals may live for hours even when the CO_2 rises to 20 per cent or more. "An atmosphere consisting of 90 per cent oxygen and 10 per cent nitrogen does not support life quite as long as does ordinary atmospheric air when the temperature is 0° C., while at a temperature of 50° C. the atmosphere rich in oxygen supports life much longer than the ordinary atmosphere."

We can scarcely explain these interesting results on the ground that the high concentration of oxygen lessened the respiration, metabolism, and formation of body heat—an effect advantageous in the high temperature but not in the low. It is more likely that oxygen maintained the beat of the heart by lessening the production of lactic acid, and thus had the same sustaining effect as we have found in men carrying out strenuous work. The experiments are few, need further confirmation, and suggest enquiry.

In the case of other animals enclosed in a chamber, the air confined was driven to and fro in the chamber through potash tubes, so that the CO_2 was absorbed. No deleterious effect developed from the continual rebreathing of this air. We must conclude from all these experiments that so long as the oxygen is sufficient and the CO_2 does not rise to a poisonous level, and the temperature is kept normal, the animals do not suffer, and there is no evidence of the presence of any exhaled organic poison.

Thirty-three experiments of the Brown-Séquard type were performed by the authors. The animals were confined one in each of a series of bell glasses, through which air was aspirated.

To begin with, trouble was experienced owing to the difficulty of making the connections air-tight. Failure to do so led to failure of ventilation and to death from asphyxia, with the ordinary postmortem appearances. None of the focal necroses or peculiar degenerative changes recorded by Brown-Séquard and D'Arsonval were noticed. "From the data accumulated with reference to the composition of the atmosphere in these bell jars by repeated analyses at short intervals, compared with the results reported by Brown-

Séquard and D'Arsonval, it seems probable that the cases in which the last animal in the series survived some of the others and a low percentage of carbonic acid was found in the jar, should be attributed entirely to defects either in methods of air-analysis or in the apparatus, or in both. If, however, the life of the last animal was apparently saved by H_2SO_4, it was due to leakage in the connections from the increased resistance caused by the interposition of the absorption tube. This is an important fact, which is in direct opposition to the theory of Brown-Séquard and D'Arsonval with regard to the influence of H_2SO_4 in the absorption tubes." . . . .

"In experiment No. 33, with a series of six rabbits confined for two days, the proportion of carbonic acid in the last two jars, for the greater part of the time, was between 4 and 7 per cent, and that of the oxygen between 12 and 16 per cent. None of the animals died or were seriously ill. Those in the first three and in the fifth jars gained in weight, those in the fourth and sixth lost slightly in weight."

An experiment of this nature, and result, once and for all negatives the organic poison theory.

The experiments have shown that animals such as mice may live in an atmosphere in which, by gradual change, the proportion of oxygen has become so low and that of the carbonic acid so high that a similar animal, brought from fresh air into it, dies almost immediately. This immunity may continue when the experiment is interrupted for a day or two. The immunity is exceptional, is limited to certain individuals, and requires further enquiry.

We (M. F. and L. H.) repeated the Brown-Séquard experiment and placed two chambers (capacity 6 liters) in series, the one containing three rats and the second a guinea-pig; in another series we placed three rats in the first and three rats in the second chamber. Air was aspirated through each series at such a rate as to give 2.5 to 4 per cent CO_2 in each of the second chambers. We cleaned out the animals' chambers each day, and filled them with dry hay so as to avoid the cooling and wetting effect of the air, which was saturated with moisture. The experiment continued for three weeks and both the guinea-pig and the rats in the second chamber increased in weight.

Finally, the first of these two experiments terminated by an accidental failure in the aspirating current which led to the asphyxiation of the animals in both chambers.

		End of first week	End of second week	End of third week	End of fourth week
(I)					
Chamber II, guinea-pig, weight in grams...	292	325.7	370.5	385	
Percentage of CO_2		2.95–3.78	3.88	3.76	
(II)					
Chamber II, rats (3) weight in grams....	1 90	96	111.2	128.7	144
	2 81	90.7	99.5	109.5	120.5
	3 78	80.5	84.8	85.2	85.5
Percentage of CO_2		2.21–2.59	2.88	2.55	2.48

We (M. F. and L. H.) also carried out experiments of a somewhat different kind, the results of which wholly negative the Brown-Séquard and D'Arsonval statements.

We confined tame rats and guinea-pigs together in a deep wooden box, the lid of which was so shut down as to give imperfect ventilation. The animals lived for 2½ weeks in an atmosphere containing 1.6 to 3.8 per cent CO_2.

	Weights				
	Feb. 1 Initial weights	Feb. 8	Increment first week	Feb. 15	Increment second week
GUINEA-PIGS	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
(1) Large, short haired, brown	335.5	381.5	46	413	31.5
(2) Large, black, short hair	331	373	42	406	33
(3) White dot and black.	191.5	229.5	38	263	33.5
(4) White dot and brown fur	139.5	176	36.5	203.5	27.5
(5) Large, long hair.....	266	316.5	50	340	24
(6) Right black and left brown	191	251.5	60.5	278.5	27
RATS					
Stumpy tail	133.5	159.5	26	162	2.5
Black + ...	165	182.5	17.5	184	1.5
Black −	186.5	212.5	26	212	−.5
Red head	126.5	153.5	27	163.5	10
Warty + ...	190	224	34	234	10
Warty −	166	190.5	24.5	197.5	7

Date	CO_2	
	Per ct.	
Feb. 1	12.3	Ventilation too little first day
2	1.6	
6	2.28	
7	2.41	
8	2.7	Second week
9	3.6	
12	3.78	
14	3.38	
15	3.0	

In the third week the lid of the box was accidentally closed and left so all night. Three guinea-pigs and one rat died from the effects of suffocation. The remainder lost weight very seriously; for example, guinea-pigs 42 to 77 grams and rats 3 to 26 grams. The loss of weight was recovered at the end of another week, during which the box lid was left full open.

The fact that the animals put on so much weight shows conclusively that there was no active toxic substance in the exhaled air; the experiment negatives the conclusions not only of Brown-Séquard and D'Arsonval, but of Rosenau and Amoss, for the surviving guinea-pigs were not sensitized in the slightest degree to an intracardial injection of 0.5 cc. of rat's serum. Subsequent intravenous injection, however, with 0.1 cc. of rat's serum killed the animals with all the characteristic anaphylactic symptoms.

The animals, especially the rats, did not gain weight so well in the second week as in the first; there was evidently some deleterious influence at work. To determine this we first tried the effect of partially drying the air. We took two boxes of equal size, but with the same number of rats and guinea-pigs in each, and arranged the same degree of ventilation. In one box we placed just above the animals large trays of granular calcium chloride, and in the other, as a control, trays of broken pumice. The temperatures wet and dry were taken, as well as the percentage of CO_2. The animals were fed and the boxes were cleaned daily. As the temperature did not exceed 22.5° C. and generally was below 20° C., it was not likely that the drying of the air and lowering the wet bulb by 2° to 3° C. would make any difference in the rate of growth; and it did not.

Ten of these guinea-pigs, after living with rats for 14 weeks, received injections of rat's serum into the veins of the ear. None of them showed any symptoms of anaphylaxis.[1]

We next tried the effect of substituting for the wooden lid of each box one made of glass, so submitting the animals to the stimulus of light and a view of the outside world, in place of dim obscurity. Periods of light and dark alternated. The growth of the animals appears accelerated by light and retarded by dark. The light and the sight of the surrounding world stimulates activity, and so the metabolism and growth. The experiment demonstrates in terms of

[1] Four of these guinea-pigs later received an intravenous injection of 0.1 cc. by the ear and were all killed by anaphylactic shock. Two of the others were injected intraperitoneally with 5 cc. of water condensed on a piece of glass covering a box containing 12 rats. This injection caused no ill effects. We have since pursued this line of research further. In all, including the above-mentioned two, twelve guinea-pigs have been injected intraperitoneally with doses varying, according to the size of the animal, from 3-5 cc. of condensation water. Subsequent intravenous injection a month later with 0.2-0.3 cc. of rat's serum has *in no case* caused any anaphylactic symptoms. A further intravenous injection of 0.2-0.3 cc. rat's serum has evoked marked anaphylactic symptoms resulting in death in all but one case, which however suffered severely and subsequently recovered. One of the young born after the first injection of rat's serum into the mother was killed by an intravenous injection of 0.1 cc. of rat's serum. (Foot-note added in proof, May, 1913.)

Box I	Initial weight	Increments of weight per week in grams												
		1	2	3	4 and 5	6	7	8	9	10	11	12	13	14
GUINEA-PIGS	*Grams*													
Fawny..........	121	1	20	36	23 (11½ 11½)	4	13	26	47	18	1	20	35	33
Browny, brown dot...........	113	5	17	29	24 (12 12)	13	36	29	36	13	— 1	31	24	4
Ginger white....	125	19	21	22	13 (6 6)	11	22	21	42	11	— 4	17	32	29
Long hair......	121	26	27	29	26 (13 13)	13	23	27	42	5	—20	45	23	10
Darky..........	161	37	26	35	31 (15½ 15½)	24	41	27	32	12	3	44	26	3
Whitey.........	165	..	15	17	— 2 (—1 —1)	7	20	20	25	14	7	21	7	2
RATS														
1 Black and white	101	..	15	—4	dead	..	..	..	..	..	....	..	..	....
2 Black and white	76	..	12	8	— 9(—4½ —4½)	8	8	16	12	8	—37 (ill)	..	..	....
3 Black and white	106	..	0	2	dead	..	..	..	..	..	....	..	..	....
4 White.........	152	..	7	10	1 (½ ½)	20	11	15	8	12	—17	25	1	— 3
5 White.........	86	..	13	3	4 (2 2)	14	14	20	11	8	8	16	10	9
		Dark				Light			Dark			Light		Dark

	Temperature		CO_2	
	Dry bulb	Wet bulb		
	Degrees C.	*Degrees C.*	*Per ct.*	
First week.....	19	15	0.73	Calcium chloride trays in from first to fifth week, inclusive
	19½	18½	5.53	
	20	16½	0.98	
	16	13	1.85	
	16½	13½	2.17	
Second week..	18	16½	5.4	
	17	15½	0.6	
	20	17½	1.01	
	21	18	0.59	
	20½	17	0.90	
Third week....	20	16	0.85	
	20	17	0.66	
	18½	16	0.99	
	15½	13½	0.67	
Fourth week...	16	14	0.85	
	18	13	0.73	
Fifth week....	18	13	1.35	
	16	14	0.782	
	16	13	1.43	
	16	13½	1.6	
Sixth week....	17½	17½	0.99	
	18½	17	0.98	
	20	19	0.31	

	Temperature		CO_2
	Dry bulb	Wet bulb	
	Degrees C.	*Degrees C.*	*Per ct.*
Seventh week..	18	17½	0.46
	16	15½	0.57
	19½	18½	1.02
Eighth week...	19	19	0.78
	22½	22½	1.14
Ninth week....	20½	19	0.51
	21½	20	0.55
Tenth week....	22	20½	0.51
	21½	20	0.61
Eleventh week.	20½	19½	....
	18½	17	0.51
Twelfth week....	21½	21¼	0.81
Thirteenth w'k.	21½	19½	9.56
	22	21½	0.61
Fourteenth wk.	22	20½	0.53
	20½	19½	0.98

Box II	Initial weight	Increments of weight per week in grams												
		1	2	3	4 and 5	6	7	8	9	10	11	12	13	14
GUINEA-PIGS	*Grams*													
Ginger white....	121	8	15	27	2(1 1)	33	39	12	53	9	—7	24	27	—12
Light brown....	141	17	22	23	27(13½ 13½)	36	34	15	53	13	—6	24	23	30
Black and tan...	115	11	25	— 1	29(14½ 14½)	22	33	13	63	14	27	14	24	5
Brown, white star...........	127	12	23	32	25(12½ 12½)	14	48	18	62	15	1	20	15	27
Dark brown.....	160	8	33	26	25(12½ 12½)	40	40	15	63	1	14	19	37	0
Fawny..........	178	..	—17	3	—17(—8½ —8½)	7	—1	—1	12	4	16	—7	7	23
RATS														
1 Black and white	90	..	1	— 4	dead	..	..	..	..	..	..	..	..	....
2 Black and white	67	..	13	12	lost	..	..	..	..	..	..	..	..	....
3 Black and white	117	..	12	7	3(1½ 1½)	—8	—7	3	5	—2	—5	7	2	0
4 White.........	165	..	31	dead	......	..	..	..	..	..	..	..	..	....
5 White.........	102	..	dead	....	......	..	..	..	..	..	..	..	..	....
6 White.........	76	..	9	— 3	4(2 2)	9	12	8	10	0	—1	9	1	— 2
		Dark				Light			Dark			Light		Dark

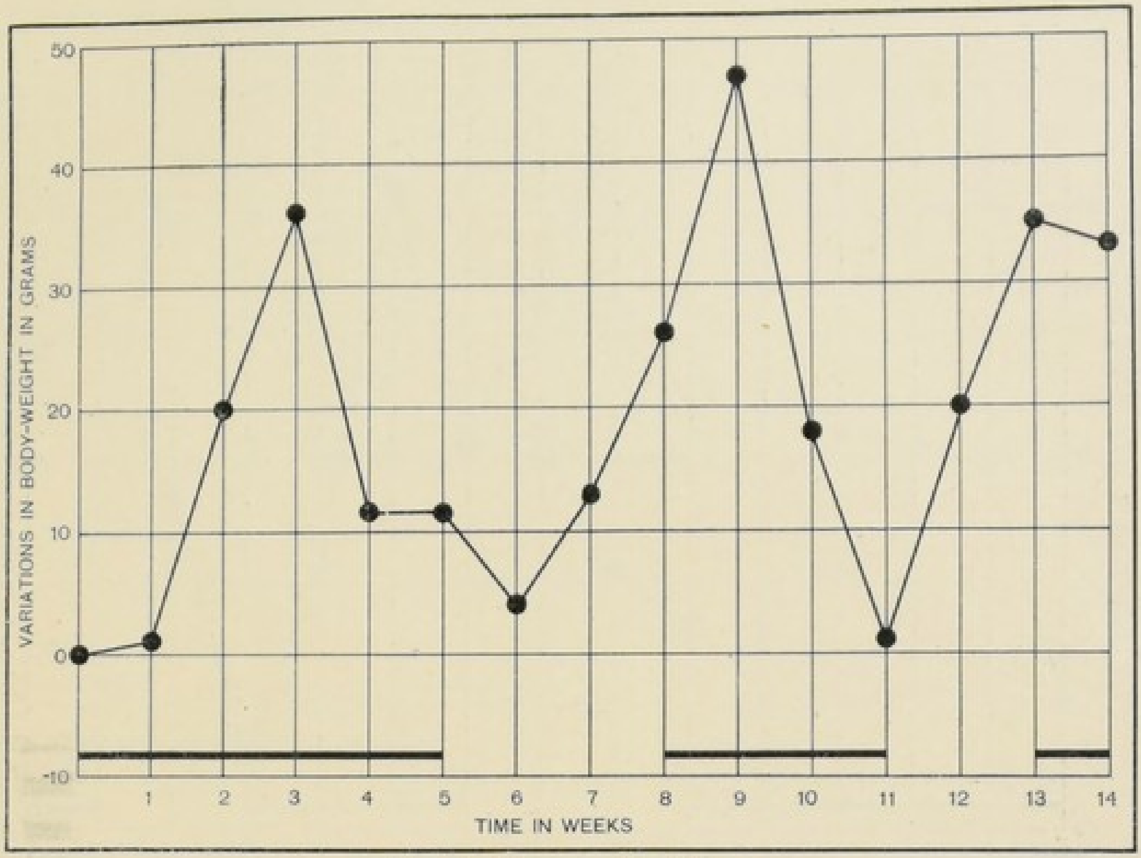
	Temperature, Dry bulb	Temperature, Wet bulb	CO_2	
	Degrees C.	*Degrees C.*	*Per ct.*	
First week...	18½	18½	0.78	Pumice trays in from first to fifth week, inclusive. In dark.
	19½	19½	1.69	
	19	18	2.01	
	14	13½	1.95	
	16½	15½	3.5	
Second week.	16½	16½	4.53	
	16	16	0.65	
	19	18	1.11	
	20½	20	1.13	
	20½	19	0.71	
Third week ..	20¼	19½	0.86	
	20	19½	0.72	
	18	17	0.63	
	16	15	0.89	
	15	15	1.23	
Fourth week.	16	15	0.9	
	18	17	0.89	
Fifth week...	17	17	1.03	
	15	13	0.749	
	16	15	0.69	

	Temperature, Dry bulb	Temperature, Wet bulb	CO_2	
	Degrees C.	*Degrees C.*	*Per ct.*	
Sixth week....	15	14	0.91	In light
	17	16	0.63	
	18	16½	0.97	
	20¼	19¼	0.34	
Seventh week..	17½	17	0.44	
	16	15½	0.49	
	19½	19½	0.88	
Eighth week...	19	19	0.78	
	22½	22	1.17	
Ninth week....	20½	19	0.51	In dark
	21½	20	0.55	
Tenth week....	22	20½	0.51	
	21½	20	0.61	
Eleventh w'k..	20½	19½	....	
	18¾	17	0.51	
Twelfth week...	22½	21½	0.01	In light
Thirt'th week..	21	19½	0.56	
	21½	21¼	0.81	
Fourt'th week..	22	20½	0.51	
	21	20	0.91	

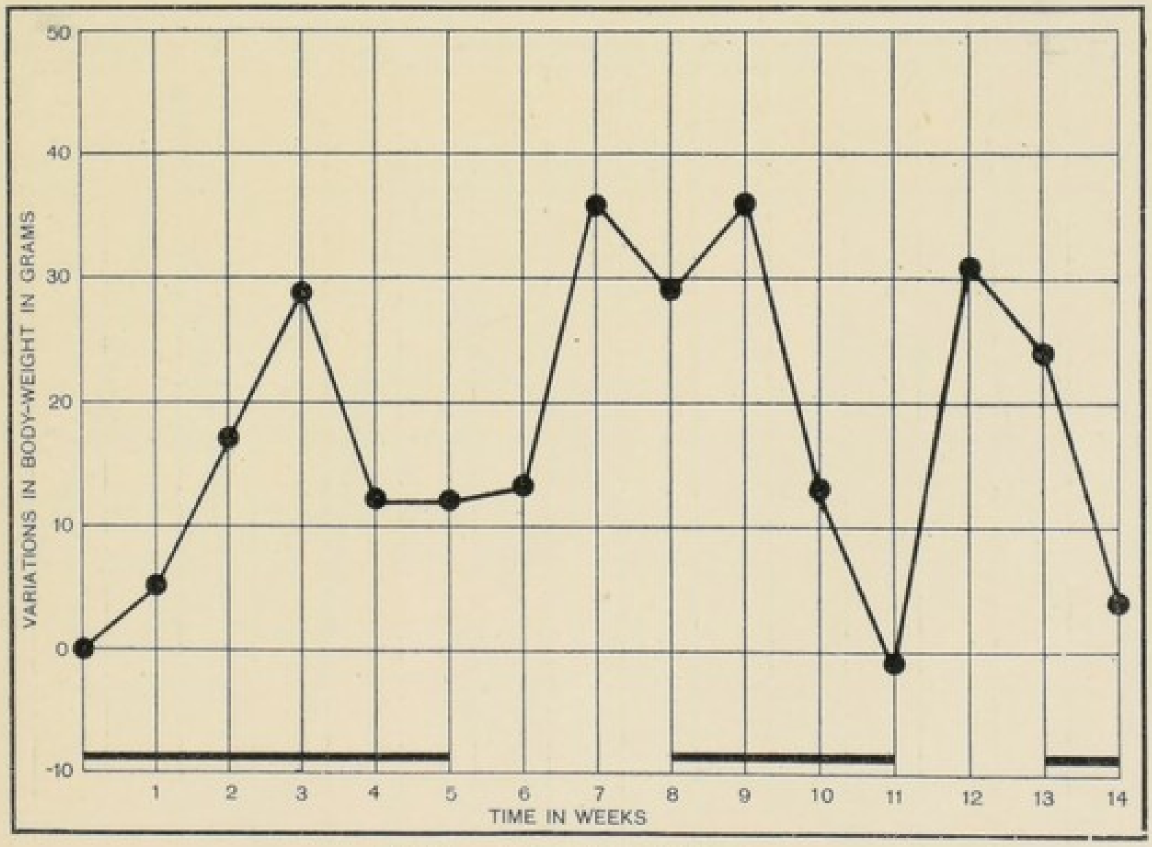
growth the depressive effect of darkness. In our cities the dullness of sunless days and fogs of winter are intensified by the smoky air. The smoke discourages cleanliness and opening of windows, damages plant life, destroys buildings, clothes, etc., is wasteful of energy, entails the needless production of artificial light, intensifies the dirt and blackness of the streets, depresses the spirits of the inhabitants, and is generally economically unsound. We counterbalance the absence of sun by the illumination of our places of business and entertainment; the shop lights, the twinkling reflections in the wet pavements, the green and red signals of the railways, the moving lamps of the vehicles, the cinema shows, etc., make up a kaleidoscopic effect which stimulates fancy and dispels the monotony and gloom of the atmosphere. The warmth and brightness of our houses impels us to stay within doors, and we suffer in winter from loss of open-air exercise. How much sun the Londoner has lost is shown by figures recorded by Russell: In four years there were 3,925 hours of sunshine in London, 5,713 at Kew and 6,880 at St. Leonards. Between November and February in one year, there were 62 hours of sunshine in London, 222 at Kew and 300 at Eastbourne. For the years 1902-1906 the yearly average of hours of sunshine in London was 1,257; and for the years 1907-1911, 1,341. Twenty per cent of the fogs in London are wholly due to smoke.[1] The great manufacturing districts suffer no less from the plague of darkness. The age of the gas-engine is now upon us, and the displacement of steam as a source of power, with its wasteful consumption of coal, and of open coal fires by smokeless methods of heating, will bring back the days of clean skies. The present dark age of coal, steam, and slums will emerge into one of garden cities and clean living. We must see to it that the method of house warming is contrived on the same lines as the open fire, otherwise we may lose in health from the want of cool moving air more than we gain from light. Gas fires fitted as open fires with flues, or sources of radiant heat combined with impulsion of cool air, are the kind of methods 56 51
which require development. The method so widely employed of heating rooms by heating the air, is the one which particularly lends itself to the production of ill effects.[2]

[1] Dr. Norman Shaw. Cited in Report of Smoke Abatement Conference, 1912, p. 68.

[2] The expenses of the foregoing part of this research were defrayed by a grant from the Science Committee of the British Medical Association.



Box I. Guinea-Pig No. 1.



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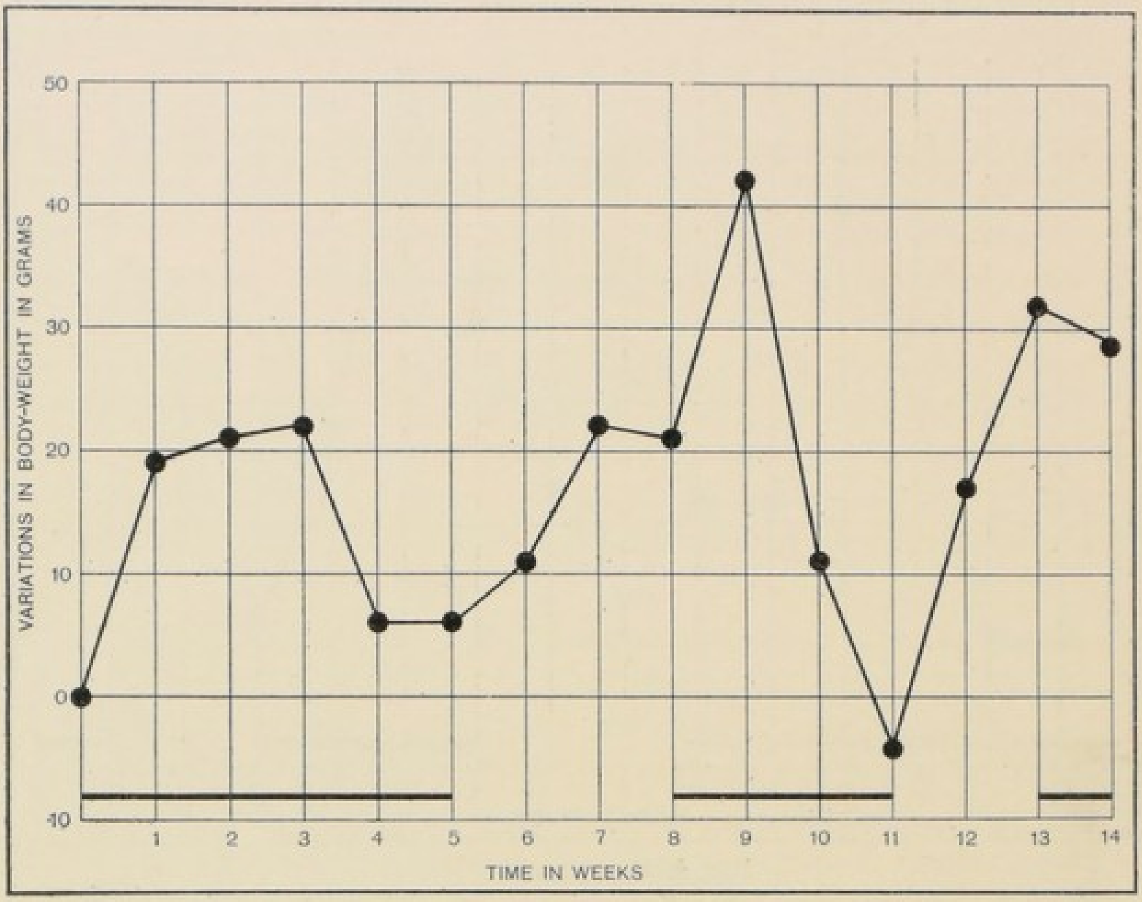

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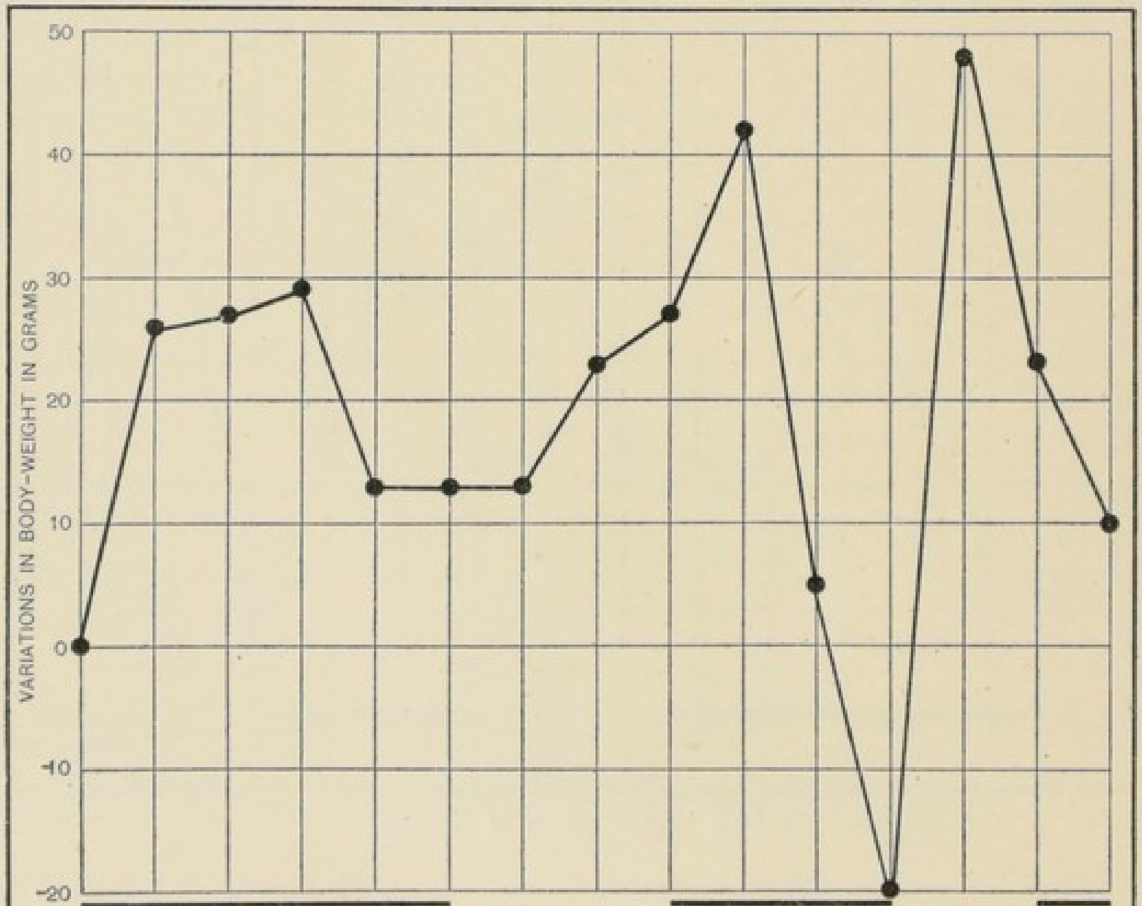

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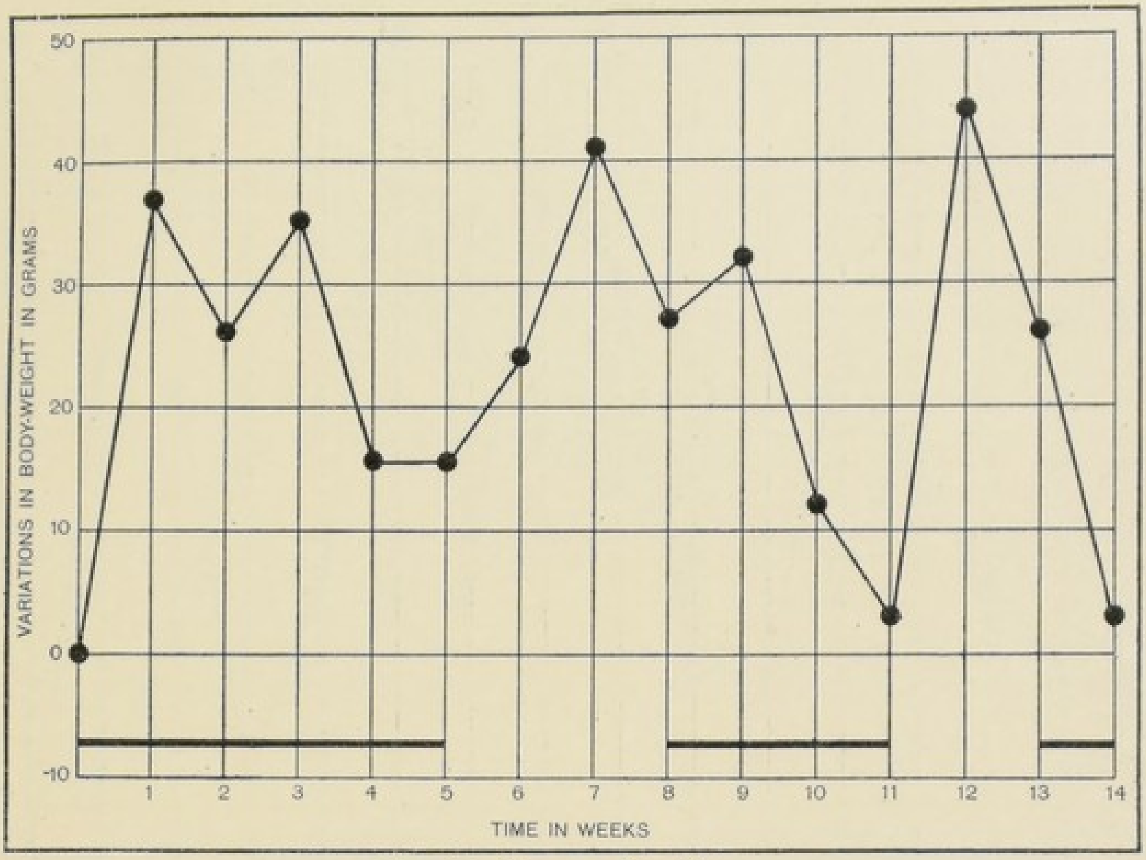

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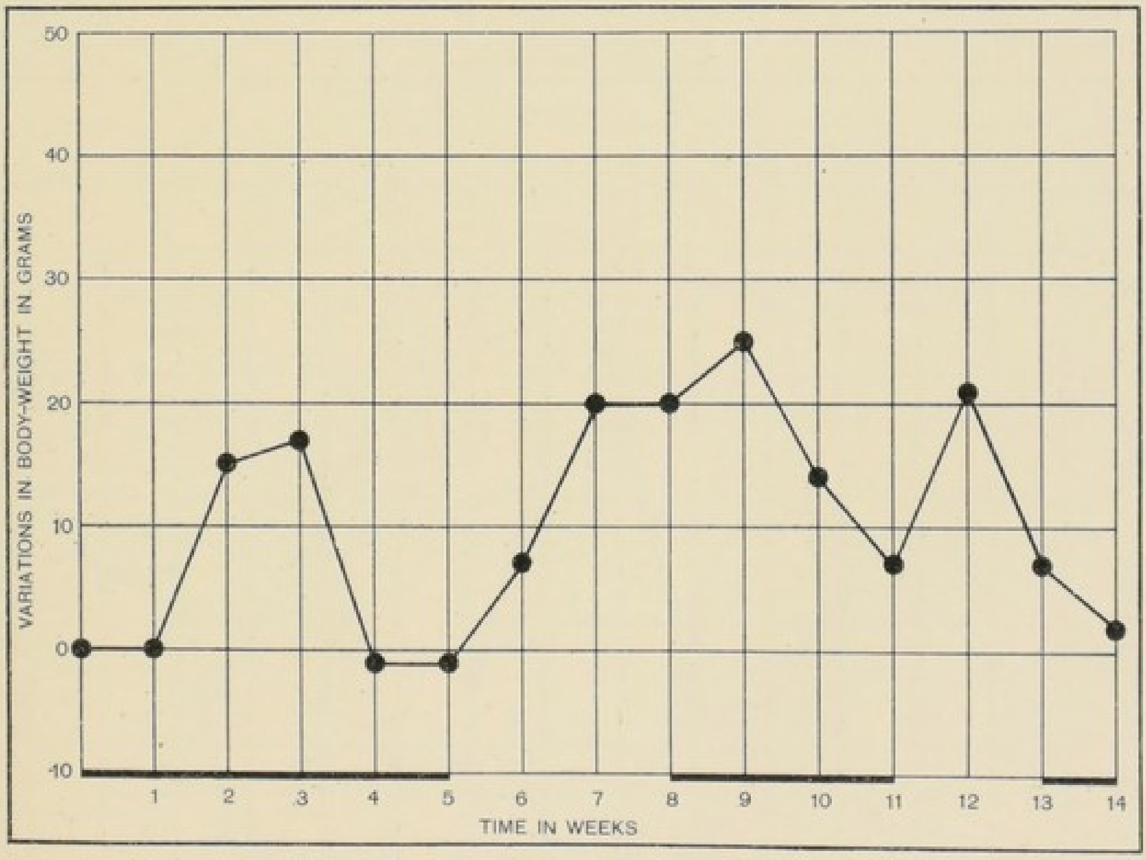

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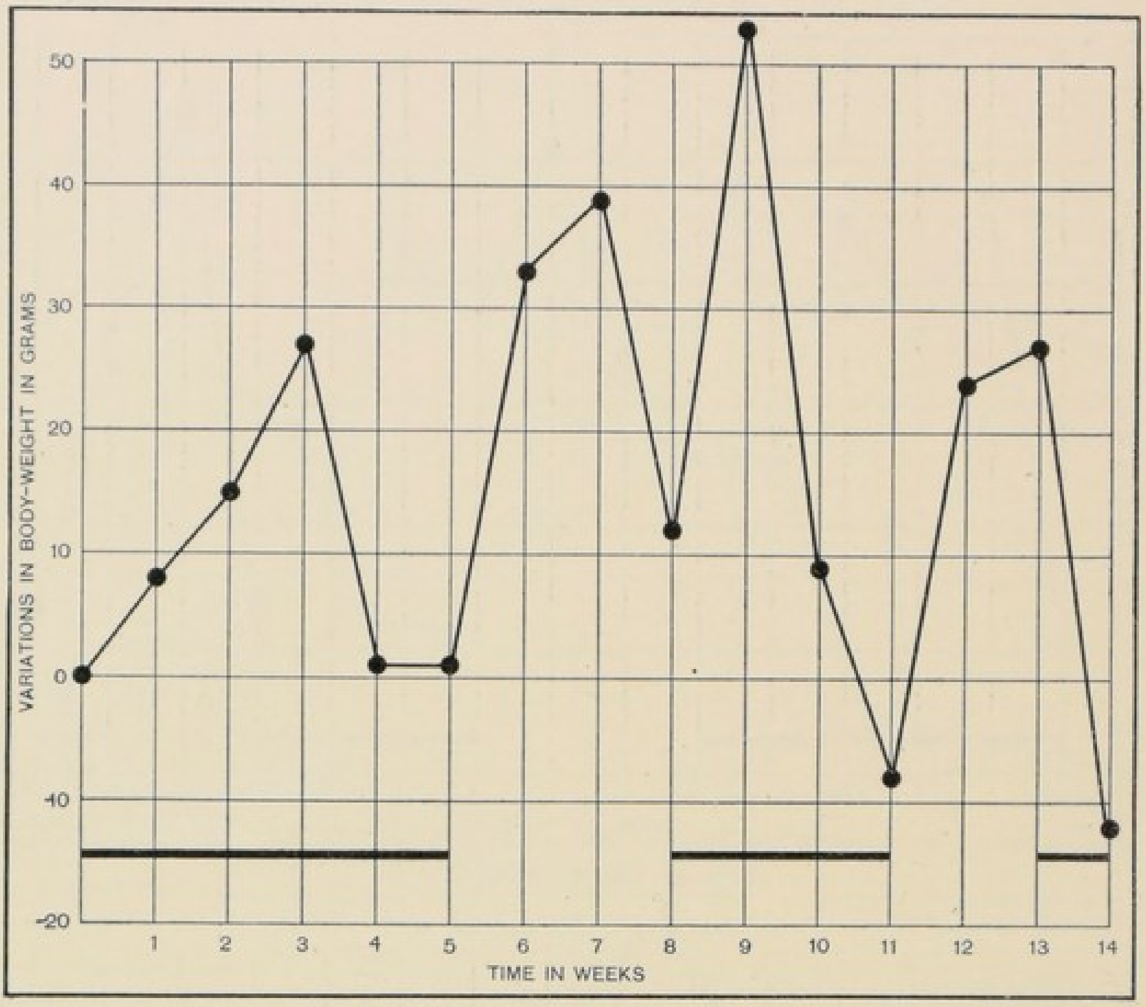

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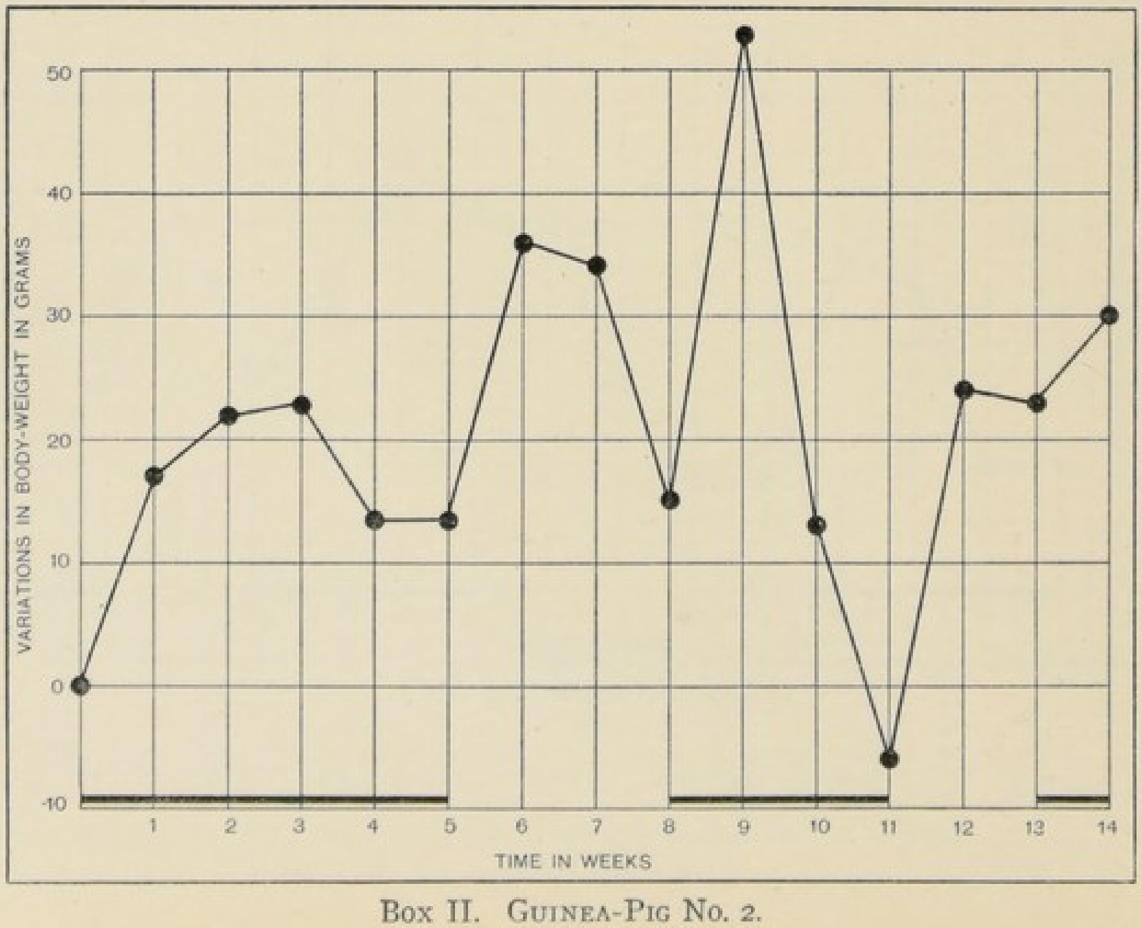

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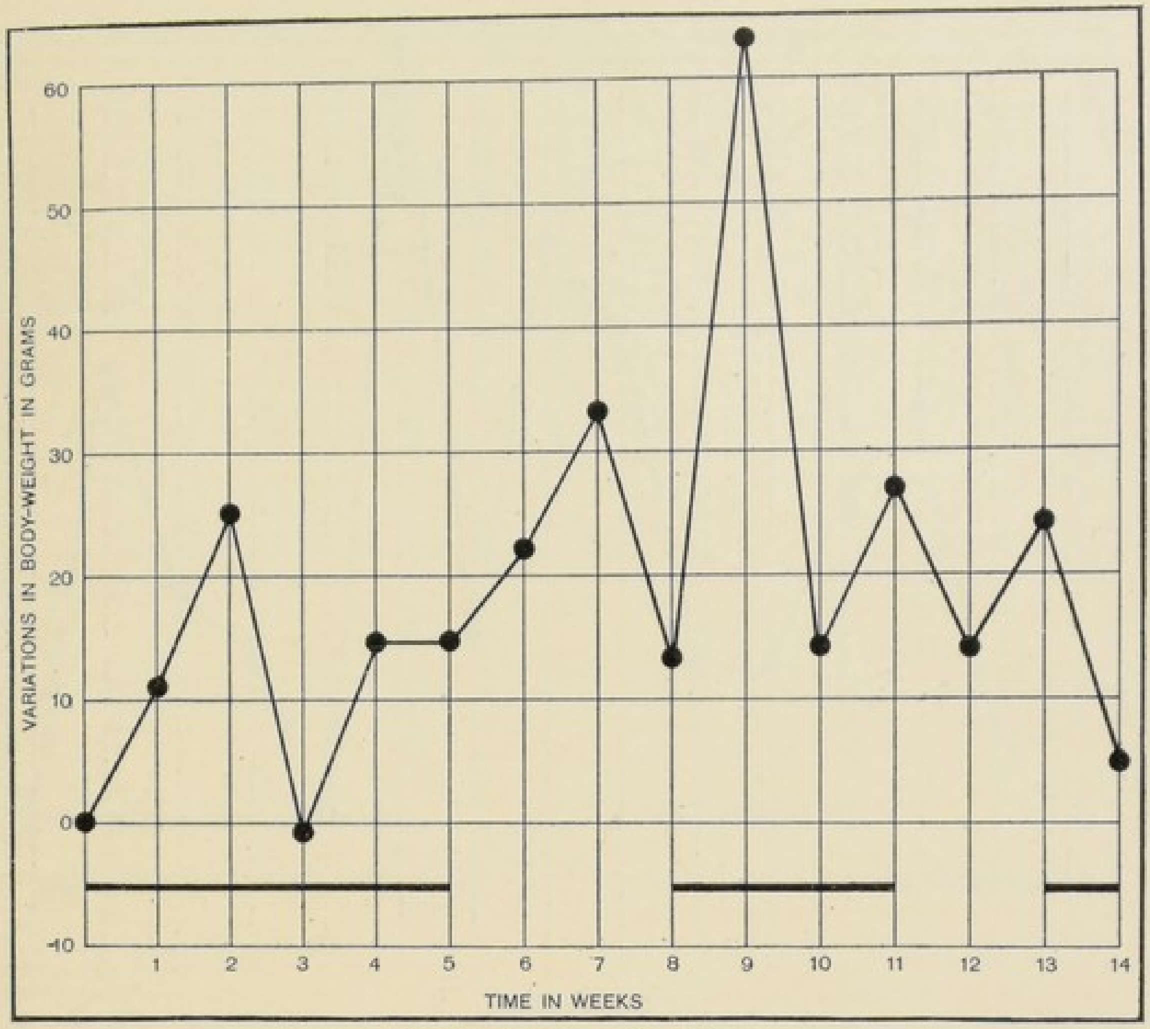

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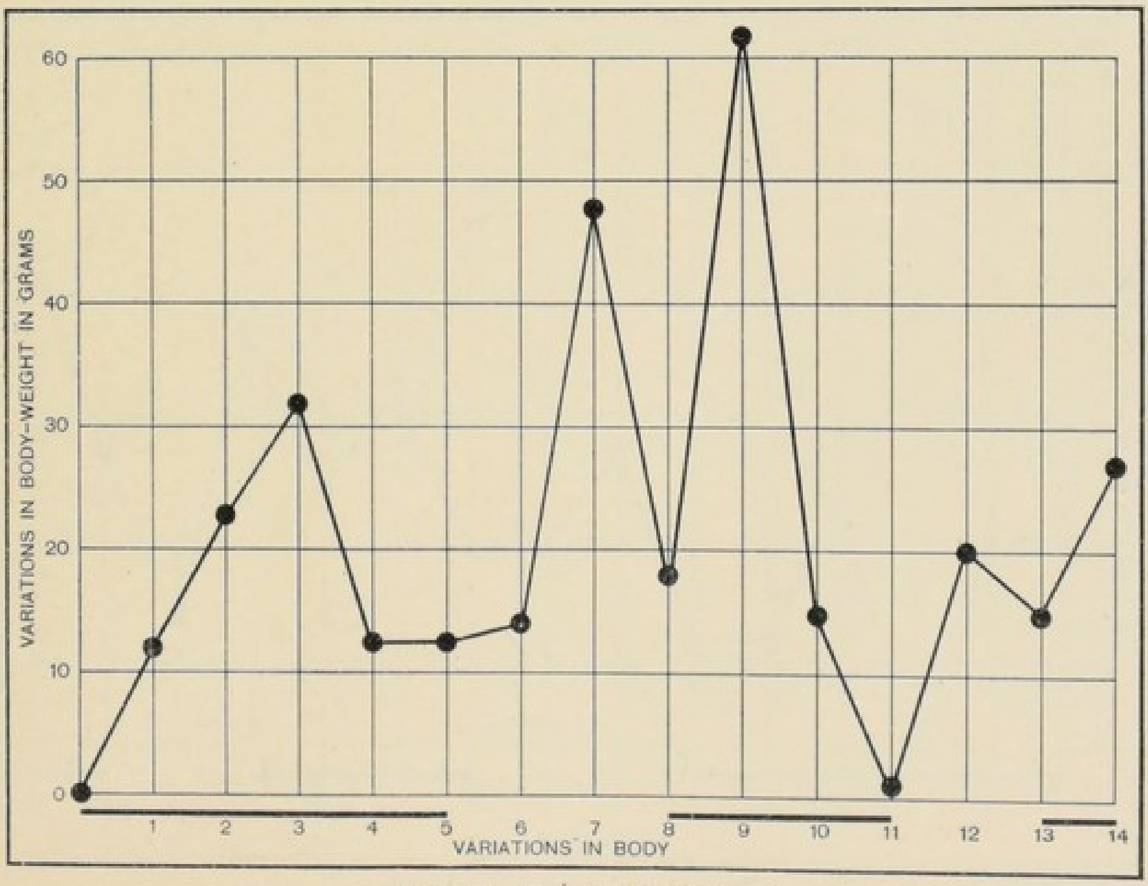

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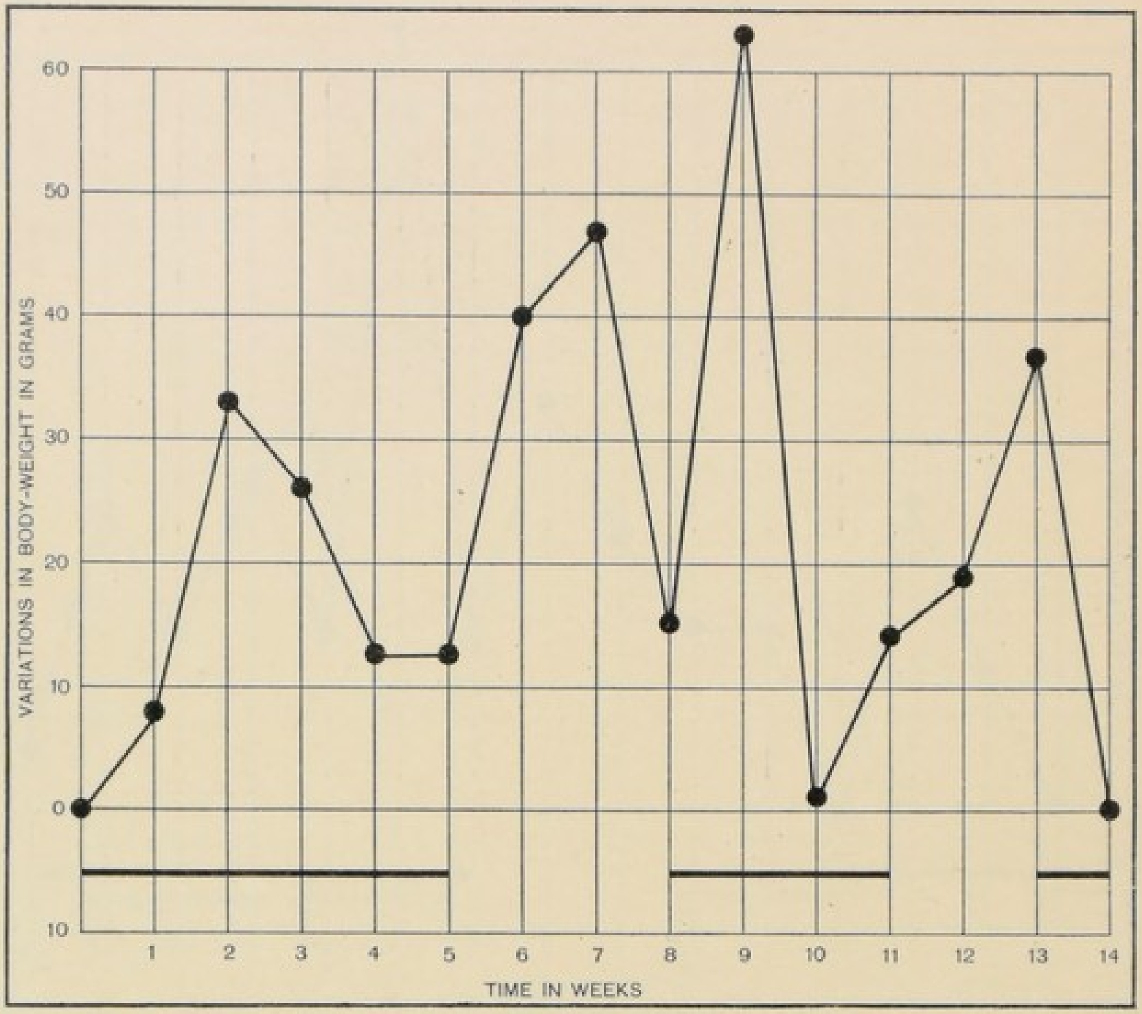

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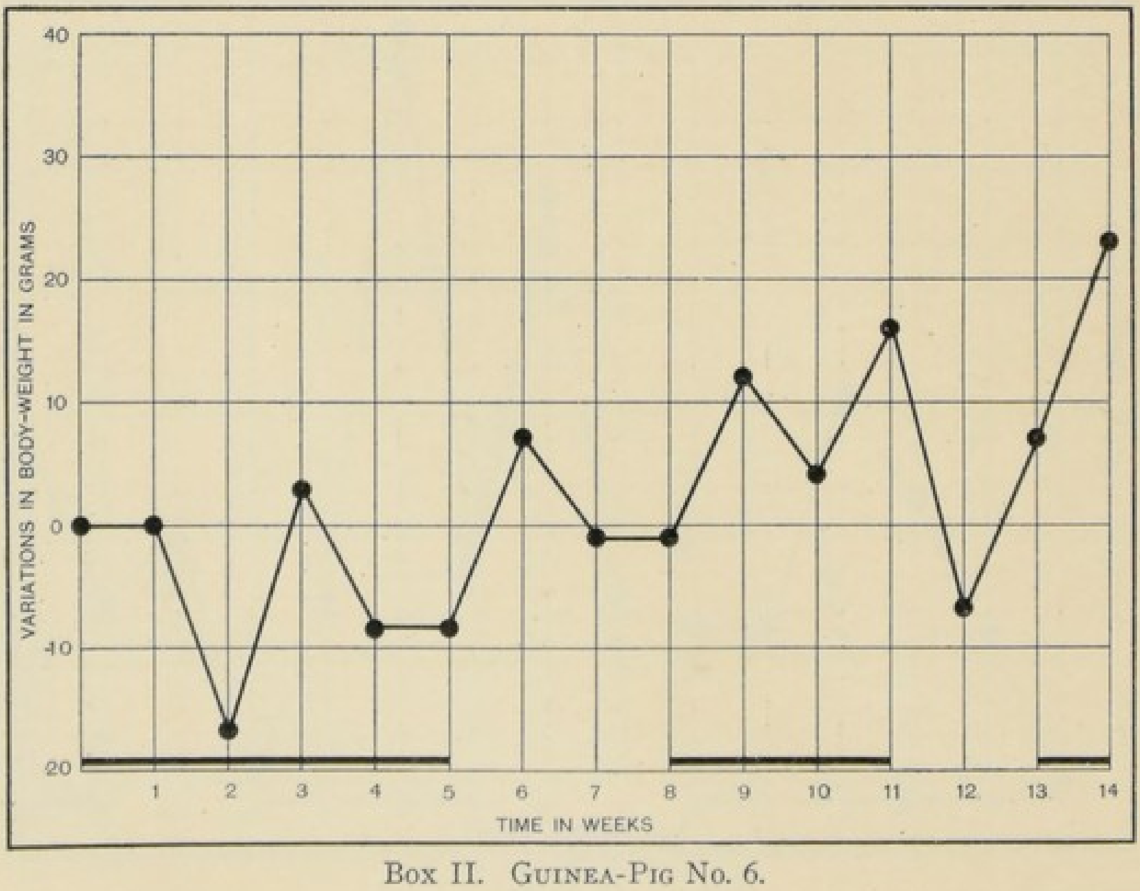

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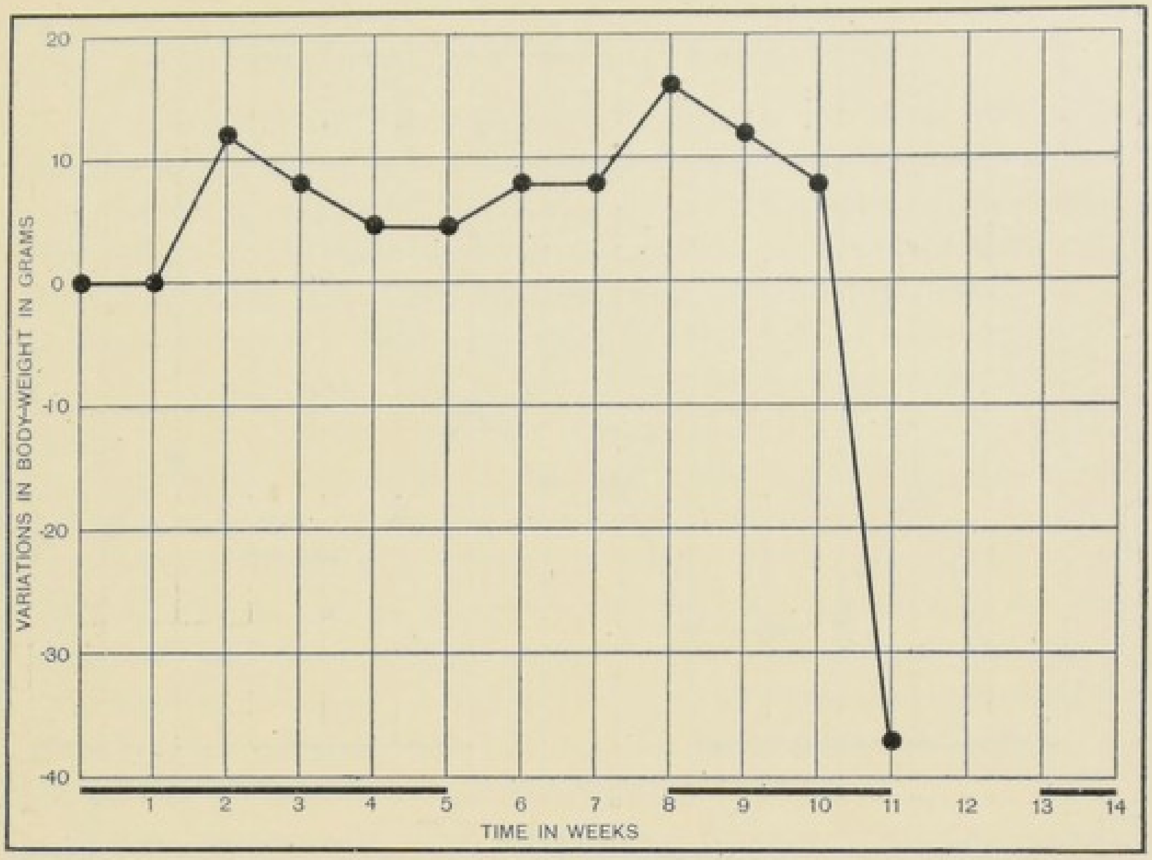

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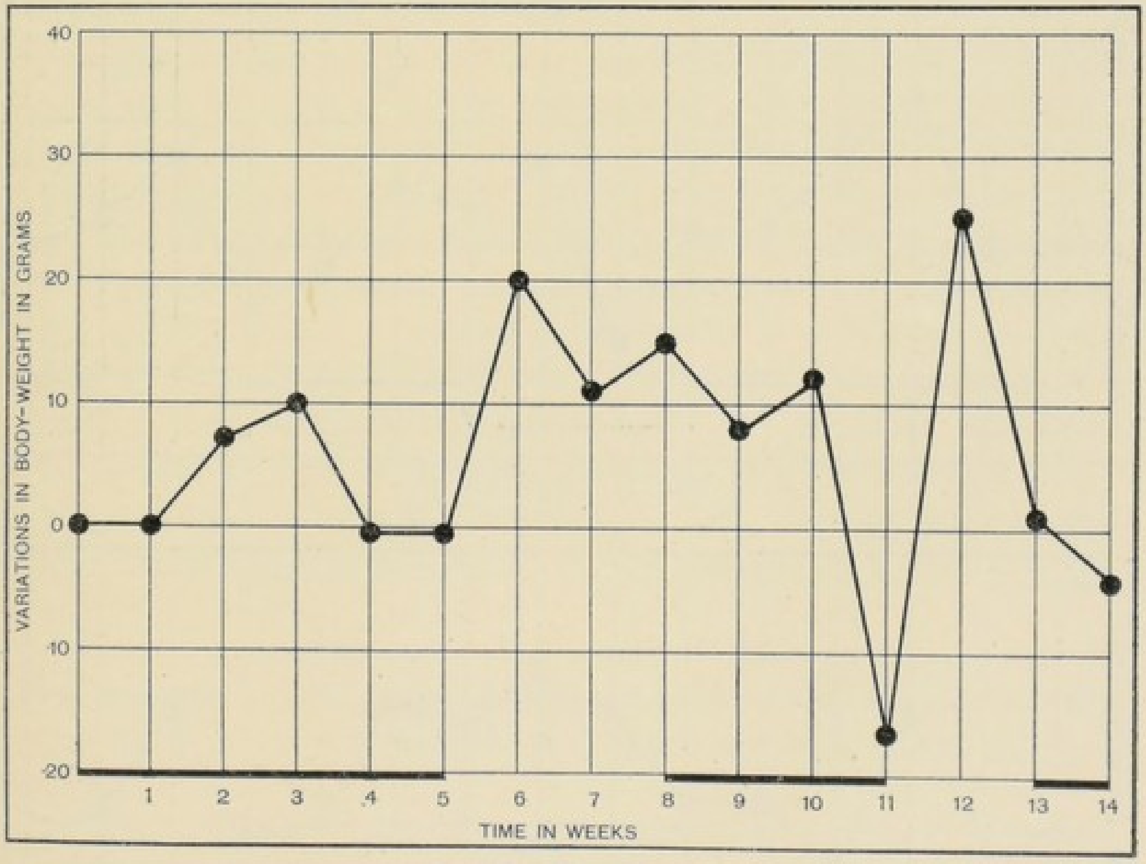

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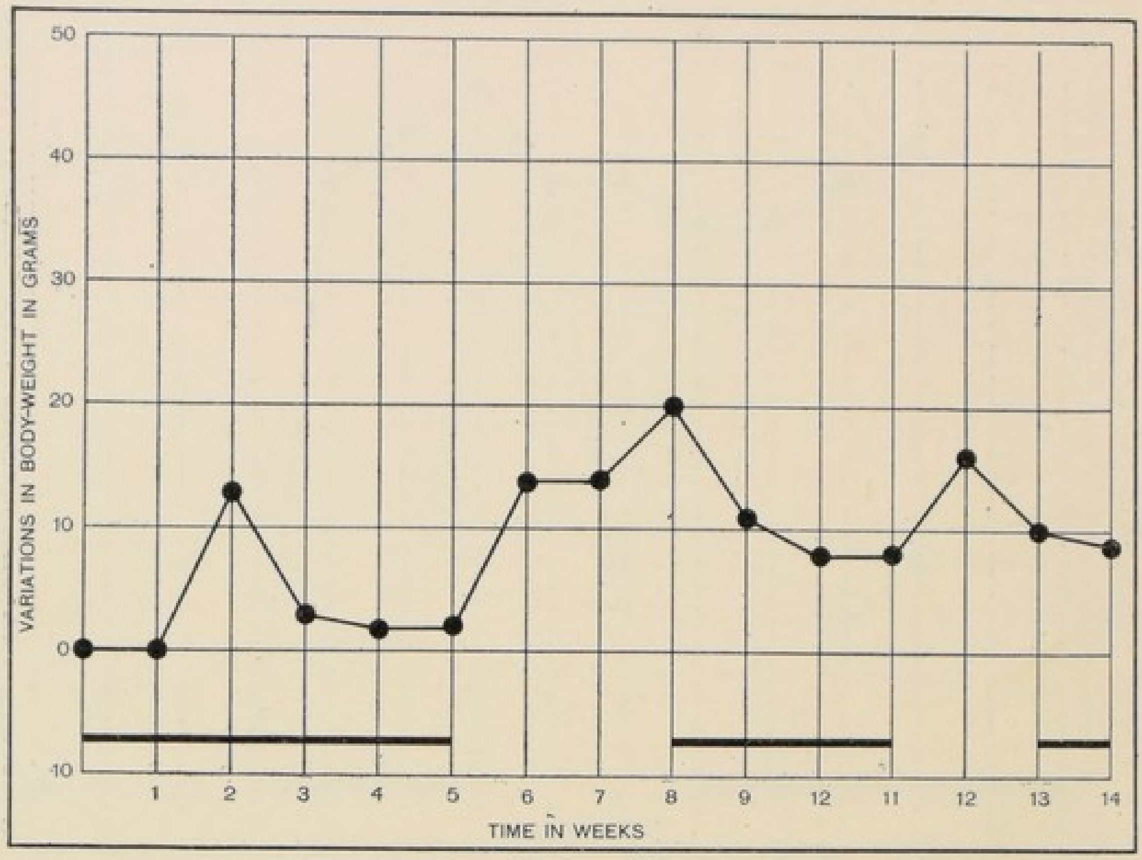
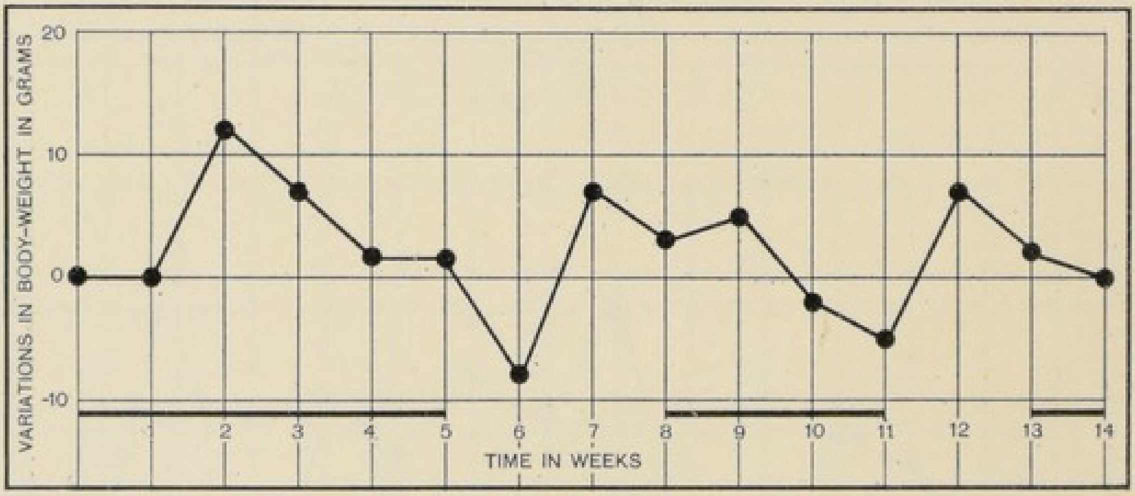


Box I. Rat No. 5.



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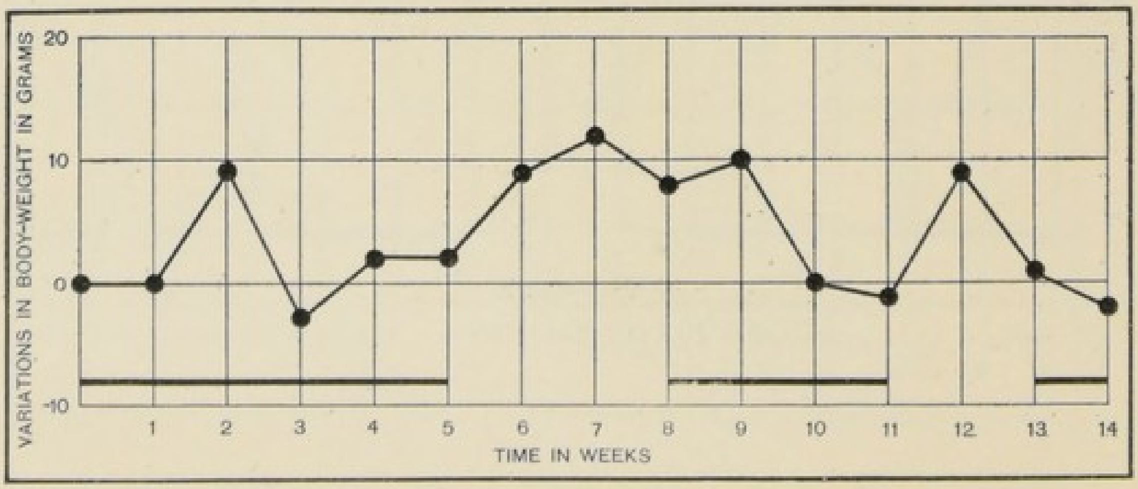

Box II. Rat No. 6.

THE HEAT AND RELATIVE MOISTURE

No less than thirty years ago Hermans[1] found the evidence in regard to the bad effect of the chemical impurities insufficient, and suggested that the results of bad ventilation are thermal in origin. Susceptible individuals suffer from oppression, headache, sickness, and may faint under certain conditions in crowded rooms. The symptoms resemble those experienced in the open air on excessively hot and humid days. The axillary temperature may be raised 0.3° to 0.6° C. in a hot theater. Heat and moisture increase very greatly in crowded places where the occupants are jammed together and the usual channels of dissipation of body heat are checked. Flannel and linen garments may increase in weight 13 to 14 per cent. The wetness of the clothes increases the unpleasant feelings and the danger of chill on coming out of warm rooms into the outer air.

Under the direction of Flügge[2] a series of admirable experiments have been carried out on this question in the Institute of Hygiene in Breslau by Heymann, Paul, and Ercklentz.

Normal individuals were placed in a cabinet of 3 cubic meters capacity, and shut within it for periods up to four hours until the CO_2 percentage rose to from 1.0 to 1.5. No symptoms of illness or discomfort were felt and the chemical impurity of the air had no influence on the power to carry out ergographic tests or mental computations so long as the temperature and moisture of the air were kept low. Paul shut a man in the chamber for 4¾ hours. The temperature rose to 24° C., the relative humidity to 89 per cent, the CO_2 to 1.2 per cent. He was very uncomfortable. Those who, from outside the chamber, breathed the air in through a mouthpiece, felt no discomfort. *Immediate* discomfort was felt by one who went into the chamber. In another experiment the temperature was 30.2° C., relative humidity 87 per cent, CO_2 1.1 per cent. Symptoms of discomfort were pronounced although the subject breathed pure air from outside through a mouthpiece. The symptoms were allayed by a fan which impelled the air in the chamber at a rate of a few meters per second.

When the chamber was cooled to 17° C. there were no symptoms of discomfort although the CO_2 rose to 1.6 per cent. Ercklentz found that the sensitivity of patients to close air is wholly due to tempera-

[1] Arch. f. Hygiene, Vol. 1, 1883, p. 1.

[2] Ztschr. f. Hygiene, Vol. 49, 1905, pp. 363, 388, 405, 433.

ture and moisture. Thus those suffering from heart disease and bronchitis—when shut in the cabinet—were comfortable so long as the temperature readings lay between 8° and 20° C., in spite of the CO_2 rising to 1.57 per cent. They were very sensitive to high readings, and endured less heat (for example, 20° to 27° C.), and for much less time (for example, only 40 to 50 minutes), than healthy men. They complained of dizziness and were generally uneasy. Normal men became uncomfortable when the temperature rose to from 27° to 31° C., with a relative humidity of 51 to 60. The skin temperature of the forehead rose 2° to 3° C., and the relative moisture of the air in contact with the skin as taken with a hygrometer under the clothes rose 20 to 30 per cent.

Benedict[1] has shown that a man can live many days in a closed calorimeter chamber in comfort, without damage to his health, and having not the slightest cognizance of any defect in ventilation when this is so reduced that the CO_2 accumulates to from 1 to 2 per cent—that is, so long as the air of the chamber is kept cool and dry. Zuntz[2] suggested that this result might be due to the circulation of the air through the H_2SO_4 driers and the destruction thereby of organic chemical poison, but no H_2SO_4 driers were used in the experiments of Haldane and Lorrain Smith, Paul, Ercklentz and in our own experiments, in which all discomfort was prevented by cooling the air.

Our experimental chamber was constructed of wood, with large glass observation windows. It was rendered air-tight by filling all cracks with putty and by pasting layers of brown paper over the wood. The chamber was entered through a man-hole which was closed by a shutter.

On one side of the chamber were fixed two small electric heaters, and a tin containing water was placed on these in order to saturate the air with water vapor. On another side of the chamber was placed a large radiator through which cold water could be circulated when required, so as to cool the chamber. In the roof were fixed three electric fans, one big and two small, by means of which the air of the chamber could be effectually stirred. A wet- and a dry-bulb thermometer were placed within, and readings were taken periodically after whirling these round in the air of the chamber.

[1] Bull. 175, U. S. Dept. Agric., p. 235.

[2] Report Brit. Asso. Adv. Sci., 1911, p. 543.

The readings were taken at about chest height. The chamber held approximately 3 cubic meters of air. In one class of experiments we shut within the chamber seven or eight students for about half an hour and observed the effect of the confined atmosphere upon them. We kept them therein until the CO_2 reached 3 to 4 per cent, and the oxygen had fallen to from 17 to 16 per cent. The wet-bulb temperature rose meanwhile to about 80° to 85° F. and the dry-bulb a degree or two higher. The students went in chatting and laughing, but by and by as the temperature rose they ceased to talk and their faces became flushed and moist. We have watched them trying to light a cigarette (to relieve the monotony of the experiment) and puzzled by their matches going out, borrowing others, only in vain. They had not sensed the percentage of the diminution of oxygen, which fell below 17. Their breathing was slightly deepened by the high percentage of CO_2, but no headache occurred in any of them from the short exposure to from 3 to 4 per cent CO_2. Their discomfort was relieved to an astonishing extent by putting on the electric fans placed in the roof. Whilst the air was kept stirred the students were not affected by the oppressive atmosphere. They begged for the fans to be put on when they were cut off. The same old stale air containing 3 to 4 per cent CO_2 and 16 to 17 per cent O_2 was whirled, but the movement of the air gave complete relief, because the air was 80° to 85° F. (wet bulb) while the air enmeshed in their clothes in contact with their skin was 98° to 99° F. (wet bulb). The whirling away of this stationary air cooled the body effectually, for air at 80° to 85° F. holds considerably more water vapor when heated up to from 98 to 99° F.

January 29, 1912. Seven students and M. F. shut in chamber.

Time	Fans	Temperature of chamber		
		Dry bulb	Wet bulb	
P. M.		*Degrees F.*	*Degrees F.*	
2.47	Off	74	63	
2.49	Off	76	67	
3.6	Off	83	77	
3.10	Off	83	77	M. F.'s pulse 108.
3.12	Off	83	78	M. F.'s pulse 96.

Analysis of air taken at 3.10 p. m.: CO_2 3.87 per cent; O_2 16.37 per cent. Matches would not burn in the air. The students acknowledged the great benefit derived from the fans, particularly those placed beneath the big fan. One student breathed the air from outside the chamber through a tube and felt little relief.

L. H., standing outside, breathed the air in the chamber through a tube, and felt no discomfort; the only result therefrom was a deepening of the respiration. After the students had left the chamber, L. H. entered it; the air was warm and moist but there was no offensive smell, or any sense of closeness when the fans were put on. The air then felt like a pleasant summer breeze.

June 3, 1910. Seven students and R. A. R. entered the chamber.

Time	Fans	Temperature of chamber		Time	Fans	Temperature of chamber	
		Dry bulb	Wet bulb			Dry bulb	Wet bulb
A. M.		*Degrees F.*	*Degrees F.*	*A. M.*		*Degrees F.*	*Degrees F.*
11.20	Off	65	62	11.50	Off	81	77
11.32	Off	74.8	73	11.55	On	83	79
11.42	Off	79.5	76	11.57	Off	84	80
11.47	On	80	76				

The surface skin temperature of a student standing close under the biggest fan rose from 31.6° at 11.29 a. m. to 34° C. at 11.42 a. m. and fell to 31.5° C. on putting on the fans. A sample of air taken at 11.40 a. m. gave CO_2 2.2 per cent, O_2 17.54 per cent; and another taken at 11.55 a. m. gave CO_2 3.61 per cent, O_2 16.4 per cent.

June 10, 1910. Eight students and R. A. R. in chamber.

Time	Fans	Temperature of chamber		Time	Fans	Temperature of chamber	
		Dry bulb	Wet bulb			Dry bulb	Wet bulb
A. M.		*Degrees F.*	*Degrees F.*	*A. M.*		*Degrees F.*	*Degrees F.*
11.10	Off	77	75	11.23	On	84	80
11.15	Off	79	78	11.25	Off	85	81
11.20	On	82	75	11.30	On	85	81

The surface temperature of two of the students was slightly lowered, 0.5° to 1.0° C., when the fans were on; they were not standing directly under the big fan.

The air contained 2.58 per cent CO_2 at the end of the experiment. All testified to great benefit derived from the fans.

June 17, 1910. Seven students and R. A. R. in chamber.

Time	Fans	Temperature of chamber		Time	Fans	Temperature of chamber	
		Dry bulb	Wet bulb			Dry bulb	Wet bulb
A. M.		*Degrees F.*	*Degrees F.*	*A. M.*		*Degrees F.*	*Degrees F.*
11.5	Off	69	65	11.45	Off	86	81
11.20	Off	81	74	11.49	Off	87	83
11.35	Off	87	82				

The air taken at 11.34 a. m. gave CO_2 4 per cent, O_2 15.63 per cent; and that taken at 11.49 a. m. gave CO_2 5.26 per cent, O_2 15.1 per cent. The surface temperature of a student standing under the big fan was raised from 32° C. at 11.7 a. m. to 33° C. at 11.34 a. m. and was lowered by the fans to 32.5° C. at 11.38 a. m., finally reaching 34° C. at 11.49 a. m., when the fans were off. The surface temperature of another student rose from 32.7° C. at 11.7 a. m. to 34.5° C. at 11.49 a. m. He was not standing directly under the fans.

Great relief was given by the fans, and the students were quite unaware of any chemical alteration in the atmosphere. The air of the chamber at the end of the experiment did not smell, but felt warm and moist.

June 20, 1910. Seven students and R. A. R. in the chamber.

Time	Fans	Temperature of chamber		Time	Fans	Temperature ot chamber	
		Dry bulb	Wet bulb			Dry bulb	Wet bulb
P. M.		*Degrees F.*	*Degrees F.*	*P. M.*		*Degrees F.*	*Degrees F.*
2.30	Off	77	72	3.0	On	86	81
2.45	Off	82	77	3.3	On	85	80

The air contained 5.05 per cent CO_2 at 2.50 p. m. and 5.24 per cent at 3.5 p. m. The figures show how the pulse was accelerated. Readings were taken at 2.30 p. m. and again when the fans were off, at 2.50 p.m.

Subject	Pulse frequency	Respiration frequency
C	72	24
	92	24
A	86	20
	96	20
E	84	20
	128	24
W	74	16
	94	20
A. B	100	30
	106	30
H	57	18
	72	22
R. A. R	86	20
	92	22

The pulse frequency was diminished in each case by putting on the fans and the discomfort relieved. No headache followed the experiment.

After making these preliminary experiments two of us (R. A. Rowlands and H. B. Walker) carried out a series of observations, each acting as subject in turn.

The subject breathed through a Zuntz meter fitted with a mouthpiece, an inlet and an outlet valve. A soda-lime tin, to absorb CO_2, was at times interposed between the inlet and the mouth. The effect on the respiratory ventilation and on the pulse rate was recorded both when resting and when working. The work consisted in pulling up a 20-kilogram weight about 1 meter high by means of a pulley and rope.

In many of the experiments CO_2 was put into the chamber from a bag full of the gas. The subjects inside could not tell when the gas was introduced, not even if the percentage was suddenly raised to 2.

The introduction of this amount of the gas made no sensible difference to them. The subjects wore only a vest, pants and shoes in most of these experiments. When they wore their ordinary clothing the effect on the frequency of the pulse was more marked and the discomfort from heat and moisture much greater.

In every one of the experiments the putting on of the fans gave great relief. The refreshing effect of the moving air acting on the skin is very great, but this cannot be measured and recorded in figures.

October 4, 1910. H. B. W. and R. A. R. in chamber. Subject, H. B. W. Fans off and CO_2 absorbed.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Temperature of chamber	
					Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*
2.30	23	6	250.9	82	78	78
2.31	19	6	316			
2.32	19	7	368		79	79
2.33	20	7.5	375	(Accel. 4)		
2.34	16	7.5	469		80	80
2.35	23	7.5	326			
2.36	22	8	363			
2.37	20	10	500	86	83	83
2.38	22	8.5	386			

Average volume breathed, 6.5 liters per minute.

3.50	23	9	391			
3.51	27	10	370		84	79
3.52	26	10.5	404			
3.53	24	7	292	(Accel. 14)		
3.54	23	8.5	369			
3.55	24	7.5	312			
3.56	23	9	371		86	79
3.57	23	9.5	413			
3.58	24	7	291			
3.59	25	9.5	380	100	86	79
4.00	24	9.5	396			

Average volume breathed, 9.6 liters per minute.

At 4.25, fans put on.

4.30	22	9	409	(Ret. 22) 78	86	83
4.31	24	11.5	479			
4.32	23	11.5	500			
4.33	24	11	460			
4.34	22	8	364			
4.35	23	8.5	370			
4.36	20	11	550		86	83
4.37	24	11.5	479			
4.38	21	10	476			
4.39	23	13	565	76	86	83

Average volume breathed, 10.5 liters per minute.

At 4.42, CO_2 let out of bag and fans put on to thoroughly mix the atmosphere in chamber. At 4.48, sample taken. Analysis: CO_2 4.75 per cent; O_2 17.4 per cent.

Fans off and CO_2 on.

Time	Body temperature	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Temperature of chamber	
						Dry bulb	Wet bulb
P. M.	*Degrees F.*		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*
4.50	98	24	28	1166	(Accel. 13) 89	87	84
4.51		24	27	1125			
4.52		27	28	1039			
4.53		24	26	1083			
4.54		25	27	1080		87	86
4.55		25	30	1200			
4.56		27	31	1146			
4.57		26	31	1192			
4.58		26	32	1230			
4.59		27	31	1148	86	89	87

Average volume breathed, 29 liters per minute.

Fans and CO_2 on.

Time	Body temperature	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Dry bulb	Wet bulb
5.10	98.5	25	26	1040	(Ret. 5)		
5.11		26	33	1269		89	85
5.12		30	37	1233	84		
5.13		27	35	1222			
5.14		26	32	1230			
5.15		27	30	1111			
5.16		27	35	1296			
5.17		27	32	1181			
5.18		26	37	1423	82	89	86
5.19		28	35	1250			

Average volume breathed 32.2 liters per minute.

At 5.20, sample taken. Analysis: CO_2 5.29 per cent; O_2 16.43 per cent.

October 12, 1910. Series I. R. A. R. and H. B. W. in chamber. Subject, R. A. R. Fans off and CO_2 absorbed.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Temperature of chamber	
					Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*
3.00	17	12	705.7	76	91	90
3.01	19	13	684.2			
3.02	18	12	666.6			
3.03	18	16	888.8			
3.04	20	19	950	(Accel. 4)		
3.05	18	15	833.3			
3.06	20	15	750			
3.07	19	11	578.9			
3.08	19	12	631.5			
3.09	20	15	750	80	89	87

Average volume breathed, 14 liters per minute.

Series II. CO_2 absorbed and fans on.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Temperature of chamber	
					Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*
3.23	16	8	500	74	90	85
3.24	15	6	400			
3.25	17	8	470.5			
3.26	17	7	411.8			
3.27	15	7	366.6	(Retard. 4)		
3.28	17	7	411.8			
3.29	17	7	411.8			
3.30	17	8	470.6			
3.31	14	7	500			
3.32	15	8	533.3	70	90	87

Average volume breathed, 7.3 liters per minute.

Series III. Breathing air of chamber. CO_2 equals 1.70 per cent. Fans off.

3.47	17	17	1,000	76	92	89
3.48	18	18	1,000			
3.49	17	15	883.5			
3.50	17	28	1,705.9			
3.51	17	8	470.5	(Accel. 4)		
3.52	17	15	882.3			
3.53	17	19	1,117.6			
3.54	18	22	1,222.2			
3.56	17	17	1,000			
3.57	18	23	1.277.7	80	92	90

Average volume breathed, 18.2 liters per minute.

Series IV. Breathing air of chamber. Fans on.

4.3	18	15	833.3	78	93	89
4.4	17	11	647			
4.5	17	12	705.9			
4.6	13	17	764.7			
4.7	16	18	888.8	(Accel. 2)		
4.8	11	18	611.1			
4.9	18	10	555.5			
4.10	17	11	647			
4.11	15	10	666.6			
4.12	15	12	800	80	96	92

Average volume breathed, 13.8 liters per minute.

Series V. CO_2 was passed into chamber from outside. Fans on.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Temperature of chamber	
					Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*
4.23	25	22	880	74	90	87
4.24	25	20	800			
4.25	23	23	1,000			
4.26	23	22	956			
4.27	22	19	863.8	(Accel. 4)		
4.28	21	17	809.5			
4.29	21	17	809.5			
4.30	20	22	1,100			
4.31	21	21	1,000			
4.32	22	19	863.6	78	95	92

Average volume breathed, 20 liters per minute.

Series VI. Fans off and same atmosphere breathed.

4.38	24	37	1,541.7	76	95	92
4.39	24	50	2,083.3			
4.40	24	40	1,666.6			
4.41	25	45	1,800			
4.42	24	44	1,833.3	(Accel. 20)		
4.43	26	40	1,538.4			
4.44	24	36	1,500			
4.45	21	36	1,719			
4.46	21	41	1,952.4			
4.47	21	38	1,809.5	96	95	93

Average volume breathed, 40.8 liters per minute. Increase, 91 per cent.

Sample taken. Analysis: CO_2 4.54 per cent; O_2 16.33 per cent.

The temperature was high and the cooling effect of fans lowered the pulmonary ventilation greatly, as well as the pulse rate.

October 19, 1910. Series I. Subject, H. B. W. Fans off and CO_2 absorbed.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
						Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
3.50	24	12	500	84	94.4	81	78
3.51	27	10	370.37				
3.52	26	7	269.23				
3.53	24	8.5	354.16				
3.54	23	9	391.3	(Accel. 6)			
3.55	27	10.5	388.8				
3.56	25	9	360				
3.57	23	9.5	413.04				
3.58	21	9	428.57				
3.59	22	9	409.09	90	99.5	88	86

Average volume breathed, 9.3 liters per minute.

Series II. CO_2 absorbed by soda lime and fans on.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
						Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
4.10	25	10	400	82	99	90	85
4.11	24	10	416				
4.12	24	9	375				
4.13	23	8	347.82				
4.14	23	8.5	369.56	(Accel. 6)			
4.15	20	8	400				
4.16	21	8.6	409.52				
4.17	21	7.9	376.2				
4.18	21	8.6	409.52				
4.19	23	9.4	409.6	88	99.1	93	88

Average volume breathed, 8.8 liters per minute.

Great relief by fans, with much less perspiration.

At 4.35, CO_2 was let into the chamber and fans were put on for a time to thoroughly mix the atmosphere of the chamber. Soda lime tin was removed and fans put off.

Series III. CO_2 on and fans off.

4.49	21	14	666.6	100	99.5	95	92
4.50	26	16	615.3				
4.51	24	12.5	520.83				
4.52	25	15.5	620				
4.53	23	14	608.7	(Accel. 8)			
4.54	24	13	541.7				
4.55	24	11.5	479.7				
4.56	25	11.5	460				
4.57	24	13	541.6				
4.58	26	17	653.8	108	99.8	97	95

Average volume breathed, 14.8 liters per minute. Bladder emptied.

Sample of air taken at 5 o'clock. Analysis: CO_2 3.935 per cent; O_2 17.91 per cent.

Series IV. Fans put on and same atmosphere as in last series breathed.

5.15	24	29	1,208.3	92	99.5	97	93
5.16	24	20	833.3				
5.17	25	23	920				
5.18	27	20	740.7				
5.19	27	18	666.6	(Retard. 8)			
5.20	27	17	629.6				
5 21	24	17	708.3				
5.22	25	18	720				
5.23	25	17	680				
5.24	26	15	576.9	84	99.5	99	95

Average volume breathed, 19.4 liters per minute. Increase 108 per cent.

At 5.25 sample taken. Analysis: CO_2 4.56 per cent; O_2 16.27 per cent.

Specimen of urine: No glucose found, or not sufficient to reduce Fehling's solution.

October 26, 1910. Series I. I. F. and R. A. R. in chamber. Subject, I. F. Fans off and CO_2 absorbed.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
						Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F*	*Degrees F.*
4.15	22	10	454.5	76	98.5	85	80
4.16	24	8	333.3				
4.17	23	8	347.8				
4.18	20	8	400				
4.19	24	9	375	(Accel. 11)			
4.20	24	8	333.3				
4.21	22	8	363.6				
4.22	21	8	381				
4.23	21	8	381				
4.24	20	7	350	87	99	89	85

Average volume breathed, 8.2 liters per minute.

Series II. CO_2 absorbed and fans on.

4.35	21	12	571.4	88	99	89	85
4.36	24	10	416.6				
4.37	19	9	473.7				
4.38	20	9	450				
4.39	19	8	421	(Accel. 0)			
4.40	22	10	454.5				
4.41	21	11	523.8				
4.42	21	9	428.6				
4.43	22	8	363.6				
4.44	22	10	454.5	88	99.4	95	89

Average volume breathed, 9.6 liters per minute.

At 4.55 CO_2 let in from bag. Fans put on to thoroughly mix atmosphere with CO_2. Sample taken. Analysis: CO_2 1.7 per cent; O_2 19.21 per cent. Fans put off.

Series III. Fans off and CO_2 on.

5.10	21	11	523.8	100	99.6	97	93
5.11	17	12	705.9				
5.12	19	15	789.5				
5.13	19	14	736.8				
5.14	21	15	714.3	(Accel. 24)			
5.15	22	15	681.7				
5.16	19	14	736.8				
5.17	20	14	700				
5.18	23	17	739.1				
5.19	22	16	727.2	124	99.8	100	96

Average volume breathed, 14.3 liters per minute.

Series IV. CO_2 and fans on.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
						Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
5.30	19	13.5	710.5	116	100	100	99
5.31	22	20	919.1				
5.32	21	16.5	785.7				
5.33	21	17.5	833.3				
5.34	22	18	818.1	(Accel. 4)			
5.35	22	16	727.2				
5.36	23	15	652.1				
5.37	22	20	909.1				
5.38	23	19	826.1				
5.39	24	18	750	120	100.1	100	95

Average volume breathed, 17.3 liters per minute. Increase, 111 per cent.

Sample taken. Analysis: CO_2 3.56 per cent; O_2 17.02 per cent.

November 2, 1910. Series I. Subject, H. B. W. Work done by lifting a weight of 20 kilograms 1 meter from the ground by means of a rope attached to it over a pulley. The weight was lifted up 6 times (once every 10 seconds) per minute, for 10 minutes. Fans off and CO_2 absorbed by tin containing soda lime attached to inspiratory valve.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
15	4	266.6	84	99.2	75	72
19	5	263.15				
21	5	238.1				
26	5	192.3				
21	6	285.6	(Accel. 30)			
19	6	315.7				
22	7	318.1				
20	6	300				
16	6	374.9				
24	10	416.6	114	99.2	81	79

Average volume breathed, 6 liters per minute.

Series II. CO_2 absorbed and fans on.

15	3	200	92	99.2	81	79
20	3.5	175				
18	6	333.3				
21	6	285.6				
20	6	300	(Accel. 10)			
20	7	350				
17	5	294				
19	8	421				
19	7	368.4				
22	9	409	102	99	81	77

Average volume breathed, 6 liters per minute.

CO_2 was let into chamber from the bag outside. Fans put on to thoroughly mix atmosphere. Sample (No. 2) taken. Analysis: CO_2 2.76 per cent; O_2 18.13 per cent.

Series III. CO_2 on and fans off.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
21	11	476.2	92	99	80	77
19	11	579				
21	14	666.6				
19	15	789.4				
19	15	789.4	(Accel. 18)			
20	16	800				
20	12	600				
19	14	736.8				
21	12	571.3				
19	13	684.2	110	98.8	80	77

Average volume breathed, 13.3 liters per minute.

Series IV. CO_2 on and fans on.

19	5	263.15	96	98.8	81	77
18	7	388.88				
19	10	526.2				
22	10	454.5				
22	11	500	(Accel. 8)			
21	12	571.4				
20	12	600				
25	16	640				
21	14	666.6				
22	14	636.3	104	99	84	80

Average volume breathed, 11.1 liters per minute.

November 9, 1910. Series I. R. A. R. and I. F. in chamber. Subject, R. A. R. Work done by lifting weight 12 times per minute. CO_2 absorbed and fans off.

20	11.7	585	80	99.2	80	77.5
20	7.3	365				
22	11	500				
24	12	500				
26	9	346.1	(Accel. 20)			
28	22	785.7				
30	24	800				
30	26	866.7				
30	26	866.7				
31	28	903.3	100	99.6	83	81

Average volume breathed, 17.7 liters per minute.

Series II. CO_2 absorbed and fans on.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
22	13	509.9	80	99.6	88	83
32	18	562.5				
25	11	440				
24	11	458.3				
31	21	677.4	(Accel. 20*)			
30	21	700				
30	21	700				
28	23	821.4				
29	23	793.1				
29	21	724.1	100	100	86	85

* No more acceleration of pulse in spite of higher temperature.

Average volume breathed, 17.3 liters per minute.

CO_2 let into chamber from bag. Analysis: CO_2 3.76 per cent; O_2 17.3 per cent.

Series III. CO_2 on and fans off.

26	18	692.3	90	100.4	90	87
23	20	869.5				
28	23	821.4				
27	25	925.92				
28	25	892.8	(Accel. 42)			
28	28	1,000				
28	26	928.5				
29	27	931				
29	32	1,103.4				
30	32	1,066.6	132	100.6	93.5	92

Average volume breathed, 26.5 liters per minute.

Series IV. CO_2 on and fans on.

30	21	700	118	100.6	94	90
30	24	800				
30	28	933.3				
33	25	757.5				
34	28	823.5	(Accel. 28)			
34	28	823.5				
34	30	882.3				
34	29	852.9				
34	27	791.2				
34	27	791.2	146	101	96	91

Average volume breathed, 27.7 liters per minute. Increase, about 60 per cent.

Sample taken. Analysis: CO_2 5.3 per cent; O_2 15.44 per cent.

November 16, 1910. Series I. R. A. R. performed work by pulling on 20-kilogram weight over a pulley, for series of 10 minutes. CO_2 absorbed by soda lime and fans off.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
20	6	300	94	100	80	78
18	11	601.11				
21	14	666.6				
21	16	761.8				
24	21	875	(Accel. 16)			
24	16	666.6				
23	3	130.4				
21	18	857.1				
21	16	761.9				
20	16	800				
24	20	833.3	110	100.2	86	84

Average volume breathed, 15.7 liters per minute.

Series II. CO_2 absorbed and fans on.

22	12	545.4	98	100.2	89	85
22	10	454.5				
21	14	666.6				
22	16	727.2				
22	16	727.2	(Accel. 16)			
25	17	680				
25	18	720				
27	21	777.7				
23	22	956.5				
21	30	1,428.5	114	100.4	90	85

Average volume breathed, 17.6 liters per minute.
Pulse little more accelerated in spite of higher temperature.

November 23, 1910. Series I. H. B. W. performed work by pulling on a weight of 20 kilograms over a pulley. This was lifted 12 times per minute for 5 minutes. CO_2 absorbed and fans off.

20	24	1,200	96	98.8	87	83
21	37	1,761.9				
22	42	1,909	(Accel. 32)			
22	41	1,863.6				
24	42	1,750	128	99	90	85

Average volume breathed, 37 liters per minute. Average tidal air, 1,697 cc.

Series II. CO_2 absorbed and fans on.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
18	16	888.8	112	99.2	90	85
20	43	2,150				
19	52	2,736.8	(Accel. 14)			
21	21	1,000				
22	39	1,772.7	126	99.4	88	84

Average volume breathed, 34 liters per minute. Average tidal air, 1,709 cc.

H. B. W. said he found the work much more easily performed when the fans were on.

CO_2 let into chamber from the bag outside. Fans were put on to thoroughly mix the atmosphere and were then stopped and records taken. Sample taken. Analysis: CO_2 3.75 per cent; O_2 16.31 per cent.

Series III. CO_2 and fans off.

22	45	2,045.4	110	99.4	91	87
21	40	1,904.8				
25	52	2,080	(Accel. 70)			
24	52	2,166.6				
25	53	2,120	180	99.6	90	87

Average volume breathed, 48 liters per minute. Average tidal air, 2,063 cc.

Series IV. CO_2 and fans on.

22	46	2,090.9	118	99.4	89	85
22	51	2,318.2				
21	51	2,428.5	(Accel. 20)			
23	51	2,217.4				
24	54	2,250	138	99.6	90	87

Average volume breathed, 51 liters per minute. Average tidal air, 2,261 cc.

Sample taken. Analysis: CO_2 5.07 per cent; O_2 14.8 per cent.

December 3, 1910. Series I. R. A. R. performed work by lifting a 20-kilogram weight over a pulley, 12 times per minute for series of 5 minutes. CO_2 absorbed and fans off.

15	16	1,066.6	88	100	80	80
16	24	1,500				
17	32	1,882.3	(Accel. 26)			
19	29	1,526.3				
18	33	1,833.3	114	100.3	85	84

Average volume breathed, 27 liters per minute.

Pulse records for a few minutes afterwards: At the end of 1st minute, 104 per minute; 2d minute, 102; 4th minute, 102; 6th minute, 94. After 3 minutes of fans on: Pulse 88.

Series II. CO_2 absorbed by soda lime and fans on.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
17	9	529.4	96	99.6	87	85
18	23	1,277.7				
19	32	1,684.3	(Accel. 20)			
17	34	2,000				
18	34	1,888.8	116	100	88	85

Average volume breathed, 26 liters per minute. Average tidal air, 1,676.04 cc.

Pulse records: At the end of 1st minute, 110 per minute; 4th minute, 106; 6th minute, 100.

CO_2 let into chamber from bag. Fans put on to thoroughly mix the atmosphere. Sample taken. Analysis: CO_2 3.45 per cent; O_2 17.64 per cent.

Series III. CO_2 and fans off.

17	30	1,764.7	92	100	87	83
20	60	3,000				
19	32	1,684.3	(Accel. 42)			
21	46	2,190.4				
25	60	2,400	134	100.5	87	85.5

Average volume breathed, 46 liters per minute.

Pulse records: At end of 1st minute, 130 per minute; 2d minute, 114; 4th minute, 98; 6th minute, 94.

Series IV. CO_2 and fans on.

28	50	1,785.7	99	100	87	85
27	58	2,148.1				
31	58	1,871	(Accel. 21)			
31	66	2,129				
30	63	2,100	120	100	87	85

Average volume breathed, 57 liters per minute. Increased, 118 per cent.

Pulse records: At the end of 1st minute, 120 per minute; 2d minute, 110; 4th minute, 100; 6th minute, 100.

Sample taken. Analysis: CO_2 4.25 per cent; O_2 16.55 per cent.

December 14, 1910. Series I. H. B. W. lifted weight 12 times per minute for series of 5 minutes. CO_2 absorbed and fans off.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
						Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
2.33	13	12	923.1	86	99.2	87	82
2.34	13	18	1,384.6				
2.35	13	22	1,692.3	(Accel 32.)			
2.36	17	28	1,647.1				
2.37	20	28	1,400.	118	99.2	89	85

Average volume breathed, 22 liters per minute. Average tidal air, 1,407.4 cc.

Pulse records: During 3d minute, 112 per minute; 5th minute, 108; 7th minute, 89.

Series II. CO_2 absorbed and fans on.

3.15	14	16	1,142.8	108	99.2	91	85
3.16	15	18	1,200				
3.17	14	25	1,785.7	(Accel. 7)			
3.18	15	33	2,200				
3.19	16	27	1,687.5	115	99.2	90	85

Average volume breathed, 24 liters per minute. Average tidal air, 1,603.2 cc.

Pulse records: During 3d minute, 97 per minute; 5th minute, 99; 7th minute, 91.

CO_2 let into chamber and fans put on to thoroughly mix atmosphere. Sample taken and fans put off. Analysis: CO_2 3.34 per cent; O_2 17.89 per cent.

Series III. CO_2 on and fans off.

3.45	14	25	1,785.7	108	99.2	90	87
3.46	14	31	2,214.3				
3.47	16	37	2,312.5	(Accel. 32)			
3.48	13	48	3,692.3				
3.49	21	47	2,238.1	140	99.4	89	86

Average volume breathed, 36 liters per minute. Average tidal air, 2,448.6 cc.

Pulse records: During 3d minute, 120 per minute; 5th minute, 118; 7th minute, 106.

Series IV. CO_2 and fans on.

Time	Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
						Dry bulb	Wet bulb
P. M.		*Liters*	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
4.5	16	31	1,937.5	110	99.2	91	87
4.6	20	39	1,950				
4.7	20	45	2,250	(Accel. 20)			
4.8	22	52	2,363.6				
4.9	22	52	2,363.6	130	99.2	90	86

Average volume breathed, 44 liters per minute. Average tidal air, 2,172.9 cc.

Pulse records: During 3d minute, 115 per minute; 5th minute, 110; 7th minute, 107.

Sample taken. Analysis: CO_2 3.97 per cent; O_2 17.4 per cent.

December 21, 1910. Series I. R. A. R. lifted weight 12 times per minute for series of 5 minutes. CO_2 absorbed and fans off.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
16	13	1,125	78	99.8	87	82
18	18	1,000				
22	22	1,000	(Accel. 18)			
23	23	1,000				
25	25	1,000	96	100	88	85

Average volume breathed, 20 liters per minute. Average tidal air, 982.5 cc.

Pulse rate during 3d minute, 97 per minute; 5th minute, 82; 7th minute, 78.

Series II. CO_2 absorbed and fans on.

13	18	1,384.6	90	99.8	90	83
13	19	1,461.5				
18	21	1,166.6	(Accel. 6)			
19	4	1,263.2				
19	26	1,368.4	96	100	90	85

Average volume breathed, 22 liters per minute. Average tidal air, 1,328.86 cc.

Pulse rate during 3d minute, 96 per minute; 5th minute, 92; 7th minute, 90.

CO_2 let into chamber and fans put on to thoroughly mix the atmosphere of chamber. Sample taken. Analysis: CO_2 2.62 per cent; O_2 19.8 per cent.

Series III. CO_2 on and fans off.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
17	28	1,647	86	99.8	89	86
19	29	1,526.3				
18	36	2,000	(Accel. 22)			
20	44	2,200				
22	47	2,136.2	108	100	89	86

Average volume breathed, 35 liters per minute. Average tidal air, 1,901.9 cc.

Pulse rate during 3d minute, 100 per minute; 5th minute, 92; 7th minute, 92.

Series IV. CO_2 and fans on.

25	41	1,640	90	99.8	90	87
27	46	1,703.7				
30	56	1,866.6	(Accel. 16)			
28	55	1,964.2				
29	57	1,965.5	106	100	90	87

Average volume breathed, 51 liters per minute. Average tidal air, 1,828 cc.

Pulse rate during 3d minute, 96 per minute; 5th minute, 94; 7th minute, 92. Sample (No. 2) taken. Analysis: CO_2 4.37 per cent; O_2 18.07 per cent.

January 9, 1911. Series I. H. B. W. lifted weight 12 times per minute for series of 5 minutes. CO_2 absorbed and fans on.

12	11	916.6	90	99.4	81	75
14	17	1,214.2				
13	20	1,538.4	(Accel. 30)			
14	23	1,642.8				
18	24	1,333.3	120	99.4	83	77

Average volume breathed, 19 liters per minute. Average tidal air, 1,329.06 cc.

Pulse rate during 3d minute, 114 per minute; 5th minute, 100; 7th minute, 80.

Series II. CO_2 absorbed and fans off.

13	15	1,153.8	92	99.4	84	80
12	16	1,333				
13	20	1,538.4	(Accel. 40)			
18	22	1,222.2				
15	25	1,666.6	132	99.4	85	82

Average volume breathed, 19.6 liters per minute. Average tidal air, 1,382.8 cc.

Pulse rate during 3d minute, 118 per minute; 5th minute, 106; 7th minute. 90.

CO_2 let into chamber. Fans put on to thoroughly mix atmosphere. Sample taken. Analysis: CO_2 2.36 per cent; O_2 17.42 per cent.

Series III. CO_2 on and fans off.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
17	28	1,647	118	99	90	86
22	38	1,727.2				
21	40	1,904.76	(Accel. 46)			
23	44	1,913				
25	53	2,120	164	99.4	91	88

Average volume breathed, 40.6 liters per minute. Average tidal air, 1,862.39 cc.

Pulse rate during 3d minute, 138 per minute; 5th minute, 120; 7th minute, 120.

Series IV. CO_2 and fans on.

15	32	2,133.3	100	99	88	82
16	24	1,500				
17	34	2,000	(Accel. 30)			
21	35	1,666.6				
20	45	2,250	130	99	90	85

Average volume breathed, 34 liters per minute. Average tidal air, 1,909.9 cc.

Pulse rate during 3d minute, 118 per minute; 5th minute, 108; 7th minute, 100.

Sample taken. Analysis: CO_2 4.13 per cent; O_2 15.3 per cent.

August 2, 1911. Series I. R. A. R. lifted weight 12 times per minute for series of 5 minutes. CO_2 absorbed and fans off.

13	19	1,461.5	80	99.6	94	90
14	23	1,642.8				
13	26	2,000	(Accel. 32)			
15	35	2,333.3				
16	37	2,312.5	112	100	100	96

Average volume breathed, 28 liters per minute. Average tidal air, 1,950.02 cc.

Pulse rate during 3d minute, 100; 5th minute, 100.

CO_2 let into chamber from bag outside. Fans put on to thoroughly mix the CO_2 with atmosphere of chamber. Sample taken. Analysis: CO_2 2.24 per cent; O_2 18.57 per cent.

Series II. CO_2 on and fans off.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
14	33	2,357.1	92	100	97	95
16	40	2,500				
16	51	3,187.5	(Accel. 48)			
18	39	2,166.1				
18	45	2,500	140	100.5	100	97

Average volume breathed, 41.6 liters per minute. Average tidal air, 2,542.14 cc.

Pulse rate during 1st minute, 140; 3d minute, 120; 5th minute, 110.

Air chamber cooled 14° F. (wet bulb) by means of water cooler.

Series III. CO_2 on and fans off.

17	38	2,235.3	84*	100.4	85	83
18	42	2,333.3				
19	55	2,894.7	(Accel. 26)			
20	50	2,500				
20	50	2,750	110	100.8	87	85

* Note retardation.

Average volume breathed, 48 liters per minute. Average tidal air, 2,542.66 cc.

Pulse rate during 2d minute, 100; 3d minute, 94.

Sample taken. Analysis: CO_2 5.31 per cent; O_2 16.54 per cent.

July 28, 1911. Series I. H. B. W. lifted weight 12 times per minute for series of 5 minutes. Fans off. Ordinary air in chamber breathed.

15	15	937.5	114	99.4	87	86
15	21	1,400				
20	28	1,400	(Accel. 28)			
18	23	1,277.7				
15	33	2,200	142	100	103	97

Average volume breathed, 25 liters per minute. Average tidal air, 1,443.04 cc.

Pulse rate during 1st minute, 142; 2d minute, 118.

CO_2 let into chamber from bag outside. Fans put on to thoroughly mix the atmosphere of chamber with CO_2. Analysis CO_2 5.09 per cent; O_2 16.71 per cent.

Series II. CO_2 on and fans off.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
19	39	2,052.6	120	99.6	95	87
20	43	2,150				
22	48	2,181.8	(Accel. 28)			
24	57	3,375				
23	52	2,260.9	148	99.6	104	101

Average volume breathed, 47.8 liters per minute. Average tidal air, 2,204.06 cc.

Pulse rate during 1st minute 148; 2d minute, 144; 3d minute, 136.

Air inside the chamber cooled 22° F. by water cooler with fans on.

Series III. CO_2 on and fans off.

20	40	2,000	100*	99.6	82	79
26	50	1,923				
27	53	1,963	(Accel. 34)			
25	55	2,200				
25	54	2,160	134	99.6	81.5	79

* Note retardation.

Average volume breathed, 50.4 liters per minute. Average tidal air, 2,049.2 cc.

Pulse rate during 1st minute, 134; 2d minute, 110; 3d minute, 104.

Sample taken. Analysis: CO_2 5.5 per cent; O_2 15.57 per cent.

August 9, 1911. Series I. H. B. W. lifted weight 12 times per minute for series of 5 minutes. Fans off. Ordinary air of chamber breathed.

12	25	2,083.3	90	99.6	94	85
13	19	1,461.5				
15	24	1,600	(Accel. 26)			
14	36	1,571.4				
15	25.5	1,700	116	99.6	100	95

Average volume breathed, 26 liters per minute. Average tidal air, 1,683.24 cc.

Pulse rate during 1st minute, 116; 2d minute, 112; 3d minute, 106; 4th minute, 95; 5th minute, 100.

CO_2 let into chamber from bag outside. Fans put on to thoroughly mix the atmosphere of chamber with CO_2. Sample taken. Analysis: CO_2 3.09 per cent; O_2 18.51 per cent.

Series II. CO_2 and fans on.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
15	26	1,733.3	94	99.2	95	91
18	29	1,811.1				
20	39	1,950	(Accel. 26)			
21	41	1,952.4				
22	47	2,136.3	120	99.2	95	93

Average volume breathed, 36.4 liters per minute. Average tidal air, 1,916.62 cc.

Pulse rate during 1st minute, 120; 2d minute, 106; 3d minute, 108; 4th minute, 108; 5th minute, 106.

Sample taken: Analysis: CO_2 3.86 per cent; O_2 17.19 per cent.

Air in chamber cooled (10° F. wet bulb) by means of water cooler and fans put on.

Series III. CO_2 on and fans off.

18	29	1,611.1	92	99.2	88	85
15	42	1,800				
16	43	2,750	(Accel. 18)			
17	41	2,176.4				
18	49	2,722.2	110	99.6	88	85

Average volume breathed, 40.8 liters per minute. Average tidal air, 2,211.94 cc.

Pulse rate during 1st minute, 110; 2d minute, 92; 3d minute, 92; 4th minute, 90; 5th minute, 91.

Sample taken. Analysis: CO_2 4.56 per cent; O_2 15.95 per cent.

August 16, 1911. Series I. R. A. R. lifted weight 12 times a minute for series of 5 minutes. CO_2 and fans off.

10	18	1,800	76	99.8	95	87
12	32	2,666.6				
17	25	1,470.5	(Accel. 22)			
26	45	1,730.8				
19	23	1,210.5	98	99.8	99	93

Average volume breathed, 28.6 liters per minute. Average tidal air, 2,219.6 cc.

Pulse rate during 1st minute, 98; 2d minute, 90; 4th minute, 84; 5th minute, 80.

CO_2 let into chamber from bag outside. Fans put on to thoroughly mix atmosphere of chamber; then the fans were put off. Sample taken. Analysis: CO_2 3.52 per cent; O_2 18.5 per cent.

Series II. CO_2 on and fans off.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
15	37	1,466.6	82	99.8	93	87
15	38	2,533.3				
17	40	2,352.9	(Accel. 36)			
18	45	2,500				
26	53	2,384.6	118	99.8	99	95

Average volume breathed, 42.6 liters per minute. Average tidal air, 2,247.48 cc.

Pulse rate during 1st minute, 118; 2d minute, 108; 3d minute, 104; 4th minute, 96; 6th minute, 96.

Water cooler put on for half an hour.

Series III. CO_2 on. Air of chamber cooled 11° to 13° F. (wet bulb).

20	30	1,500	86	99.8	87	84
19	45	2,368.4				
20	35	1,750	(Accel. 22)			
20	60	3,000				
23	50	2,173.9	108	99.8	85	82

Average volume breathed, 44 liters per minute. Average tidal air, 2,584.6 cc.

Pulse rate during 1st minute, 108; 2d minute, 96; 3d minute, 92; 4th minute, 92; 5th minute, 88.

Sample taken. Analysis: CO_2 4.63 per cent; O_2 17.50 per cent.

August 19, 1911. Series I. H. B. W. lifted weight 12 times per minute for series of 5 minutes. CO_2 off and fans on.

12	14	1,666.6	87	99.4	95	85
13	18	1,384.6				
15	25	1,666.6	(Accel. 15)			
17	30	1,764.7				
18	28	1,555.5	102	99.4	90	89

Average volume breathed, 23 liters per minute.

Pulse rate during 1st minute, 102; 2d minute, 104; 3d minute, 98; 4th minute, 90; 5th minute, 95.

CO_2 let into chamber from a bag outside. Sample taken. Analysis: CO_2 4.4 per cent; O_2 17.29 per cent.

Series II. Fans off.

Number of respirations per minute	Total volume breathed per minute	Tidal air	Pulse rate	Rectal temperature	Temperature of chamber	
					Dry bulb	Wet bulb
	Liters	*c. c.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
13	31	2,384.6	106	99.4	97	93
16	47	2,937.5				
16	39	2,437.5	(Accel. 26)			
25	48	1,920				
30	52	1,733.3	132	99.4	97	93

Average volume breathed, 43.4 liters per minute.

Pulse rate during 1st minute, 132; 2d minute, 122; 3d minute, 112; 4th minute, 115; 5th minute, 115.

Series III. Air in chamber cooled 10° F. by means of water cooler.

25	34	1,360	94	99.4	87	84
30	53	1,766.6				
27	49	1,814.8	(Accel. 18)			
28	54	1,928.5				
31	57	1,838.7	112	99.4	86	93

Average volume breathed, 59.4 liters per minute.

Pulse rate during 1st minute, 112; 2d minute, 106; 3d minute, 98; 4th minute, 96; 5th minute, 98.

Sample taken. Analysis: CO_2 5.66 per cent; O_2 16.61 per cent.

The following results summarize the effects of cooling the air:

CO_2 absorbed and fans off

Temperature of chamber		Pulse rate	Analysis of air
Wet bulb	Dry bulb		
Degrees F.	*Degrees F.*		
86 to 97	87 to 103	142 118 2d min. after work	
CO_2 on and fans off			
87 to 101	95 to 104	148 144 2d min. 136 3d min.	CO_2 5.09 per cent O_2 16.71 per cent

Temperature of chamber		Pulse rate	Analysis of air
Wet bulb	Dry bulb		
CO_2 and water cooler on			
Degrees F.	*Degrees F.*		
79 79	82 to 81.5	134 110 2d min. 104 3d min.	CO_2 5.5 per cent O_2 15.57 per cent
CO_2 absorbed and fans off			
85 to 89	85 to 90	102 104 2d min. 98 3d min. 90 4th min. 95 5th min.	
CO_2 on and fans off			
93	97	132 122 2d min. 112 3d min. 115 4th min. 115 5th min.	CO_2 4.4 per cent O_2 17.29 per cent
CO_2 and water cooler on			
83	86	112 106 2d min. 98 3d min. 96 4th min. 95 5th min.	CO_2 5.66 per cent O_2 16.61 per cent

In a crowded room the air confined between the bodies and clothes of the people is warmed almost up to body temperature and saturated with moisture, so that cooling of the body by radiation, convection by evaporation, becomes almost impossible. This leads to sweating, wetness and flushing of the skin, and a rise of skin temperature. The blood is sent to the skin and stagnates there instead of passing in ample volume through the brain and viscera. Hence arise the feelings of discomfort and fatigue. The fans in our chamber whirled away the blanket of stationary wet air around the bodies of the students, and brought to them the somewhat cooler and drier air in the rest of the chamber, and so relieved the heat stagnation from which they suffered. The relief became far greater when we allowed cold water to circulate through a radiator placed in the chamber, and so cooled the air of the chamber about 10° F. The discomfort of crowded rooms and overwarm places of business can be entirely removed by moving and cooling the air. When work is done without over-fatigue, the frequency of the pulse, which is accelerated by work, quickly returns to normal. Our results show that increased percentages of CO_2 and diminished oxygen percentages of 2 to 3 per cent, and even 4 to 5 per cent, have little effect in modifying the frequency of the pulse, while the temperature and humidity of the air have a profound effect. The feelings of discomfort depend on the excessive heat and humidity, and are relieved by cooling and whirling the air in the chamber. If we suddenly raised the percentage of CO_2 in the chamber up to 2 per cent, we found the subjects inside were quite unaware of this. If we sat outside and breathed the air in the chamber through a tube, we felt none of the discomfort which was being experienced by those shut up inside. Similarly, if one of those in the chamber breathed the pure air outside through a tube, he was not relieved.

The pulmonary ventilation mainly depends on the percentage of CO_2 but may also be used as part of the heat-regulating mechanism.

The observations made by Pembrey and Collis[1] on the weaving mill operatives at Darwen show that the skin of the face may be 4° to 13° F. higher in the mill when the wet bulb is 71° F. than at home when the wet-bulb temperature is about 55° F. The tendency of the warm, humid atmosphere of the mill is to establish a more uniform temperature of the body as a whole (surface and deep temperatures) and to throw a tax upon the power of accommodation, as indicated by the rapid pulse and low blood-pressure.

The mill workers are wet with the steam blown into the sheds, their clothes and bodies are moist, and the long hours of exposure to such uncomfortable conditions are most deleterious to physical vigor and happiness. The operatives asked that they might be allowed to work without steam-injectors and with diminished ventilation, so that the mill rooms became saturated with moisture evaporated from the bodies of the operatives. The old regulations, while forbidding more than 6 parts in 10,000 CO_2, put no limit to the wet-bulb temperature, and this often became excessive on hot summer days. The operatives were quite right; less ventilation and a lower wet bulb is far better than ample ventilation and a high wet bulb. The permissible limit of CO_2 has now been raised to 11 parts in 10,000 and the wet-bulb temperature has been controlled within reasonable limits. (Home Office Departmental Committee Reports on Humidity and Ventilation in Cotton Weaving Sheds, 1911.)

[1] Proc. Physiol. Soc. Oct. 21, 1911; Journ. Physiol., Vol. 43.

The efficiency of workers in mills, mines, tunnels, stoke holes, etc., is vastly increased by the provision of a sufficient draught of air, so as to prevent over-taxing of the heat-regulating mechanism. 600,000 cubic feet of outside air are pumped every minute into the engine rooms of the *Lusitania,* and the temperature thus lowered from 150° to 70° and the men feel no draught and are comfortable.

The human skin, if exposed to a tropical sun, is warmed 3° to 4° C. above the normal surface temperature; a rise of body temperature is alone prevented by movement of the air and by evaporation of sweat. If the air is still and evaporation is checked by a high wet-bulb temperature, or by deficient action of the sweat glands, the body temperature rises and danger of heat-stroke arises. Rabbits, monkeys, and dogs evaporate water from the lungs and mouth, and their capacity to stand exposure to a hot sun is limited. Monkeys exposed to sunshine in Manila died within 70 to 80 minutes, while the protection afforded by an umbrella saved them from all harm.

A tracheotomized dog died when exposed to the sun, for the heat regulation was inhibited and the body temperature rose to febrile heights.[1]

The experiments of J. Haldane, and others made by us on the wearers of the Fleuss dress, show that a very rapid pulse, low blood-pressure, rapid respiration, rise of rectal temperature, faintness, vomiting, and collapse result from prolonged exposure to a wet-bulb temperature of 95° F. The same symptoms result from a few minutes exposure to a hot bath (110° F.) if all the body is immersed except the face.[2] The skin is greatly flushed and the skin temperature raised. The rectal temperature may reach 103° F., the pulse rate rise to 150, the blood-pressure sink to 80, the respiratory rate rise to 30, and pulmonary ventilation to 50 liters. The symptoms are immediately relieved by a cold douche, with the exception of the rectal temperature. It is the circulation which fails, and this is immediately restored by the constriction of the skin. The rapid and dangerous sequence of events which follow exposure to these high temperatures points conclusively to the true cause of the discomfort which people feel in crowded rooms. Those who have a feeble circulation and deficient heat-regulating mechanism may collapse at a wet-bulb temperature 10° or 15° F. below that which affects a strong man, while almost all may feel discomfort and suffer fatigue.

Flügge has found in German high schools temperatures as high as 23° to 26° C. (73.5° to 79° F.). He made observations on 29

[1] H. Aron, B. M. J., 1911, II, p. 777.

[2] Hill and Flack, Proc. Physiol. Soc.; Journ. of Physiol., Vol. 38, 1909.

days in January and February in seven rooms. At the beginning of school the temperature was over 22° C. (71.5° F.) in 3 class-rooms 8 times, in one 10 times, in one 13 times, in one 16 times, in one 18 times. The temperature frequently reached 24° C. (75° F.), and even 26.5° C. (80° F.). When the windows were opened it fell to 14° or 13° C. (57° F.), a variation of over 10° C. (18° F.). Flügge says that the temperature of a public room should never be allowed to go above 21° C. (70° F.) because of the increased water vapor in the atmosphere produced by evaporation from the bodies of the occupants. He says that thermometers should be placed in every public room so that people can protest if the temperature exceeds 19° to 20° C. (66° to 68° F.). For a man wearing the usual clothing and keeping quiet a temperature of 13° to 15° C. (55° to 59° F.) suffices. In trains in winter, when warm overclothing is worn, 10° to 12° C. (50 to 53° F.) is enough.

We are of the opinion that 60° F. should be the highest temperature tolerated except for the old and infirm. The old should work in a different room and not compel the young to live in rooms heated to a tender-plant temperature.

The temperature of a school-room must be regulated by a thermometer, not by the feelings of the teacher.[1] The reduction in the number of scholars and the periodic emptying and blowing out of the room is the best way of avoiding heat stagnation.

Individual weaklings who suffer from the cold must put on more clothing. The absurd décolletée dress of women must not be made an excuse for high temperatures in rooms which are set aside for social functions.

Flügge points out that the great infant mortality occurs in the hottest summer weather. The child should be protected from heat stagnation by the cooling of its food, and exposure to open air during the cool parts of the day and night.

We may remind the reader that by absolute humidity is meant the amount of water in the air per cubic foot; by relative humidity, the percentage that this water is of the amount which the air can hold at the same temperature when saturated. The amount of water vapor varies with the temperature, but is uninfluenced by the pressure of the

[1] The thermometer does not show the rate of heat loss, which is the important thing in relation to body heat stagnation. One of us (L. H.) has recently invented *kata-thermometers,* which are empirically graduated and show the proper rate of heat loss in school rooms, factories, etc. See Lancet, May 10, 1913, p. 1290.

atmosphere. Air saturated at 18° F. holds only 1 grain of water vapor per cubic foot, while air saturated at 70° F. holds 8 grains. Thus if in winter the outside air is saturated at 18° F. and this air is heated up and driven into a room which is kept at 70° F., the air will hold the same absolute amount of moisture, but the relative humidity will only be 12.5 per cent against 100 per cent outside. Suppose the air outside is only half saturated; then the relative humidity inside will be only 6.25 per cent. This is an unusual condition of affairs in the moist and temperate climate of Britain, but a common occurrence during the rigorous winters of North America, and there the schools and dwellings are heated with this desert air.

In Britain if the air were saturated at 32° F. and raised to 60° F., the relative humidity would be only 34.9 per cent; and if the relative humidity of the outside air at 32° F. were 70 per cent, that inside would be only 24.5 per cent.

The Chicago Ventilating Commission say "it is probably safe to say that not more than 2 per cent of the public schools in the United States have any humidifying apparatus. The air, having been heated to about 100° F. and cooled to about 70° F. before it reaches the children, is superdried and seeks to obtain its proper balance of moisture from the school structure and the bodies of the children; hence shrunken furniture, dust, dry throats, parched lips, and a rapid rate of skin evaporation, rendering it necessary to maintain a high temperature for comfort." "In the high-grade installations the temperature is held at 72° F. One thousand eight hundred cubic feet of air per pupil are pumped into the room. In the older installation we frequently find the temperature well over 75° F." (Dr. Evans, Chicago). The citizens of Chicago are paying for a system which is most expensive, and no less pernicious and absurd. The dry, hot "desert" air makes the children stupid, spoils their complexions, swells up the respiratory tract and lowers the immunity.

In contrast with American women, the fresh complexion of English women, and still more of Irish women, seems to be correlated with a moist atmosphere and less indoor life.

The Chicago Commission say that in cold weather it is not possible to ventilate unoccupied rooms in that climate, except with air previously warmed, but that heating and ventilating are separate questions and must always be so considered. It is economic not only to health but to fuel to maintain a sufficient relative humidity and avoid "desert" air. We agree that the dry-bulb temperature for the schools ought not to exceed 55° to 58° F. and the relative humidity ought to be 60 per cent. This will cause the window-panes to frost in cold weather. Every three-quarters of an hour the school-rooms should be emptied and the scholars set to drill or exercise for a few minutes in the open air, or under open sheds, and the air in the rooms should be blown out by opening all the windows and doors. This lowers the bacterial count very greatly, and relieves the monotony of the conditions. The exercise invigorates the circulation of the children and antagonizes the ill effects which a sedentary occupation has on the metabolism.

The suitability of the clothing is of the greatest importance not only to the comfort but to the efficiency of man as a working machine; for example, the power of soldiers to march. On a still day the body is confined by the clothes as if by a chamber of stagnant air, for the air is enclosed in the meshes of the clothes and the skin layer becomes heated to body temperature and saturated with moisture.

The observations of Pembrey[1] show that himself and four soldiers marching in drill order on a moderately warm day (dry bulb 69° F., wet bulb 59° F.) lost more water and retained more water in their clothes than on another similar day when they worked with no jacket on (dry bulb 67° F., wet bulb 58° F.). The average figures were loss of moisture 1,600 against 1,200 grams and water retained in clothes 254 against 109 grams. With no jacket the pulse was on the average increased 28 against 41 in drill order, and rectal temperature 1° against 1.5° F. The taking off of the jacket or throwing open of the jacket and vest very greatly increases the physiological economy of a march. It is absurd that on a hot summer day boy scouts should march with a colored scarf knotted round the neck. Nothing should be worn for ornament or smartness which increases the difficulty of keeping down the body temperature. The avoidance of fatigue of the heart, the power to march, and the efficiency depend on prevention of heat stagnation.

A series of experiments carried out by one of us (L. H.) and Mr. R. H. Davis on the Fleuss rescue apparatus (for use in mines) show the danger which arises from heat stagnation in fighting fires in mines. The wearer of this apparatus breathes through a mouthpiece, fitted with inlet and outlet valves, in and out of a vulcanized rubber bag. The bag contains sticks of caustic soda, and a continuous supply of oxygen is maintained within it by means of oxygen cylinders (worn on the back) and a reducing valve. The CO_2 in the inhaled air is kept down under 0.5 per cent.

[1] War Office Committee on Physiological Effects of Food, Training, and Clothing on the Soldier, 4th report, 1908.

In using the apparatus to put out fires in the mine, the men may be exposed to high temperatures of the air and to radiant heat from the fire. The caustic soda, too, owing to absorption of CO_2 and moisture, becomes hot and this contributes greatly to the high temperature of the inspired air. The high temperature of the inspired air dries up the throat and contributes to heat stagnation and fatigue.

The following experiments were conducted on workmen wearing the Fleuss apparatus at Messrs. Siebe, Gorman & Co.'s works, in a chamber about 8 ft. long, 8 ft. high, and 5 ft. wide. In this chamber were placed two coke fire pails and the walls were splashed with boiling water kept on the top of the stove. The men wore the dress weighing about 34 lbs. and breathed oxygen. The temperature of the inspired air becomes uncomfortably hot, owing to the heat produced in the breathing bag from the caustic soda combining with CO_2 and water vapor. In order to reduce this a cooler was tried consisting of a thick felt bag filled with carbonic acid snow and placed so as to surround the inspiratory tube. Care had to be taken to prevent the inspiratory valve from freezing. The effect of this cooler in keeping down the pulse rate was excellent and much better than that of other evaporation coolers which were tried, filled with methylated spirit and water. The cool inspired air added very greatly to the comfort and endurance of the men. By acting directly on the blood going to the heart, it checks any great acceleration or failure of the heart and so prevents heat-stroke.

Chamber warmed by two coke fires with pail of water boiling on one fire.

Time	*A.* "Silence and Fun"* Wearing Fleuss dress, with carbonic acid snow cooler		*B.* "Jaw me Dead"* Wearing Fleuss dress, with methylated spirit and water cooler		Temperature of chamber	
	Pulse rate	Temp. of inspired air (wet bulb)	Pulse rate	Temp. of inspired air (wet bulb)	Dry bulb	Wet bulb
P. M.		*Degrees F.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
3.40	94		100		102	80
4.20	114	51	132	70	119	93
4.55	116	48	142	84	108	84
5.24	124	60	152	97.5	113	92
				100.4		
5.40	170	62.6	152	103.1	106	91

* Their nick-names.

A.—Lean and medium-sized but clothed.
B.—A fat, strong man stripped to the waist.

The men did some work shifting bricks to and fro and piling them up, but the work was not of a severe character.

Time	"Silence and Fun" CO_2 snow cooler		"Jaw me Dead" Methylated spirit cooler		Temperature of chamber	
	Pulse rate	Temp. of inspired air (wet bulb)	Pulse rate	Temp. of inspired air (wet bulb)	Dry bulb	Wet bulb
P. M.		*Degrees F.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
3.03	108		108		112	90.5
3.30	108	39	108	66	115	95
Bricks moved to and fro and stacked.						
4.00	138	52				
4.20	116		152	79	110	95.5
4.30	End of experiment		140			

This and the former experiment show the advantage given by the CO_2 snow cooler as seen in the pulse rate.

Time	"Silence and Fun" Fleuss dress, with CO_2 snow cooler			
	Pulse rate	Temp. of inspired air (wet bulb)	Temperature of chamber	
			Dry bulb	Wet bulb
P. M.		*Degrees F.*	*Degrees F.*	*Degrees F.*
3.45			100	
4.05			110	89
4.11	140 (Has just moved pile of bricks twice)	60		
4.22	120 (Resting)	56	108	88
4.33	134 (Has moved bricks twice)	67	115	91
5.00	(Moved bricks six times)		110	88
5.18	132	77	110	87
5.25	124		111	89
5.48	152	99	111	89

At the end of the time the snow was nearly all evaporated.

Time	"Jaw me Dead" CO_2 snow cooler		"Silence and Fun" Long tube cooler covered with wet rag		"O. K." Methylated spirit and water cooler		Temperature of chamber	
	Pulse rate	Temperature of inspired air (wet bulb)	Pulse rate	Temperature of inspired air (wet bulb)	Pulse rate	Temperature of inspired air (wet bulb)	Dry bulb	Wet bulb
P. M.		*Degrees F.*		*Degrees F.*		*Degrees F.*	*Degrees F.*	*Degrees F.*
2.40							102	83
3.15 } 3.20 }	120		134		112		120	92
3.45 } 3.50 }	128	68	148	79	140	86	119	92
4.05 } 4.10 }	132	74	156	87	144	95	120	98
			(Came out feeling sick and faint)					
Door opened a bit to cool off chamber a little.								
4.30 } 4.35 }	136	80.6			148	95	119	97

The long tube probably increased the resistance to the breathing in the case of "S. & F." "O. K." was slender and much younger than "J. me D." The bricks were moved to and fro but no severe work was done.

Time	"H" Fleuss dress, with CO_2 snow cooler			
	Pulse rate	Temp. of inspired air (wet bulb)	Temperature of chamber	
			Dry bulb	Wet bulb
P. M.		*Degrees F.*	*Degrees F.*	*Degrees F.*
3.45	92	32	100	82
4.15	99	47	97	86
4.45		52		
"O. K." put on the same dress and worked fairly hard moving bricks all the time.				
4.50	90		108	88
5.20	124	62.5	120	92
5.45	130	90.5	120	95

The snow was mostly evaporated at the end of the time.

The following experiment kindly communicated to us was carried out by Dr. Green at Howe Bridge Rescue Station in a gallery 15 ft. long, 8 ft. wide, and 7 ft. high, heated by a stove, with walls and floor splashed with boiling water. The temperatures were taken at either end of the gallery.

Two men, "F" and "B," moved bricks to and fro continuously and stacked them. They wore the Fleuss dress, and the canvas covers of the breathing bags were wet with water, and now and again a full stream of oxygen was turned on in order to wash out the breathing bag and cool the soda.

Time	"F"			"B"			Temperature of chamber	
	Pulse rate	Temperature of inspired air (wet bulb)	Body temperature	Pulse rate	Temperature of inspired air (wet bulb)	Body temperature	Dry bulb	Wet bulb
P. M.		*Degrees F.*	*Deg. F.*		*Degrees F.*	*Degrees F.*	*Degrees F.*	*Degrees F.*
2.00	62		Normal	120		Normal	85 99	80 88.5
2.30	108	67	Normal	136	64	Normal	91 101	83 88
3.00	132	68	100	136	67	100	95 105	89 94
3.30	160	79	102	172	75	102	97 100	93 100
	Came out faint, sick, and done							
4.00				200	82	102	100 119	93 103

The oxygen allowance was reduced to 0.75 liter per minute and found to be ample at these temperatures. The men were stripped to the waist.

"B" worked up to the end, and his pulse temperature soon returned to normal after he came out.

In the modern battle-ship men are confined very largely to places artificially lighted, and ventilated by air driven in by fans through ventilating shafts. The heat and moisture derived from the bodies of the men, from the engines, from cooking ranges, etc., lead to a high degree of relative moisture, and therefore all parts of the iron-work inside are coated with granulated cork to hold the condensed moisture and prevent dripping.

The air smells with the manifold odors of oil, cooking, human bodies, etc., and the fresh air driven in by fans through the metal conduits takes up the smell of these and is spoken of by the officers with disparagement as "tinned" or "potted" air. This air is heated when required by being made to pass over radiators. Many of the officers' cabins and offices (for example, for clerks, type-writers, etc.) in the center of a battle-ship have no port-holes and are lighted and ventilated only by artificial means. The steel nature of the structure prevents the diffusion of air which takes place so freely through the brick walls of a house. The men in their sleeping quarters are very closely confined, and as the openings of the air conduits are placed in the roof between the hammocks, the men next to such openings receive a cold draught and are likely to shut the openings. To sleep in a warm moist " fugg " would not matter if the men were actively engaged for many hours of the day on deck and were there exposed to the open air and the rigors of sea and weather. In the modern war-ship most of the crew work for many hours under deck, and many of the men, unless disciplined to do so, may scarcely come on deck for weeks or even months. Considering the conditions which obtain, it seems to be of the utmost importance that all the men in a battle-ship should be inspected at short intervals by the medical officers, so that cases of tuberculosis may be weeded out in their incipiency. The men of every rating should be compelled to deck drill for some part of every day.

In a destroyer inspected by one of us 12 men occupied quarters containing about 1,700 cubic feet of air. There was an open stove with iron pipe for a chimney, from which fumes of combustion must leak when in use, and a fan which would not work. When the men are shut down, the moisture is such that boots, etc., become mouldy and the water drips off the walls and ceilings. The cooling effect of the sea-water washing over the steel shell of the boat is very beneficial in keeping down the temperature in these confined and ill-ventilated quarters.

On the manœuvring platform in the engine room the wet-bulb temperature reaches a very high degree, owing to the slight escape of steam round the turbines.

Captain Domvile was kind enough to take the wet- and dry-bulb temperatures for us while in command of the destroyer *Lyra*.

The wet bulb was found to be never below 80° F., and sometimes reached 95° and even 98° F.

It is impossible for men to work at these temperatures without straining the heat-regulating mechanism of the body and diminishing the working capacity of the men. If such wet-bulb temperatures are unavoidable, means should be provided, such as fans, which would alleviate the discomfort and fatigue caused thereby. A cylinder of compressed air fitted with a nozzle might be arranged and used occasionally to douche the body with cool air. We have tried this plan and found it very effectual. We recommend the compressed-air bath as a substitute for a bracing cold wind.

Temperature, Fahrenheit, wet and dry bulb, on H. M. S. *Lyra,* September and October, 1911.

Date	Where taken	Time									
		4 A. M.		8 A. M.		Noon		4 P. M.		8 P. M.	
		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
20-9-11	Engine room	...	...	...	...	...	...	87	98	85	100
	Deck	...	...	...	...	...	...	58	60	55	58
	Wind							NW		NW by N	
21-9-11	Engine room	84	96	85	97	82	95	78	96	...	...
	Deck	59	60	55	56	55	60	60	62	...	...
	Wind	SW		W by N		W by N		SW			
22-9-11	Engine room	...	...	...	...	...	...	90	110	...	...
	Deck	...	...	...	...	...	...	61	67	...	...
	Wind							NE			
25-9-11	Engine room	...	...	95	108	90	105	81	97	80	105
	Deck	...	...	57	61	62	67	62	65	60	62
	Wind			NW		S		S		Nil	
26-9-11	Engine room	...	...	80	95	85	100	85	108	...	...
	Deck	...	...	60	63	63	66	64	66	60	61
	Wind			SSW		NNW		SSE		SW	
27-9-11	Engine room	75	95	85	102	...	...	...	...	...	...
	Deck	57	58	60	63	...	...	...	...	...	...
	Wind	SW		WSW							
28-9-11	Engine room	...	...	86	105	85	105	80	100	98	105
	Deck	...	...	56	59	56	58	56	62	58	60
	Wind			NW		NNW		NW		NW	
29-9-11	Engine room	...	...	80	95	84	102	95	115	...	...
	Deck	...	...	53	55	51	59	55	61	...	...
	Wind			NW		NW		NW			
3-10-11	Engine room	...	...	85	100	86	102	85	105	...	...
	Deck	...	...	50	50	50	50	56	56	...	...
	Wind			Nil		Nil		Nil			
4-10-11	Engine room	...	...	84	100	85	100	80	96	...	...
	Deck	...	...	46	48	56	58	53	53	...	...
	Wind			N		NE		ENE			

CONCLUSIONS

The conclusions to be drawn from our experiments and those of others are, we trust, definite and well proven. They are these:

No symptoms of discomfort, fatigue, or illness result, so long as the temperature and moisture are kept low, from air rendered, in the chemical sense, highly impure by the presence of human beings.

Such air can be borne for hours without any evidence of bodily or mental depression. At 80° F. with moderate humidity, or 70° to 75° F. with high humidity, almost all persons begin to show depression, headache, dizziness, and a tendency to nausea. School children and cases of emphysema react least and those with heart troubles most. The subjective symptoms appear when the surface temperature reaches a certain height, for example, 93° to 95° F. on the forehead (89.5° to 91.5° F. in cases of heart disease), and the relative moisture of the layer of air in contact with the skin increases 20 to 30 per cent (Ercklentz). Under these conditions the normal loss of body heat is interfered with and symptoms appear which are similar in every way to those produced in stuffy, crowded rooms.

When those within the chamber are allowed to breathe from outside fresh air raised to the same temperature and degree of humidity, they experience no relief. When those outside the chamber breathe the impure air from within they experience no discomfort. The suffering of those inside the chamber can be immediately relieved by rapidly moving, cooling, or drying the air—mechanical means which enable the body to throw off its heat. On suddenly raising the percentage of CO_2 within the chamber the symptoms are not made worse, while on cooling the air relief is immediately felt.

Heat stagnation is therefore the one and only cause of the discomfort, and all the symptoms arising in the so-called vitiated atmosphere of crowded rooms are dependent on heat stagnation. The moisture, stillness, and warmth of the atmosphere are responsible for all the effects, and all the efforts of the heating and ventilating engineer should therefore be directed toward cooling the air in crowded places and cooling the bodies of the people by setting the air in motion by means of fans. The strain on the heat-regulating mechanism tells on the heart. The pulse is accelerated, the blood is sent in increased volume to the skin and circulates there in far greater volume, while we must assume that less goes through the viscera and brain. As the surface temperature rises, the cutaneous vessels dilate, the veins become filled, the arteries may become small in volume and the blood-pressure low, and the heart is fatigued by the extra work thrown upon it. The influence of the heat stagnation is shown by the great acceleration of the pulse when work is done and the slower rate at which the pulse returns to its former rate on resting.

The increased percentage of carbonic acid and the diminution of oxygen which have been found to exist in badly ventilated churches, schools, theaters, and barracks, are such that they can have no effect upon the incidence of respiratory disease and the higher death rate which statistical evidence has shown to exist among persons living in crowded and unventilated rooms. The conditions of temperature, moisture, and windless atmosphere in such places primarily diminish the heat loss, and secondarily the activity of the occupants, as also the total volume of air breathed, oxygen taken in, and food eaten. The whole metabolism of the body is thus run at a lower plane, and the nervous system and tone of the body are unstimulated by the monotonous, warm, and motionless air. At the same time, the number of pathogenic organisms is increased in such localities, and the two conditions run together,—diminished immunity and increased mass influence of infecting bacteria.

The volume of blood passing through, and of water vapor evaporated from, the respiratory mucous membrane must have a great influence on the mechanisms which protect this tract from bacterial infection. Mr. F. F. Muecke[1] and one of us (L. H.) have found that convected heat, from steam coils, closed stoves, etc., swells the mucous membrane of the nose and air sinuses, and obstructs the air-way. On the other hand, radiant heat, from an open fire or gas fire, causes the skin to sweat and does not affect the nasal mucous membrane. The swelling of the nose favors massive local infection.

We conclude that rooms should be heated by radiant heat and ventilated with cool outside air, and the conditions of a spring day—sunlight and cool breeze—approximated to as nearly as possible. The heated air of rooms is the factor which favors infection and the spread of coryza, influenza, phthisis, etc.

In the warm, moist atmosphere of a crowded place, the infection from spray, sneezed, coughed, or spoken out, is great. On passing from such an atmosphere out into the cold, moist external air the respiratory mucous membrane is suddenly chilled, the blood-vessels are constricted, and the defensive mechanism of cilia and leucocytes is checked. Hence the prevalence of colds in the winter. In the summer the infection is far less, and the sudden transition from a warm to a cold atmosphere does not occur. We believe that infection is largely determined, (1) by the mass influence of the infecting agent; (2) by the swelling of the mucous membrane of the nose, and (3) by the sudden transition from warm to cold surroundings, which checks the immunizing mechanisms. Colds are not caught by expos-

[1] Lancet, May 10, 1913, p. 1291.

ure to cold *per se,* as is shown by the experience of arctic explorers, sailors, shipwrecked passengers, etc.

We have very great inherent powers of withstanding exposure to cold. The bodily mechanisms become trained and set to maintain the body heat by habitual exposure to open-air life. The risk lies in overcrowding, so that infection becomes massive, and in overheating our dwellings and overclothing our bodies, so that the mechanisms engaged in resisting cold become enfeebled and no longer able to meet the sudden transition from the warm atmosphere of our rooms to the chill outside air of winter. The dark and gloomy days of winter confine us within doors and, by reducing our activity and exposure to open air, help to depress the metabolism; the influence of smoke and fog, diet, gloom of house and streets, cavernous places of business, and dark dwellings, intensifies the depression. The immunity to a cold after an infection lasts but a short time. When, after the summer holidays, children return to heated schoolrooms and to damp, chill autumn days, infection runs around.

The unpleasant smell of crowded rooms is sensed only by newcomers, and by them for only a short time after entering such rooms. Most men, for example, sailors, are quite indifferent to this smell and regard it no more than they regard tobacco smoke. Offensive trade smells are unnoticed by the workers in such trades. The smell nauseates sensitive educated people largely because they have been taught to believe that the smell indicates the existence of an organic chemical poison. A century or so ago, sick people went to breathe the air in crowded school-rooms on the fanciful supposition that the breath of the young and vigorous would heal their sickness. Possessed of such a fancy, the consumptive felt no nausea or loathing of the smell but breathed in the close air with faith and hope. The evidence of other workers and the experiments detailed in this paper make it certain that there is no chemical volatile poison in the exhaled air.

The history of hospital gangrene and its abolition by the aseptic methods of Lister, as likewise the history of insect-borne disease, show the great importance of cleanliness in crowded and much occupied rooms. The essentials required of any good system of ventilation are, then: (1) movement, coolness, proper degree of relative moisture of the air, and (2) reduction of the mass influence of pathogenic bacteria. The chemical purity of the air is of very minor importance and will be adequately insured by attendance to the essentials.

The reduction of spray (saliva) infection by ventilation is impossible in crowded places. It therefore behooves us to maintain our immunity at a high level, and, if possible, to diminish the spray output of those infected with colds by teaching them to cough, sneeze, and talk with a handkerchief held in front of the mouth, or to stay at home until the acute stage is past.

In all these matters, nurture is of the greatest importance, as well as nature.

A man is born with physical and mental capacities small or great, with inherited bodily characteristics, with more or less immunity to certain diseases, with a tendency to longevity of life or the opposite; but his comfort and happiness in life, the small or full development of his physical and mental capacities, his immunity and his longevity of life, are undoubtedly determined to a vast extent by nurture.

By nurture (we use the world in its widest sense, to include all the defensive methods of sanitary science), plague, yellow fever, malaria, sleeping sickness, cholera, hospital gangrene, and like diseases can be prevented by eliminating the infecting cause; small-pox and typhoid by this means, and also by vaccination; and most of the other ills which flesh is supposed to be heir to can be kept from troubling man by approximating to the rules of life which a wild animal has to follow in the matter of a simple and often spare diet, hard exercise, and exposure to the open air. "For whosoever will save his life shall lose it."

There is nothing more fallacious than the supposition commonly held that overfeeding and overcoddling indoors promotes health. The two together derange the natural functions of the body.

The body of a new-born babe is a glorious and perfect machine, the heritage of millions of years of evolution.

> "Not in entire forgetfulness,
> And not in utter nakedness,
> But trailing clouds of glory do we come."

A race-horse or a dog kept in perfect physical health and training is as clean, sweet, and beautiful as a wild animal. A pampered, ill-fed, underexercised dog becomes fat and gross, vomits on the mat, and passes offensive motions.

> "Shades of the prison house begin to close
> Upon the growing boy."

The ill-conditioned body, anæmic complexion, and undersized muscles, or the fat and gross habit, the decay of the teeth, the more offensive qualities of human evacuation, the nervous incapacity, irritability and unhappiness, are almost entirely the result of "nurture"—not nature.

In school, children may be disciplined to vigorous health. After leaving school they are set adrift to all the temptations of the world,

> "And custom lies upon them with a weight
> Heavy as frost and deep almost as life."

Monotonous work in confined places, amusement in music halls and shows in place of open air and manly exercise, injudicious diet, alcohol, and tobacco—everything which the trainer of an athlete would repel—these we should avoid.

We do not propose that all men should be athletes, but we do see that perfect physical health gives happiness and efficiency of life, and that our present methods of organizing the life of the masses in our industrial communities are such as to seriously diminish physical health and happiness and shorten life.[1]

Coal mines and chemical factories have a low rate probably because of the necessity for good ventilation. The figures show that the rate for hotel servants is ten times that of engine drivers. Massive infection, intemperance, warm, confined atmospheres, and conditions of employment are the factors. Such figures cannot be explained by differences of stock and inborn powers of resistance.

Hendhède says that out of 10,000 deaths in later life, 2,700 die in Copenhagen between the ages of 40 and 60 who would die in the country between 60 and 90.

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[1] The *comparative* mortality figures for phthisis in Britain are:

OPEN AIR WORKERS.

Railway Engine Drivers and Stokers	63	Farm Laborers	82
Gamekeepers	73	Gardeners and Nurserymen	83
Agriculturists	79	Fishermen	96

TOWN AND FACTORY WORKERS.

Chemical Manufacturers	96	Messengers and Porters (otherwise than Railway)	368
Printers	290	Costermongers and Hawkers	516
Furriers and Skinners	314	Inn and Hotel Servants	533
Brush Makers	314	Do. Do. in London	667
Tool, Scissors, etc., Makers	353		

—Suppl. Vol. from Registrar General's 65th Annual Report, Publ. 1908.