Respiratory Apparatus of Theodore Schwann

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THEODORE SCHWANN (1810–1882), celebrated anatomist and physiologist of the nineteenth century and famous for all time for his brilliant formulation of the cell theory, namely, that the basic element common to each form of life is the cell, also designed and constructed several closed circuit respiratory apparatus. Schwann's work in developing these appliances was unrelated to his previous researches in biology. The reasons why he applied his creative ability to the practical problem of building respiratory equipment and the details of construction of the instruments may be of interest to anesthesiologists and respiratory physiologists.

Schwann was assistant to the Berlin physiologist Johannes Mueller when, in 1838, he developed the cell theory. In March 1839 he went to the University of Louvain as Professor of Anatomy. Nine years later he transferred to the University of Liège, first as Professor of Anatomy, then Professor of Physiology. The period of his sojourn at Liège coincided with the emergence of this ancient city into an industrial complex. Located in the industrial world of Liège, Schwann, the physiologist, commenced a new career, that of inventor.

On March 6, 1852, in the coal mine of Long-Terne-Ferrand at Elouges, a fire damp explosion killed sixty miners. On April 17, the Minister of Public Works asked the Royal Academy of Belgium to create a prize award for a protective process enabling a person to survive in an underground mine invaded by noxious gases. On June 5, 1852, the Academy declared the contest open and fixed the termination as December 31, 1853. Theodore Schwann, who was present at the meeting, conceived forthwith the idea of a protective apparatus. He did not take part in the contest, but deposited instead a sealed note with his recommendation on January 7, 1854.[1] The statements of many writers attest that Schwann's note contained a description of the apparatus which he was to publish in 1877 and 1880. Schwann's correspondence and publications would tend to substantiate this contention. However, Professor Marcel Florkin of Liège and Professor Rembert Watermann of Neuss both have had the opportunity in recent years to examine in detail Schwann's laboratory notes and these reveal a different story as we shall presently see.[2, 3, 4]

Development of the Apparatus

The laboratory notebooks show that Schwann began on November 7, 1853, to experiment with the use of peroxide of barium for the absorption of carbon dioxide and simultaneous liberation of oxygen. The heading of the notes was, "Experiments on the means of living underwater or in an irrespirable atmosphere." From November 7 to December 27, 1853, he conducted numerous experiments on peroxide of barium mixed with peroxide of manganese to absorb carbon dioxide and liberate oxygen. A trial made with a respiratory apparatus constructed according to this principle did not, however, produce results according to expectations; the peroxide of barium furnished oxygen in insufficient quantities. On August 5, 1855, he returned to the problem and wrote in his journal of experiments on a generator-absorber in which peroxide of potassium was mixed with that of magnesium. In April 1856, he conceived the idea of using compressed oxygen and designed a flow regulator for the compressed gas. Concurrent with the trials on the peroxide of barium, from 1854 to 1856 Schwann pursued a series of experiments on the absorption of gases by porous bodies, especially by charcoal, and showed that the presence of the latter at a particular

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pressure permitted the accumulation of a large quantity of gas in a reservoir.

The first regulator appeared in 1856 in the form of a sketch in his laboratory notebook: The model consisted for the most part of a simple needle valve. In May of the same year he began to construct reservoirs for compressed air. They were at first semicylindrical and the air within was compressed to four atmospheres. At the same time he experimented with charcoal as an absorbent.

In June 1856, Schwann proceeded with experiments on the absorption of carbon dioxide with lime. He used hydrated lime placed in sacks of muslin and separated by sheets of cardboard in order to produce a circuitous pattern of circulation. In the same month he conducted a complete experiment with an absorption canister of hydrated lime, a semicylindrical reservoir of compressed air, and a primitive model of regulator. Utilizing a reservoir 31 cm. in height and 28 cm. in diameter, in which the air was compressed to 4½ atmospheres, and with an absorption canister containing 600 g. of hydrated lime, Schwann was able to respire with this apparatus for 1¾ hours.

A new design was evolved in 1858. This carried two cylinders of compressed oxygen separated by an absorption canister. In 1867 the study was resumed and after several trials he constructed a new absorption canister for carbon dioxide composed of eight superimposed chambers joined to form a cylinder. The next step was the completed apparatus shown at the exposition of Hygiene and Life Saving in 1876. Before attending this meeting Schwann wrote to his friend Jean-Servis Stas: [5]

"I wish to ask you for the advice of a friend. You know that there will be at Brussels an exposition for life saving apparatus and hygiene. The Academy had placed before it about twenty years ago the issue of competition to invent an apparatus permitting one to live and move about with visibility in an irrespirable atmosphere. Being present at the meeting I conceived an idea for such an apparatus and I carried it out right away; but not wishing to enter the competition, I deposited instead a sealed note at the Academy at the termination date with a description of the apparatus. The sealed note still remains deposited there.

Moreover, I have perfected the apparatus and it has cost me considerable money out of my pocket. The idea is to always breathe the same air by means of continuously absorbing the carbon dioxide formed and replacing the oxygen consumed, anew, from oxygen stored in two cylinders where the gas is compressed to five atmospheres. I can live in this manner two or three hours under water without communicating with the atmosphere. . . . Do you advise me to send the apparatus to the exposition at Brussels?"

The Apparatus of 1876–77

Schwann demonstrated his apparatus at Brussels at the Exposition d'Hygiène et de Sauvetage in 1876. Alfred Habets, an editor and a mining engineer at the School of Mines, University of Liège, supplied an illustrated description in the widely circulated *Revue Universelle des Mines* for January–February 1877.[6] Schwann himself published a detailed description in January of the same year in the *Bulletin du Musèe de l'Industrie de Belgique*.[7] The illustrations are not the same in these two articles. The text likewise varies and for what follows, I have abstracted descriptive sections and illustrations from the original article by Schwann:

"We absorb about 25 liters of oxygen per hour, more or less. Two cylinders each of 7 liters capacity are sufficient for our needs if the gas is compressed to 4 or 5 atmospheres. After some experiments that I made, it is possible to put more gas in the cylinders or to take it out again without changing the pressure, if one fills the 2 cylinders with porous charcoal, a substance which has the property of condensing the oxygen volume. But the use of compressed oxygen supposes a means of rendering the flow of gases uniform, despite the continual diminution of pressure."

The portable apparatus (Pl. 1, figs. 1 and 2) consisted of two cylinders, D and F, filled with compressed oxygen at 4–5 atmospheres. They were connected to each other at the lower ends by a short transverse tube, T. At the center of the latter was to be found the principle stopcock, m, to the inferior surface of which the regulator, E, was attached. The stopcock was constructed in such a manner that both cylinders or each individually could be connected to the regulator from which the gas flowed, or by which the entire system could be closed.

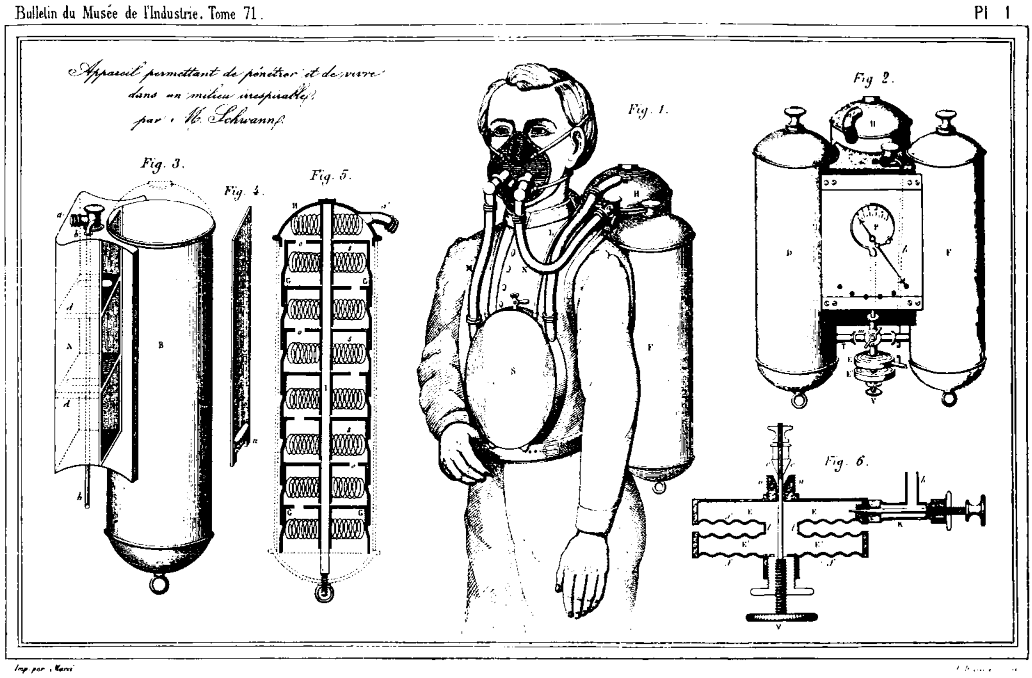

PLATE 1 (figs. 1–6). Apparatus of 1876–77 (from *Bulletin du Musée de l'Industrie de Belgique* vol. 71, 1877).

A manometer, P, was attached to the center of the anterior surface of the absorption canister and communicated through the principal stopcock, m, with the cylinder of oxygen. It was possible for the operator to reach the pointer and knobs of the manometer scale and thus to determine the amount of gas flowing even in darkness.

The regulator (Pl. 1, fig. 6) consisted of two flat copper chambers, EE′, each having the form of a cylinder 6 cm. in diameter and 1 cm. in height. The walls of these cylinders were undulating and elastic in order to yield to the internal pressure. A short tube placed in the axis of the cylinder connected the chambers; another tube, vv, soldered to the upper cylinder head, was screwed into the four way stopcock, m, from which the compressed gases flowed. Attached to the superior cylinder of the regulator EE′ there was a small control valve R whose opening could be accurately regulated. When the control valve was closed compressed gases entered the two chambers and their walls bulged, thus drawing the conical valve pin, cc, suspended on the adjusting rod, V, into its seating, vv. The passage consequently closed and the flow of oxygen ceased. If the small control valve, R, was opened the gas flowed from the chambers, pressure diminished, the walls flattened, the valve, c, opened and permitted the compressed gas to enter anew. It was necessary carefully to regulate in advance the opening of the small control valve in order to provide a flow rate of approximately half a liter of oxygen per minute. The gas was conducted via a short tube, b, into the reservoir of lime, A (Pl. 1, fig. 3) and mixed with expired air.

The apparatus serving to absorb carbon dioxide was placed between the two oxygen cylinders. The carbon dioxide absorber contained large fragments of calcium hydroxide intermixed with sodium hydroxide. It consisted of canister, A, situated between the two lateral oxygen cylinders and a third medium cylinder, B. The partition wall C (Pl. 1, fig. 4) separated canister A from cylinder B. Gas flowed through the slit, n, in the lower part of the partition, C, from the canister A into the cylinder B. The expiratory tube, a, entered the upper part of the canister from which the air then traversed the three layers of lime from top to bottom, in order to pass under the partition into the cavity of the cylinder. This cylinder (Pl. 1, fig. 5) contained eight superimposed cylindrical segments filled with calcium and sodium hydroxide. The separating walls of each segment each had an opening placed eccentrically so that the gas followed a longer course through the absorption material. A circular tube of copper spiral wire, s, assured the passage of air. After passage through the cylinder B, the gas flowed through tube, a′, fully regenerated, that is free of carbon dioxide. The gas finally arrived at the inspiratory sac S on the abdomen, via the elastic tube, L, and from here through the elastic tube M to the mask. Expired air was finally separated by a valvular arrangement in the tube, M, and flowed through the elastic tube, N, back to the absorption canister, A, where it mixed with fresh oxygen. The circuit was now completed. After a two hour experiment it was necessaroy to renew the lime in the middle canister which absorbed the principle share of the carbon dioxide. This precaution taken, it was possible to use the inner cylinder for a long period without it being opened.

What was truly new in Schwann's apparatus and why is it significant in the history of breathing apparatus? One of the greatest merits is that both components, the carbon dioxide absorption and compressed oxygen systems, were combined. This was not a simple concept. It presented obstacles well known to anesthesiologists and respiratory experts today, not so well known at that time. Since the force and ampliutde of breathing are dependent on several factors such as work, and emotional state, oxygen in a closed system must flow uniformly from the pressure system into the circuit. If the oxygen supply is not adapted to the prevailing situation, an increased supply would result in increased pressure and, conversely, a decreased supply in a decreasing pressure. In addition carbon dioxide excretion varies. Finally, the oxygen pressure naturally declines with time through constant escape from the pressure cylinder. All these variables were regulated by Schwann's reducing valve. In spite of the above, it provided a constant pressure in the system equal to that of the atmosphere.

The development of this apparatus required twenty-three year, from 1853 to 1876. As a result of Schwann's labors came a solution to an objective long sought, namely, that of providing a portable respiratory apparatus in a closed circuit permitting autonomous existence for several hours either underwater or in an irrespirable atmosphere. Schwann's completed apparatus thus was a giant step forward in the history of the development of respiratory equipment.

Apparatus of 1878–80

After exhibiting the first closed circuit respiratory apparatus at the Brussels Exposition, Schwann turned in 1877 to the problem of reducing the weight of the apparatus which he had found much too heavy. In 1878, at the World Exposition in Paris, Schwann demonstrated two new devices described in a brochure comprising twelve pages.[8] The text of this brochure was reprinted by the *Revue Universelle des Mines* in 1880, from which the following illustrations and description are taken.[9]

The first apparatus (Pl. 24, fig. 6) resembles that of 1877 in many of the components such as the cylinders, pressure reducing valve, D, manometer B′, tubular system (a, b, c) and chest sac, A. But the parts were assembled somewhat differently. The entire dorsal section was carried horizontally and the regulator was placed on the right side so that it was easier for the wearer to reach the controls. The diameter of the flat regulator chambers was 7 cm. but they were still made of thin corrugated copper. There is a model of this apparatus in the Museum of the Laboratory of Physiology at the University of Liège. Oxygen was led from cylinders C and C′, over the copper tube, g, to the main stopcock K (Pl. 24, figs. 1 and 2) and from here over the tube, d′, to the gas pressure reducing valve, D. After passage through the pressure reducing valve, the oxygen passed through outlet, l, into the next tube, d, then into the large elastic hose, b, from where it mixed with the expired air in the first carbon dioxide absorption canister B, and then arrived at the second canister B′. The regenerated air now flowed through the large elastic hose, c, into the chest sac, A, and through hose, a, to the mouthpiece. The small tube, e, called by Schwann *le biberon*

APPAREILS AEROGENES DE M SCHWANN

Pl. 24.

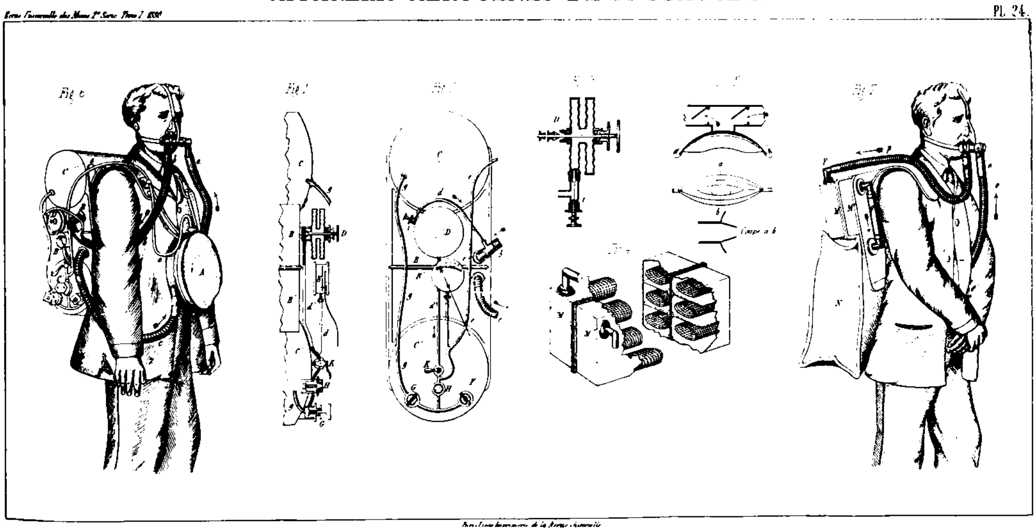

PLATE 24 (figs. 1–7). Apparatus I and II of 1878–80. The term "Aerogenes" was not used by Schwann (from *Revue Universelle des Mines* vol. 7 1880).

(suck tube) could supply oxygen directly for inspiration in case of acute need, without having first to pass through the absorption canister. The nose was clamped by a clip attached to the head strap. It was necessary for the apparatus to be completely closed so that poisonous gas would not contaminate the oxygen. The mouthpiece (Pl. 24, fig. 5) contained two unidirectional flap valves to separate inspired and expired air. In the apparatus of 1877 the face mask did not provide an airtight fit and Schwann had abandoned this design.

In the German Museum at Munich there is an example of the third fully portable, closed circuit breathing apparatus which Schwann exhibited at the World Exposition at Paris in 1878. The oxygen was carried on the back in a 30 liter rubber sac (Pl. 24, fig. 7). This design was sufficient for one hour of breathing. Expired air was led into a filter case, MM′ (Pl. 24, fig. 4) whose contents consisted of calcium hydroxide impregnated with sodium hydroxide. This filter absorbed carbon dioxide. Oxygen was again led into the rubber breathing sac: the oxygen supply of this light weight apparatus lasted for one hour. If it were necessary to remain for a longer time in an irrespirable environment, another rubber bag was provided, or oxygen was added from a cylinder. The contents of the carbon dioxide absorption canisters were sufficient for four hours of usage allowing also for the supply of three additional breathing bags. This apparatus was not only meant, as were the two others, as an oxygen apparatus for miners but was also designed for the medical needs of patients.

Schwann said, "One can attach to this apparatus a small rubber bag which is compressed and relaxed alternatively by the hand and which is furnished with appropraite entrance and exit valves. Oxygen is fed into the bag. This arrangement enables one to furnish oxygen to an asphyxiated patient."

Misconceptions Concerning the Date of Invention

It is necessary here to retrace our story and to inquire why it is that many science historians have stated erroneously that Schwann's apparatus dates from 1853 rather than 1876 as the recorded facts so clearly indicate. It is because Schwann himself, for reasons unknown, stated this in correspondence and printed it in his first publication. Thus, in writing to his friend Stas in 1876, he says, "Being present at the meeting, I conceived an idea for such an apparatus and I carried it out right away. . . . I deposited a sealed note." Subsequently, in the publication of 1876, he says, "The invention dates, therefore, from 1853." *

A. Habets also remarks "The apparatus of Schwann was constructed in 1853." [6] Habets adds that Schwann's modesty and the course of his studies dissuaded him from making it known at the time. However, we have seen from a detailed examination of the laboratory notes that the apparatus of 1853/54 was based upon the liberation of oxygen and the absorption of carbon dioxide by means of the peroxide of barium, and that the apparatus was not successful. The laboratory notes instead reveal a long struggle of design and redesign lasting twenty-three years. What of the sealed note? Fortunately, a copy of the note was obtained by Sir Robert H. Davis before it was lost in World War I: [10] he has published the contents which reveal that the description of the design was of an apparatus in which barium peroxide was employed. There were no illustrations or diagrams. In a letter accompanying the sealed packet which Davis reproduced,[11] Schwann says:

> "For the past two months I have been engaged from morning till night on preliminary tests and there is no time left to draw them up as I would like to. I only received my apparatus on 30 December, and the few remaining hours must be employed by me in ascertaining that the idea can be carried out."

Davis reproduced the following short paragraph from the original document.

> "Unfortunately I only received my apparatus on the 30th of December and it worked sufficiently to show me that it functions, but having been built for muriatic acid, I can only use it temporarily for acetic acid. I have sufficiently assured myself that respiration is not troubled by the fumes of acetic acid nor by the baryta dust; however, it must be altered for acetic acid."

These statements concur with the laboratory notes which show that Schwann first worked with barium peroxide for a period of two months before writing the sealed note. The notes also reveal that he worked with acetic acid, muriatic, nitric and vitrolic acids to activate the peroxides. A trial made with an apparatus constructed according to this principle did not give satisfactory results at the time.

Thus, we can conclude that although Schwann conceived his idea for a respiratory apparatus in 1852 (not 1853 as he later stated), it required twenty-three years for construction of the completed product.

Schwann evidently was influenced in the design of his apparatus by the physiologists Regnault and Reiset who had, in 1849, used the method for measurement of metabolism in animals, for he says:

> "The two apparatus are based on the method introduced into science by Regnault and Reiset, a method which consists of always breathing the same air by absorbing carbonic acid and replacing the oxygen disappearing in respiration."

There are no references to previous workers other than these, in either of his articles.

The Influence of Schwann's Apparatus

It was on seeing the second apparatus at the Exposition Universelle de Paris in 1878 that the physiologist Leon Fredericq conceived the idea of the "oxygenographe" used to measure basal metabolism. In the model of that apparatus for measurements on man, the absorption canister of Schwann's apparatus is used for the absorption of carbon dioxide.[12] The portable pieces of apparatus for measuring metabolism developed by the famous respiratory expert, Francis Gano Benedict, at the Nutrition Laboratory in Boston were in turn derived from the oxygenograph.[13] Both the pharmacologist, Dennis Jackson and the anesthesiologist, Ralph Waters, in their early work on the use of the carbon dioxide absorption method in anesthesia referred directly to the work of Benedict on carbon dioxide absorption.

Dräger Werk at Lübeck, one of the world's largest factories producing apparatus for mine rescue protection, as well as diving and anesthetic equipment, grew from a small work shop which produced reducing valves for carbon dioxide used in dispensing beer on draught. As early as 1902, Dräger's first self-contained oxygen breathing apparatus for mine rescue work was placed on the market. Dräger, in his book on mine rescue breathing apparatus,

* Schwann's memory erred. The date of the meeting at which the competition for construction of the apparatus was announced was June 5, 1852.

included an illustration of Schwann's apparatus and refers directly to his publication of 1877.[14] Dräger says that Schwann's apparatus was a research model only and that he could find no evidence that it was ever manufactured. However, the Model II on exhibition at the German Museum in Munich bears the firm name "Mulkay Frères," Liège, Belgium, a firm engaged in making safety lamps for miners.[15]

The anesthetic apparatus designed in 1906 by Franz Kühn of Kassel, Germany, for absorption of carbon dioxide, was manufactured for him by Dräger Werk. Kühn says, "It is derived from the construction of the modern mine rescue apparatus. Consequently, two carbon dioxide absorption canisters serve for the removal of carbon dioxide from the expired air." [16] Thus it is apparent that in Germany as early as 1906, the details of Schwann's respiratory apparatus known to Dräger were incorporated into early anesthetic appliances employing the carbon dioxide absorption technique.

Summary and Conclusion

The history and development of a closed circuit respiratory apparatus made by Theodore Schwann are presented. It required twenty-four years for Schwann to complete the construction—from 1852 when he first conceived the idea—until 1876 when the first complete apparatus was exhibited and described in print. A summary of the construction details is presented.

Schwann's influence upon the subsequent development of devices for breathing in irrespirable atmospheres, metabolism testing and anesthetic practice is discussed. The history of apparatus permitting life in an irrespirable atmosphere for a practical time began with the closed circuit respiratory apparatus of Schwann demonstrated at the Exposition d'Hygiene et de Sauvetage at Brussels in 1876.

The Library of the Marquette University School of Medicine provided service and facilities.

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   The Exposition Internationale d'Hygiène et de Sauvetage was held from June 26, to Oct. 9, 1876 and attended by 278,000 people. A congress was held from 26 Sept. to 4 Oct. 1876 and attended by 1500 persons. Habets was a member of the general committee of the congress and secretary for the section on Sauvetage. On Oct. 2, 1876 he delivered a report to the section in which he briefly describes Schwann's apparatus. See pp. 106–128 of vol. II *Congrés International d'Hygiène, de Sauvetage et d'economie sociale,* 2 vol., Bruxelles 1876.
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MUSCLE BLOCK BY ETHER Diethyl either does not produce a depolarization type of muscle block in the frog. Like both general and local anesthetic agents, ether blocks muscle excitability by antagonism of sodium conductance. Ether not only blocks the production of action potentials when locally applied to excitable tissues but in low concentrations it can increase the excitability of such tissues to electrical stimuli applied either by extracellular or intracellular microelectrodes. Increasing the extracellular sodium concentration readily overcame the block of electrical excitability produced by 2 per cent ether. *(Inove, F., and Frank, G. B.: Action of Ether on Frog Skeletal Muscle, Canad. J. Physiol. 43: 751 (Sep.) 1965.)*