

RELIABILITY OF THE CLOSED CIRCUIT

DARGATZ MAGNA TEST TYPE 510

SPIROGRAPH

A Thesis

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In Partial Fulfillment  
of the Requirements for the Degree  
of Master of Science



by

© Joseph Jean-Claude Mondor

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# CHAPTER I

## THE PROBLEM

### GENERAL CONSIDERATIONS

Accurate determinations of oxygen consumption and minute ventilations are desirable for many physiological and clinical purposes. Needless to say, one must be fully aware of the characteristics of the types of apparatus he uses as well as of possible inherent sources of errors.

Several procedures have affirmed themselves for the measurement of oxygen consumption. Modern instruments in both the open and closed circuit categories have relegated the traditional but accurate Douglas bag and Micro-Scholander to the rank of reference method.

In fact, efforts to simplify procedures and save time, to improve the precision of results, to allow more elaborate experimental designs, have led to the production of a series of increasingly automated closed circuit systems. In these, the quantity of circulating air, the air temperature and humidity and the partial gas concentrations can be regulated and the ventilatory parameters continuously monitored.

### STATEMENT OF THE PROBLEM

The object of this study on a closed circuit system (spiograph Dargatz Magnatest type #510, figure 1.1) was to observe if there could

be detected, inherent to the functioning of the apparatus or associated with its operation, variables which could affect and/or misrepresent the true physiological behavior of the subjects performing in the range of physical working capacities of normal adults.

More specifically the study was conducted to find out what could be:

1. the nature and extent of oxygen and carbon dioxide concentration changes and temperature variations in the closed circuit system at various work loads,

2. what would be the effects of the variations, if any, on the physiological behavior of the subject, and on the oxygen consumption slope obtained when the oxygen concentration in the apparatus is regulated manually.

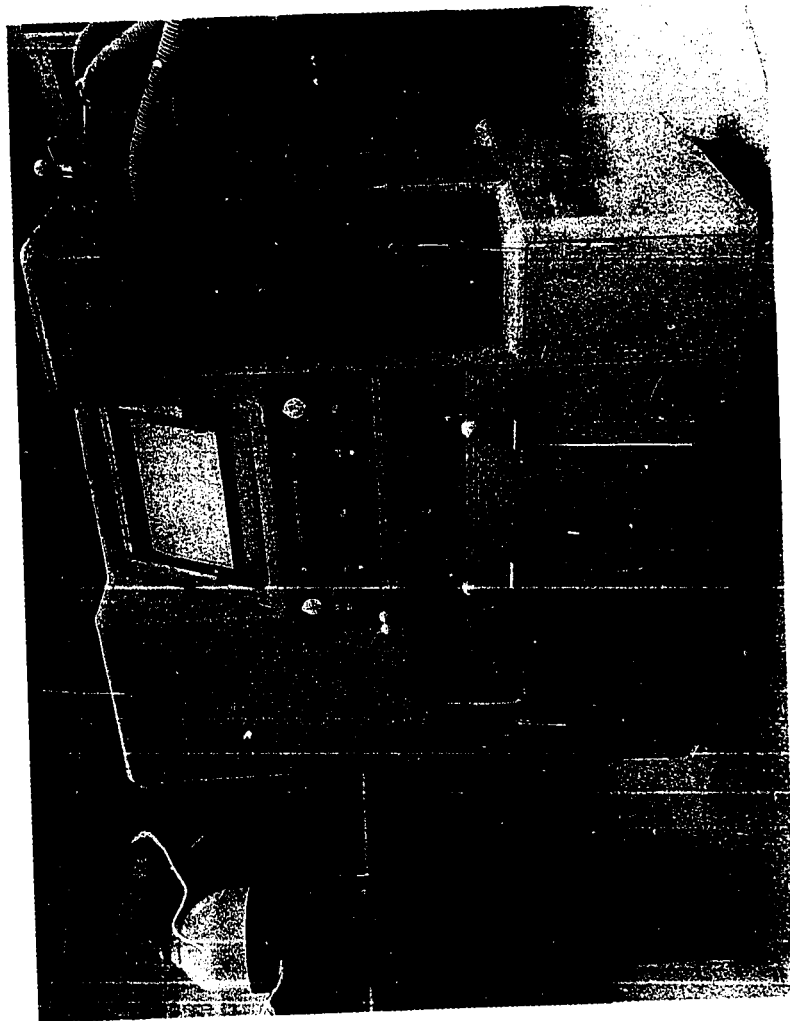
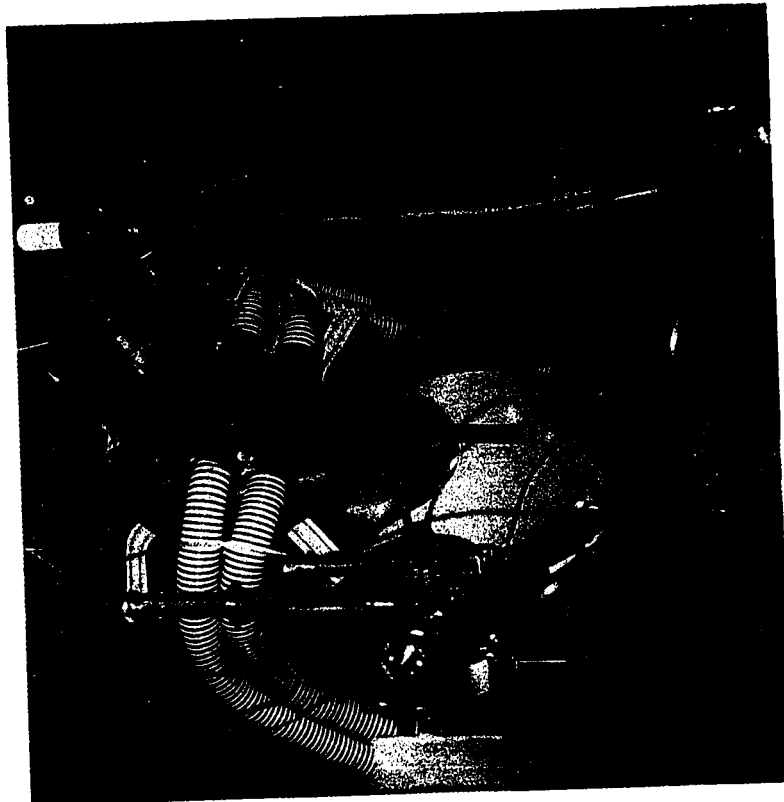
#### NEED FOR THE STUDY

The spiograph 510 is available with or without certain automatic features, one of which continuously restores the oxygen concentration in the system according to the latter's oxygen pressure. Should the apparatus not be equipped with this option, the oxygen concentration is maintained through manual volume stabilization.

It is known that volume stabilization of spiographs may fail to maintain the proper oxygen concentration, that carbon dioxide absorption is sometimes incomplete, that local dynamic temperature changes and differences cannot be controlled entirely and that air leaks in and/or out of the system may occur.

These variables, in different combinations, may affect the

FIGURE 1.1  
THE DARGATZ MAGNA-TEST TYPE 510  
HIGH CAPACITY SPIROGRAPH



concentration of gases in the apparatus and the oxygen consumption slope; therefore, they were observed individually with the objective of identifying the nature and extent of their influence on the accuracy of metabolic measurements obtained with the Dargatz type 510 spiograph operated manually.

### BACKGROUND CONSIDERATIONS

A comprehensive understanding of the functional relationships in the spiograph leads to the detection of certain factors which could directly or indirectly alter oxygen concentration and oxygen consumption results. Most of these are related to the basic laws<sup>1</sup> describing the behavior of gases.

Charles' law states that the volume of a gas at constant pressure is proportional to the absolute temperature. Charles showed that the coefficient of volume expansion of all noncondensing gases at constant pressure and 0 degree centigrade is equal to  $1/273$ .

Dalton's law stipulates that the pressure exerted by any gas in a mixture of gases is equal to the pressure which the quantity of that gas would exert were no other gases present in that same volume.

It is also known that one mole of a gas has a volume of 22.4 liters containing, according to Avogadro's number,  $6.02 \times 10^{23}$  molecules

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<sup>1</sup>F.W. Sears, N.W. Zemansky, College Physics (3rd ed.; Reading, Massachusetts: Addison - Wesley Publishing Company, Inc., 1960), pp. 349-382; A.W. Smith, J.N. Cooper, Elements of Physics (7th ed.; New-York: McGraw-Hill Book Company, 1964), pp. 250-268; R.P. Graham, L.H. Cragg, The Essentials of Chemistry (2d ed.; Toronto, Ontario: Clarke and Irwin Co. Ltd., 1959), p. 239.

at 0 degree centigrade and 760 millimeters of mercury.

Volumes, temperatures and concentrations in the spiograph are subject to variations. The following explains how the variations in oxygen concentration and in the slope of the oxygen consumption are related to the behavior of gases as described in the laws.

The three bell system is so conceived that insufficient or excessive oxygen refilling, although altering the oxygen concentration, will not directly affect the oxygen consumption slope provided the mixing gases are in thermal equilibrium. This effect is achieved by the action of the balance bell, mechanically linked to the oxygen one, which expands in volume by that of the oxygen added into the system. The spirometer bell volume is therefore independent of the oxygen volume added. The functional interrelationships in the three bell system will be thoroughly discussed farther. Large oxygen concentration variations do indirectly affect the oxygen consumption slope, which may then not reflect the otherwise expected physiological behavior of the subject.

Temperature alterations in the closed air circuit result in volume instead of pressure variations because of the mechanical behavior of the spirometer bell which absorbs the variations. Therefore, since the oxygen consumption should equal the total spirometer bell volume change over a given period of time, thermal increases would tend to decrease the volume change associated with the consumption, thereby leading to an underestimation of the latter, while thermal decreases increase the volume change, leading to an overestimation of the consumption.

Unlike the spirometer bell, the oxygen bell has no cooling system. Temperature differences between them can cause more or less perceivable alterations in the oxygen concentration and in the consumption slope since

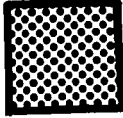
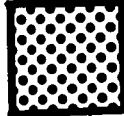

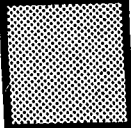
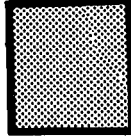

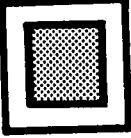
two volumes equal to each other in different ATPS conditions do not remain the same when they are brought to common ambient conditions. It is so that comparatively colder air in the spirometer bell tends to oxygen concentration decreases and oxygen consumption slope increases while comparatively warmer air in the same bell tends to produce the opposite effects.

Figure 1.2 illustrates the former case where the spirometer air is colder than that in the oxygen bell. Although  $x$  liters of oxygen were consumed and  $x$  liters of oxygen were added, these do not cancel each other in terms of molecules per liter since their temperatures differ. At equal pressures, there are less molecules in a liter of which the temperature is higher than that of another. This explains why the initial oxygen concentration decreases in the present case (figure 1.2A).

In other words, if these volumes which are numerically equal were brought to STPD conditions, the volume with the higher temperature would, at the end, be smaller than that with the initially lower temperature. Since the number of molecules per unit volume is identical at STPD conditions, the number of oxygen molecules added into the system would prove to be insufficient.

Besides decreasing the oxygen concentration, colder spirometer air leads to oxygen consumption overestimations (figure 1.2B). Because the spirometer and oxygen bells are mechanically linked, a volume decrease in the latter is accompanied by an equal volume increase in the former, at equal temperatures and pressures. When an expanded volume is created in the spirometer system by an upper displacement of the balance bell it should be precisely filled up by the oxygen volume added into the spirometer. Because of the temperature differences between the bells, the

FIGURE 1.2  
 OXYGEN CONCENTRATION AND SPIROMETER VOLUME CHANGES CAUSED BY THE  
 ADDITION OF WARM OXYGEN TO COLD SPIROMETER AIR

<p style="text-align: center;">CONCENTRATION</p> <p style="text-align: center;">A</p>	 <p style="text-align: center;">relative number of molecules per liter of oxygen consumed from the spirometer system at a temperature <math>\times</math></p>	 <p style="text-align: center;">relative number of molecules per liter of oxygen added from oxygen bell at a temperature greater than <math>\times</math></p>	 <p style="text-align: center;">relative number of molecules missing per liter to restore the initial oxygen concen- tration in the spirometer system</p>	
<p style="text-align: center;">VOLUME</p> <p style="text-align: center;">B</p>	 <p style="text-align: center;">relative volume of oxygen added from oxygen bell at a temperature <math>\times</math></p>	 <p style="text-align: center;">relative expansion volume created in spirometer system at a temperature lower than <math>\times</math> to balance oxygen volume added</p>	 <p style="text-align: center;">relative volume of oxygen added into spirometer after temperature equili- bration; part of the expansion volume occupied by the <math>O_2</math> volume added</p>	 <p style="text-align: center;">blank space: relative excess in the expansion volume caused by a decrease in the added <math>O_2</math> volume after equili- bration</p>

added oxygen volume shrinks as a result of thermal equilibration, leaving the expanded volume created incompletely filled. A transfer of air from the spirometer to the balance bell fulfills the expanded volume. The transferred volume is recorded and interpreted as a volume consumed.

Figure 1.3 illustrates the effects of warmer spirometer air on the oxygen concentration and consumption.

Although the numbers of liters of oxygen consumed and added are identical when reported at their respective ATPS conditions, they do not exactly equal each other when converted to STPD conditions. In fact, when both volumes are brought to a comparable basis, the oxygen volume added is actually larger than the one consumed. The initial oxygen concentration in the spirometer is therefore increased (figure 1.3A).

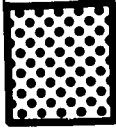
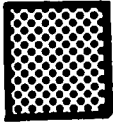

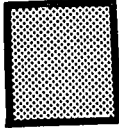
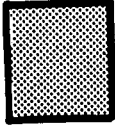
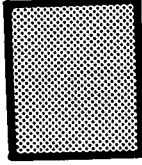
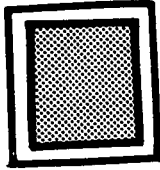
On the other hand, when the oxygen volume added reaches the spirometer's temperature, its increased volume is larger than the expanded volume. The difference between the former and the latter volumes is absorbed by the rising of the spirometer bell (figure 1.3B). This reaction leads to an underestimation of consumption.

An additional source of gas increasing the spirometer air volume manifests itself when carbon dioxide is incompletely absorbed. It decreases the volume change associated with consumption in the bell thereby leading to a subestimation of the oxygen consumption. Incomplete carbon dioxide absorption could be due to saturated soda lime and/or to air flow rates, inside the system, which would not allow the carbon dioxide molecules to be in contact long enough with the chemical agent to favor a reaction between the two elements.

Air leaks into and out of the spirometer lead to volume and oxygen concentration variations.

FIGURE 1.3

OXYGEN CONCENTRATION AND SPIROMETER VOLUME CHANGES CAUSED BY THE ADDITION OF COLD OXYGEN TO WARM SPIROMETER AIR

<p style="text-align: center;">CONCENTRATION</p> <p style="text-align: center;">A</p>	 <p>relative number of molecules per liter of oxygen consumed from the spirometer system at a temperature <math>\times</math></p>	 <p>relative number of molecules per liter of oxygen added from oxygen bell at a temperature smaller than <math>\times</math></p>	 <p>relative excess number of molecules increasing the initial oxygen concentration in the spirometer system</p>	
<p style="text-align: center;">VOLUME</p> <p style="text-align: center;">B</p>	 <p>relative volume of oxygen added from oxygen bell at a temperature <math>\times</math></p>	 <p>relative expansion volume created in spirometer system at a temperature higher than <math>\times</math> to balance oxygen volume added</p>	 <p>relative volume of oxygen added into spirometer after temperature equilibration; therefore, true volume occupied by the O<sub>2</sub> added after equilibration</p>	 <p>blank space: relative lack in the expansion volume caused by an increase in the added O<sub>2</sub> volume after equilibration</p>

Exfiltrations lower the spirometer bell and mislead into over-estimations of oxygen consumption. Obviously a leak-out in itself does not alter gas concentrations inside the system. However, a leak-out is recorded as a spirometer volume decrease and is therefore associated with an increased rate of oxygen consumption. When oxygen is added to replace what is thought to have disappeared, the oxygen concentration in the system is increased.

Infiltrations raise the spirometer bell. This results in under-estimations of oxygen consumption. The leak-in in itself does not alter the oxygen concentration provided the gas concentrations in the room air and in the system are equal. However, the leak-in conceals the true disappeared oxygen volume by counteracting the effect of consumption on the spirometer volume change. The leak-in is recorded as a decrease in spirometer volume change which is then associated with a lower or decreased rate of oxygen consumption. As oxygen will only be added according to the spirometer volume change, believed to reflect the true oxygen volume consumed, the oxygen concentration is decreased in the system.

The oxygen concentration could also decrease during normal operation if the minute oxygen consumption exceeded the maximal minute oxygen flow that can come through the manual oxygen regulator.

#### SCOPE OF THE STUDY

The present study was conducted with twenty voluntary adult subjects selected on the basis of their ability to perform a maximal work capacity test up to and including 325 watts.

The work period on the Lanooy bicycle ergometer lasted six minutes

at each of the following levels: 100, 150 and 200 watts. Observations were made during six minutes while the subject remained seated at rest prior to the 100 watt period.

From 250 watts on, the work load changed by minute increments of 50 watts until 325 watts.

While a rest was accorded to the subject in between the successive six-minute work periods, the spiograph was washed out and filled with room air.

New carbon dioxide absorber was used with each subject.

The parameters recorded every minute were:

1. inspired oxygen and carbon dioxide concentrations,
2. respiratory parameters,
3. four local temperatures in the system,
4. duration of operation of the two cooling systems.

#### LIMITATIONS

Although the gas sampling lines were kept at minimal lengths, time lags in the gas concentration analysis could not be entirely avoided.

The commercially obtained soda-lime (BDH) was considered as having a normal absorbing capacity.

The commercially obtained pure oxygen cylinder was considered as containing 100 percent oxygen.

Time lags could not be avoided in the analysis of gases by the oxygen and carbon dioxide analysers.

The work pattern and work times selected did not tax the spiograph to its reported functional limits.

## DEFINITIONS

Spirograph Dargatz Magna Test 510: closed circuit system; with automatic temperature and humidity control; adjustable ventilation: 400 liters per minute; reported maximal oxygen uptake measurement capacity to seven liters.

Mixing box: five liter plastic box added to the spirometer system on the side of expired air, before the soda lime containers.

Three bell system: it is a closed circuit system in which the spirometer, oxygen and balance bells are utilized.

Two bell system: it is a closed circuit system in which the spirometer and oxygen bells only are utilized. The balance bell is cut off from the system.

Spirometer bell: it is the bell recording the breathing movements and the volume changes in the spirograph.

Oxygen bell: it is the bell containing the pure oxygen used to replace the oxygen consumed.

Balance bell: it is the bell linked to the oxygen bell by a small chain and linked to the spirometer bell by a large air hose.

Volume stabilization of oxygen: it is a method by which the oxygen concentration is maintained by adding into the system the same volume of oxygen as the volume of oxygen consumed.

Oxygen regulator: it is an oxygen inlet valve which can be gradually opened by the spirograph operator to replace the oxygen consumed.

Manual operation of the spirograph: it is an operation method which requires the operator to restore the oxygen concentration by manipulating the oxygen regulator.

Oxygen consumption slope: it is the slope drawn at the end of all the expiration movements traced in red on the spirographic paper. It represents a volume change in the spirometer normally caused by the oxygen consumed.

Added oxygen slope: it is the slope on the spirographic paper representing the volume changes in the oxygen bell. These changes are brought about by the addition of oxygen into the spirometer system to replace the oxygen consumed.

ATPS ratio: it is the ratio of the number of liters of oxygen added into the system to the number of liters of oxygen consumed during the same one minute period, when both volumes are expressed at their respective ATPS conditions before being divided.

STPD ratio: it is the ratio of the number of liters of oxygen added into the system to the number of liters of oxygen consumed during the same one minute period, when both volumes are brought to STPD conditions before being divided.

Cumulative ATPS ratio: it is the ratio of the oxygen volume added into the system, from the start to a specified moment of a given period of work, to the oxygen volume consumed during the same period of time, when both volumes are kept at their respective ATPS conditions before being divided.

Cumulative STPD ratio: it is the ratio of the oxygen volume added into the system, from the start to a specified moment of a given period of work, to the oxygen volume consumed during the same period of time, when both volumes are brought to STPD conditions before being divided.

## CHAPTER II

## LITERATURE REVIEW

In the review of literature which follows the accent will be placed on research reports and findings related to gas concentrations in closed spiograph systems, to carbon dioxide absorbing reagents, to respiratory responses to carbon dioxide concentrations up to one or two percent, and to respiratory responses to oxygen concentrations as low as fifteen percent.

GAS CONCENTRATIONS  
IN CLOSED SPIROGRAPH SYSTEMS

Roskamm et al.<sup>1</sup> reported oxygen and carbon dioxide concentration variations in the Dargatz, type 510, spiograph. Their subjects worked for 6 minutes at 50, 100 and 200 watts, after which their load was increased by 25 watts per minute until they were exhausted. The oxygen concentration was automatically restored according to the oxygen pressure in the system.

For loads up to 200 watts corresponding to an oxygen consumption of about 2.5 liters, the oxygen concentration in the inspired air decreased from 20.72 percent to 20.41 percent. At maximal work loads the concentration dropped to 20.12 percent.

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<sup>1</sup>H. Roskamm et al., "Über die Genauigkeit der O<sub>2</sub> - Aufnahme und Atemminutenvolumenbestimmung in einem geschlossenen Spirometer-system," Sportarzt und Sport Medizin, Heft 3:57-61, 1970.

The carbon dioxide concentration in the inspired air showed no variations at work loads up to 100 watts. At 200 watts, it increased on the average to 0.165 percent. In maximal work, higher than acceptable values were found in some cases.

The authors concluded that the gas concentration variations recorded did not lead to limitations of efficiency.

The automatic restoration of oxygen concentration seems therefore quite acceptable.

One could expect greater variations with volume stabilization of oxygen concentration since it can be affected by such factors as temperature differences between bells, air leaks in and out of the system, operator's judgment and carefulness, purity of oxygen, etc...

Beneken Kolmer and Kreuser<sup>2</sup> found that the change in the oxygen concentration in the spirometer during the experiment was significantly greater with volume stabilization than with concentration stabilization both at rest and at a 75 watt load. However there were no systematic difference in mean oxygen concentration before and after the experiment with the volume stabilization technique and with the concentration stabilization technique. The variability as expressed by the standard deviation was about ten times smaller with concentration than with volume stabilization.

The way in which the oxygen was added with the volume stabilization method is different from that in the Dargatz 510 spirometer. It was done automatically and intermittently by a mechanically operated

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<sup>2</sup>H.H. Beneken-Kolmer, F. Kreuser, "Stabilization of Oxygen Tension in Closed Spirometer Systems," Respiration Physiology, 4:246-254, 1968.

valve which opened only during inspiration. In the Dargatz spirometer there is a continuous oxygen refilling regulated by the operator according to the slope of the expiration curve. Descriptive information on the system used are too scarce to determine whether the engineering characteristics of the refilling mechanism influenced the concentration restoration. In the 510 spirometer, the oxygen regulator is opened according to the need. Because of the foregoing differences it is difficult to predict whether or not similar variations would be obtained with the Dargatz. Moreover, the work load was quite light.

#### CARBON DIOXIDE ABSORBING REAGENTS

Margaria et al.<sup>3</sup> built their own carbon dioxide absorber because the conventional soda lime canister or other type of filters based on absorption by alkaline solutions could not absorb the carbon dioxide at a high enough rate without introducing too high a resistance to the air flow. Their absorber was a cylindrical vessel in which a potassium hydroxide solution was watered from above and was kept circulating by a pump. The expired air flowed through the cylinder countercurrent to the solution. They obtained complete absorption of carbon dioxide in expired air with a two-tower absorber at ventilation of 140 liters BTPS per minute.

The 510 spirometer has two parallel tower absorbers filled with

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<sup>3</sup>R. Margaria, E. Galante and P. Cerretelli, "An Efficient CO<sub>2</sub> Absorber for Experiments on Metabolism," Journal of Applied Physiology, 14:1066-8, 1959.

conventional soda lime. Roskamm et al.<sup>4</sup> reported relatively high concentrations of carbon dioxide at maximal work in their 510 spiograph.

### RESPIRATORY RESPONSE TO CARBON DIOXIDE

Some characteristics of the respiratory response of man to inhalation of a constant concentration of carbon dioxide in the inspired gas were described by Dripps and Cumroe<sup>5-6</sup>. The tidal volume increased slowly to a maximum during the inhalation and returned slowly to previous levels when air replaced the carbon dioxide mixture. Frequency of breathing also increased as the concentration of carbon dioxide increased. When the gas mixtures contained one percent and two percent of carbon dioxide the minute ventilation increased by one and two liters respectively.

These are two levels of carbon dioxide concentration expected to be found in the spirometer system. The changes in ventilation were much more important when the carbon dioxide concentration was greater than three percent.

Sensitivity of the respiratory center to carbon dioxide is calculated as the change in minute ventilation volume for each change of

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<sup>4</sup>Roskamm et al., loc. cit.

<sup>5</sup>R.D. Dripps, J.H. Cumroe, Jr., "The Respiratory and Circulatory Responses of Normal Man to Inhalation of 7.6 and 10.4 Percent CO<sub>2</sub> with a Comparison of the Maximal Ventilation Produced by Severe Muscular Exercise, Inhalation of CO<sub>2</sub> and Maximal Voluntary Hyperventilation," American Journal of Physiology, 149:43-51, 1947.

<sup>6</sup>R.D. Dripps, J.H. Cumroe, Jr., "The Effect of the Inhalation of High and Low Oxygen Concentrations on Respiration, Pulse Rate, Ballistocardiogram and Arterial Oxygen Saturation (Oximeter) of Normal individuals," American Journal of Physiology, 149:277-291, 1947.

one millimeter of mercury in alveolar or arterial  $P_{CO_2}$ . The average value reported by Cumroe is about 2.5 liters per minute per millimeter of mercury change in  $P_{CO_2}$ . He did not state whether this was at rest or at a certain level of work<sup>7</sup>. Lloyd found that the sensitivity increased as arterial  $P_{O_2}$  decreased<sup>8</sup>.

Shepard<sup>9</sup> reported results similar to those of Cumroe<sup>5</sup>. At rest the ventilation increment was smaller than one liter when one percent of  $CO_2$  was inspired while with four percent the ventilation was approximately doubled.

Schaefer<sup>10</sup> showed that a carbon dioxide concentration as low as 1.5 percent maintained a continuous stimulating effect on the respiratory center throughout an exposure period of 42 days during which the respiratory minute volume was significantly elevated. The control mean differed from the experimental mean by one liter per square meter of body surface area. The oxygen consumption did not change significantly during the experiment. Alveolar carbon dioxide tension was elevated 2 or 3 mm. Hg. throughout exposure to 1.5%  $CO_2$ . The increase in ventilation was accomplished mainly through an increase in tidal volume.

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<sup>7</sup>J.H. Cumroe, Jr., Physiology of Respiration, (Chicago: Year Book Medical Publishers Incorporated, 1966), p. 62.

<sup>8</sup>B.B. Lloyd, M.G.M. Jukes, D.J.C. Cunningham, "The Relation Between Alveolar Oxygen Pressure and the Respiratory Response to Carbon Dioxide in Man," Quarterly Journal of Experimental Physiology, 43:214-227, 1958.

<sup>9</sup>R.J. Shephard, "Some Effects of Carbon Dioxide on Foreign Gas Uptake," Journal Applied Physiology, 14(3):333-338, 1959.

<sup>10</sup>K.E. Schaefer et al., "Respiratory Acclimatization to Carbon Dioxide," Journal Applied Physiology, 18(6):1071-1078, 1963.

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Asmussen and Nielson<sup>11</sup> showed that during work the respiratory center reacted to increases in alveolar  $P_{CO_2}$  in much the same way as during rest, i.e. the ventilation increased linearly up to a certain value with increasing values of  $P_{CO_2}$ , but the stimulus-response curves were displaced to the left of the resting curve and the more so the higher the work intensity. In low oxygen ( $P_{O_2}$ : 54 mm. Hg.) and increased alveolar  $P_{CO_2}$  experiments, the lower part of the stimulus-response curves were much steeper than and displaced to the left of the corresponding curves from the experiments in atmospheric air at the same work intensity.

From Cumroe and Shephard's studies reported previously it was shown that a one percent carbon dioxide concentration in inhaled air produced a minute ventilation increase of one liter; Schaefer showed that a 1.5% carbon dioxide concentration caused an alveolar pressure increase of 2 or 3 mm. Hg. In view of these findings and of these of Asmussen, the minute ventilation could be expected to increase approximately two to four liters around three hundred watts if carbon dioxide concentrations of one percent were reached.

Craig<sup>12</sup> reported results similar to those of Asmussen. His subjects were measured at rest and at work intensities of 1.5, 3.0, 4.0 and 6.0 miles per hour. The inspired carbon dioxide concentration varied from zero to ten percent at each speed. At rest a two percent concentration increased the ventilation by approximately two liters. The

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<sup>11</sup>E. Asmussen, M. Nielson, "Ventilatory Response to CO<sub>2</sub> during Work at Normal and Low Oxygen Tensions," Acta Physiologica Scandinavica, vol. 39, fasc. 1, 1957.

<sup>12</sup>F.N. Craig, "Pulmonary Ventilation during Exercise and Inhalation of Carbon Dioxide," Journal of Applied Physiology, 7(5):467-471, 1955.

ventilation increase paralleled the load increase. At six miles per hour about ten liters of a 35 liter ventilation were due to the presence of a two percent carbon dioxide concentration.

Bellville and Seed<sup>13</sup> plotted the theoretical relationship between the partial pressure of carbon dioxide in the inhaled air and in the alveolar gas under conditions of constant net carbon dioxide excretion. They assumed a respiratory response curve slope of 1.5 liters per minute per mm. Hg.  $P_{CO_2}$  and a carbon dioxide excretion of 240 ml. per minute. A one percent concentration at rest would raise  $P_{A_{CO_2}}$  by one mm. Hg.; two percent would raise it by two mm. Hg. This is in agreement with the previously reported studies.

#### RESPIRATORY RESPONSE TO OXYGEN LACK

The height and slope of the oxyhemoglobin dissociation curve illustrates that, at the  $P_{O_2}$  normally existing in arterial blood, hemoglobin is 97.5 percent saturated with oxygen. At oxygen tensions greater than 100 mm. Hg., hemoglobin cannot accept much more oxygen. Between oxygen tensions of 100 and 70 mm. Hg. there is very little change in the amount of oxygen held by hemoglobin. A decrease from 100 to 90 decreases the saturation to only 96.5 percent, from 100 to 80, to 94.5 percent and from 100 to 70, to 92.7 percent<sup>14</sup>.

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<sup>13</sup>J.W. Bellville, J.C. Seed, "The Effect of Drugs on the Respiratory Response to Carbon Dioxide," Anesthesiology, 21:727-741, 1960.

<sup>14</sup>J.H. Cumroe, Jr., Physiology of Respiration (Chicago: Year Book Medical Publishers Incorporated, 1966), pp. 161-162.

Dripps and Cumroe<sup>15</sup> observed that the respiratory minute volume was not affected at rest when men breathed air with oxygen concentrations of eighteen percent. It increased slightly at 16, 14 and 10 percent. There was a powerful response when the oxygen concentration in inspired air decreased further. When men inhaled 18 or 16 percent oxygen, slight tachycardia resulted. The arterial oxygen saturation dropped to 93 percent when 17 percent oxygen was inspired.

Hollmann<sup>16</sup> obtained significantly higher oxygen consumption, minute ventilations and heart rates when his subjects breathed 15 rather than 21 percent oxygen during a maximal work load lasting fifty seconds. The increments were approximately two hundred milliliters in consumption, twenty liters in ventilation and fifteen beats in heart rate.

An oxygen concentration drop to eighteen percent in the spiograph air would seem to be within acceptable limits with an arterial blood saturation of 94 percent. Seventeen percent might provoke slight increases in ventilation and perhaps oxygen consumption.

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<sup>15</sup>R.D. Dripps, J.H. Cumroe, Jr., "The Effect of the Inhalation of High and Low Oxygen Concentrations on Respiration, Pulse Rate, Ballistocardiogram and Arterial Oxygen Saturation (Oximeter) of Normal Individuals," American Journal of Physiology, 149:277-291, 1947.

<sup>16</sup>W. Hollmann et al., "Der Einfluss unterschiedlicher O<sub>2</sub> - Konzentrationen in der Inspirationluft auf das Kardio-pulmonale Verhalten bei 12-bis 50 sekundigen Maximal belastungen," Sportarzt und Sportmedizin Jargang XVII/1966, Heft 4:137, 1966.

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## CHAPTER III

## RESEARCH METHODOLOGY

## INTRODUCTION

The primary objective of this study was to observe the oxygen and carbon dioxide concentrations in a closed spirometer system, and to determine the effects of their variations on the physiological behavior of the subject and on the oxygen consumption slope during submaximal and maximal work on a bicycle ergometer.

Decisions relative to the duration of the total exercise period, the intensity of the work per unit of time, were made in the light of the following considerations:

1. The desirability of having a suitably long testing period to allow the subjects to perform aerobically and anaerobically up to maximal work loads.
2. The desirability of simulating frequently used procedures in routine testing or research experiments.
3. The necessity of observing the absorption capacity of the soda lime on the long run.
4. The desirability of comparing the ability to maintain, by manual operation, appropriate gas concentrations in the system during submaximal and maximal work loads.

## THE WORK PATTERNS

### Type of Work

Work consisted in cycling from a sitting position on a Lanooy ergometer.

### Duration

The total test period lasted 28 minutes. It was divided into four six-minute periods, each interrupted by a pause; a fifth and final work period lasted four minutes.

### Work Rates

The cycling rate was left to the convenience of the subjects since they were familiar with this type of work.

During the first six-minute period the subjects remained at rest, seated on the bicycle ergometer.

The second, third and fourth six-minute periods were of 100, 150 and 200 watts, respectively.

The initial minute load of the fifth period was set at 250 watts and was then increased every minute by 25 watts, up to 325 watts.

### Pauses

Work was stopped after each period. The subject remained connected to the system which was opened to room air in order to insure identical conditions at the onset of each work period. Work resumed a few minutes afterwards with the consent of the subject.

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### THE SUBJECTS

Twenty subjects from the region of Quebec were selected on the basis of their expected ability to work up to a level of 325 watts on the Lanooy ergometer. The mean age, height and weight were: 23.8 years, 175.0 centimeters, 74.1 kilograms.

Most of the subjects were involved in bicycle racing from the regional to the international level. A few were involved in athletics, cross-country skiing or kayak competition.

### THE OBSERVATION POINTS

Seven observation points were determined during each six-minute period. Measurements were taken at the end of the minute preceeding the official six-minute period while the subject was at rest, and at the end of each minute of the period. In the final period where the work load was increased every minute, measurements were taken in the same manner as in a six-minute period.

### THE VARIABLES MEASURED

In this experiment, an observation meant the actual measurement of a variable at a specific and pre-determined point on the time axis. For all practical purposes, the measurements were considered as "simultaneous" measurements. At each observation point the following were retained amongst measured variables.

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## Respiratory

Ventilation

Oxygen consumption

## Gas Concentrations

Percentage of oxygen in inspired air

Percentage of carbon dioxide in mixing box, before CO<sub>2</sub> absorption

Percentage of carbon dioxide in inspired air

## Temperatures

Temperature of inspired air as recorded on the Dargatz thermometer

Temperature in the oxygen bell

Temperature of inspired air as recorded by a YSI thermistor probe

Temperature in the balance bell

## Gas Volumes

Volume of oxygen added in the spirometer

## Cooling Systems

Cooling system I operation time

Cooling system II operation time

## EQUIPMENT AND FURNITURES

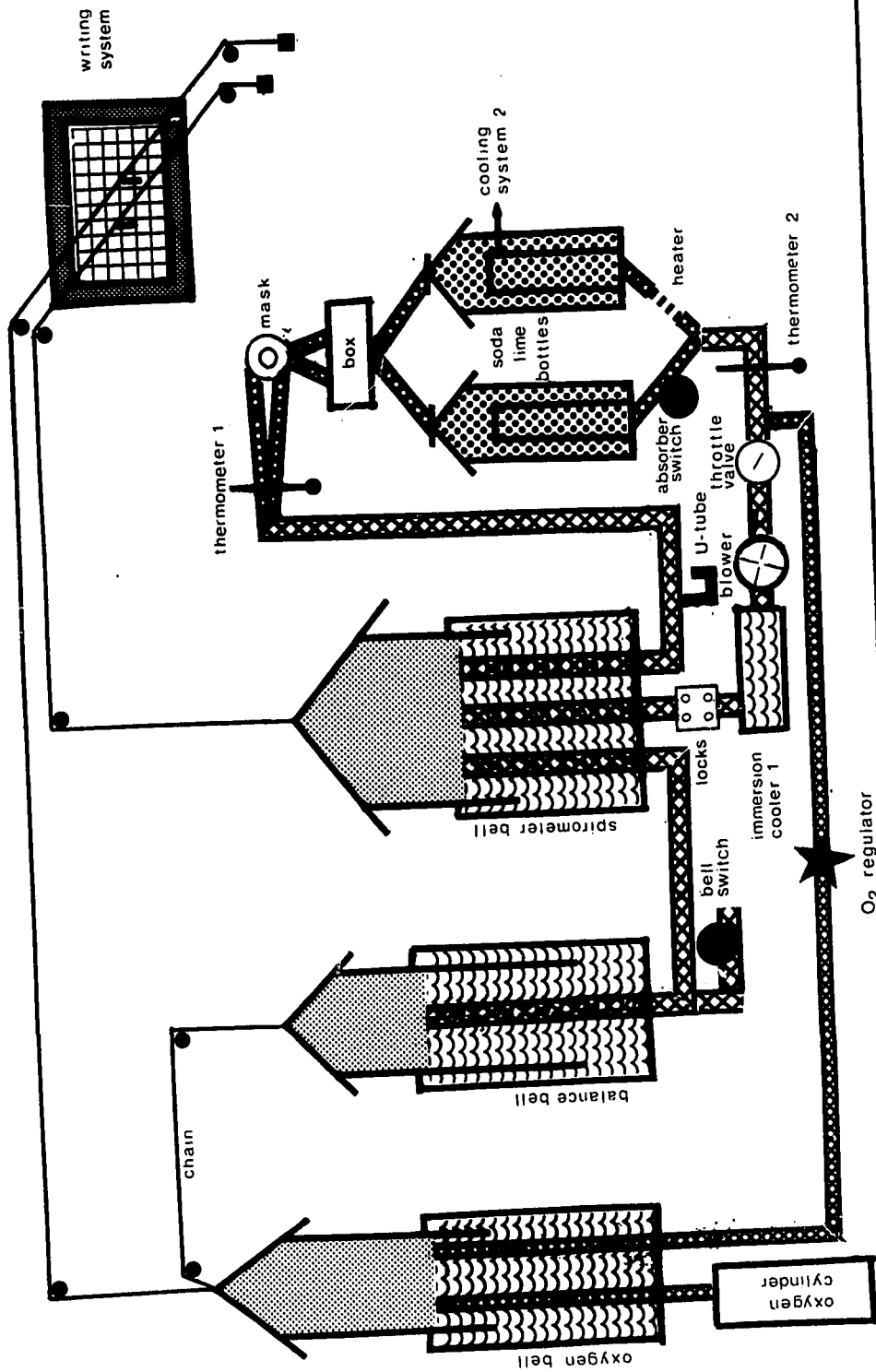
### Spirometer System

The apparatus used was a Dargatz<sup>1</sup> Magna-Test, type 510, high capacity spirometer with a closed air-circulation system. A simplified diagram of the spirometer is presented in figure 3.1.

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<sup>1</sup> Albert Dargatz, Hamburg 28, West Germany.

FIGURE 3.1  
SIMPLIFIED DIAGRAM OF THE SPIROGRAPH



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The air system. The main air circuit is made up of a blower (Gebläse) and filter, an immersion cooler (Tauchkühler), the air locks (Schotts), a spirometer bell (Spirometerglocke), a U-shaped safety delivery tube (Einleiter), a contact thermometer (Kontaktthermometer I), a mask (Maske), a gas box, two parallel water-cooled soda-lime absorbers (Absorber), a heater (Vorheizung), a second contact thermometer (Kontaktthermometer II), and a throttle valve (Drosselklappe).

Important elements connected to this main circuit are an oxygen bell ( $O_2$  - Nachfüllglocke), a manual oxygen regulator (Sauerstoffregler), a balance bell (Stabiglocke) and a writing system.

The blower can circulate up to 400 liters of air per minute in the system. An air filter is adjusted to it to eliminate any soda-lime or other foreign particles within the air flow. The filter is easily removed and cleaned with tap water.

The immersion cooler is half-filled with water from the central water supply. The temperature of this water is regulated by conduction process where running water flowing through tiny pipes (Tauchkühlerkühlrohr) in contact with the immersion cooler reduces the inside water temperature. This automatic cooling system eliminates the rising heat in the blower resulting from mechanical friction and air turmoils. Immediately after leaving the blower the air passes into the immersion-cooler where it is cooled and humidified. The automatic cooling and moistening elements guarantee that temperature in most of the air circulation system can be kept at a level of room temperature, or slightly below, and that the relative humidity remains between 95 and 100 percent. Furthermore, the air is always pleasant to inhale.

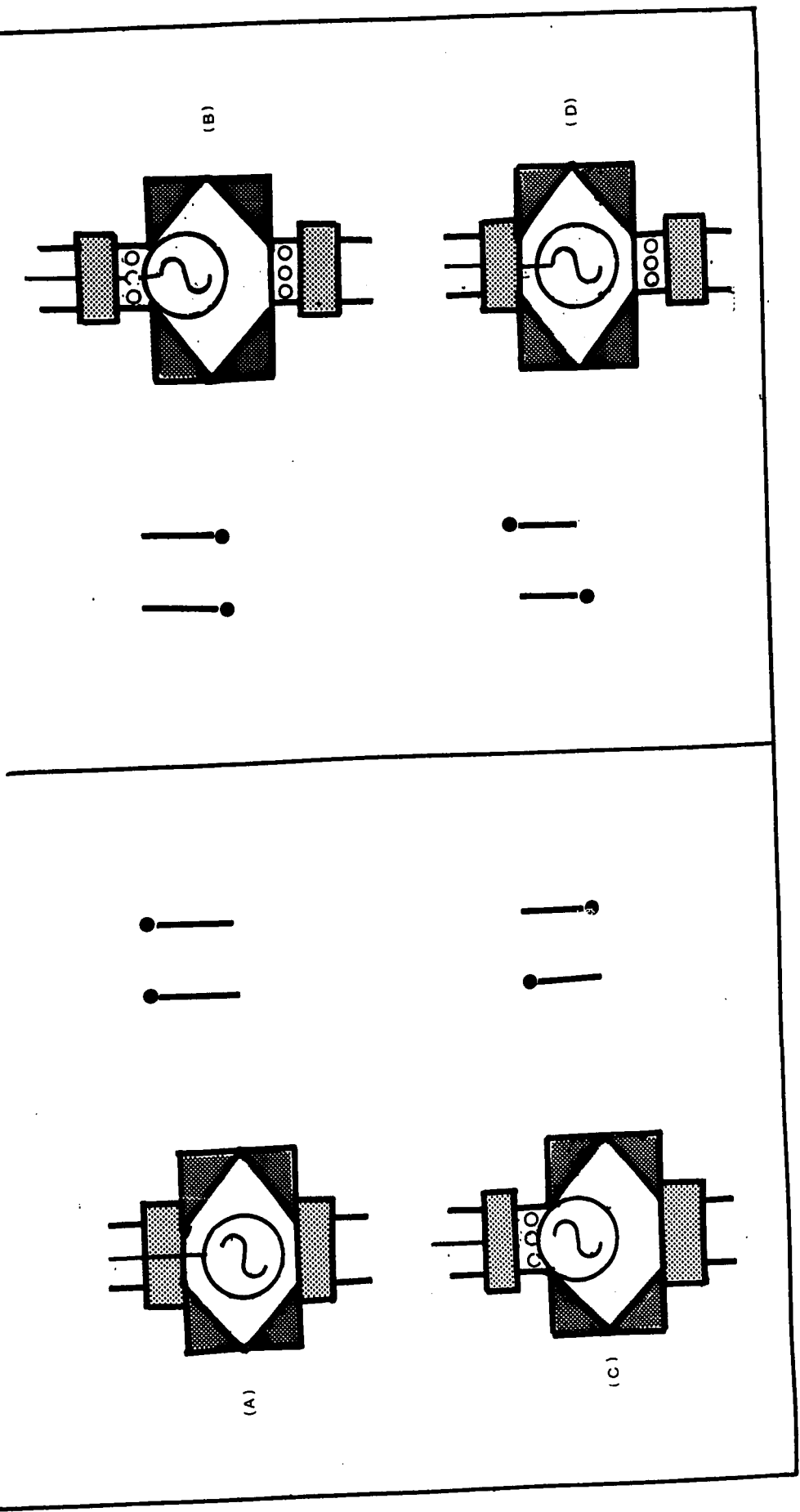
The air locks (Schotts) give the opportunity to ventilate the air circulation system within the shortest time and to supply it with fresh air. It also gives the opportunity to move the spirometer bell to the desired height. A special mechanism in the air locks allows to quickly fill or empty the spirometer bell. Figure 3.2 illustrates the four functions of the air locks. The levers at the side of each diagram are the Schotts manoeuvring controls on the front panel of the spirometer. The left side lever operates the lower airlock while the right one operates the upper lock. Their actual position for each function is illustrated. When the Schotts are opened they uncover small holes by which air can enter or leave the system. In figure 3.2a both locks are closed, that is no air exchange occurs between the spirometer and the room.

In figure 3.2b both locks are opened. When the upper lock is lifted it pulls up a ball that blocks the air way below the openings just uncovered, preventing straight through circulation. Therefore the circulation arriving from below cannot pass through; since the lower lock is opened the air is forced out of the spirometer by the blower. At the same time the blower sucks room air into the system by the upper openings; therefore the spirometer is completely opened to room air.

In figure 3.2c room air is sucked in through the openings since the upper lock is lifted. This increases the spirometer air volume because the straight through circulation is blocked and the lower lock is closed.

In figure 3.2d the lower lock is opened. Air can either move on straight through or leave the system through the openings. Since the air locks are only separated from the blower by the immersion cooler, the

FIGURE 3.2  
AIR LOCK SYSTEM



AVIATION SAFETY

high pressure at that point causes the air to leave the system, thereby decreasing the spirometer volume.

The 18-liter spirometer bell (Spirometerglocke) as well as the other bells, is extremely light in fabrication. It is this part of the spirometer that absorbs the changes in volume occurring in the spirometer. It records the inspiration and expiration movements as well as the volume of oxygen consumed by the subject. A string connects the moving parts of the bell with the recorder. To keep the moving parts as light as possible, there is no counter-weight installed; a spring system serves as a balance of weight and lift.

The U-shaped safety delivery tube (Einleiter) filled with water up to an overflow level serves as a safety valve, preventing dangerously low pressures from reaching the patient if the spirometer bell were empty. Because of the atmospheric pressure gradient between the interior and exterior of the spirometer, room air forces its way into the system.

The contact thermometer (Kontaktthermometer I) between the spirometer bell and the mask controls the immersion-cooling system. It indicates the inspired air temperature. The desired temperature is set on the thermostat above the thermometer.

Two wide hoses bring the air at each side of the mask while two others return it to the system. The mask's surface must adhere completely to the subject's face so that no air leak occurs. A high air circulation is desirable to quickly remove from the mask the expired carbon dioxide. For the subject's comfort the mask system is hung on springs. The position of the mask can be adjusted at any required height.

A mouth piece system can be used for basal metabolic measurements and must be used for lung residual volume determinations. When used, one

soda-lime absorber is cut off from the system by the absorber switch (Absorberschaltwalze).

A five-liter gas mixing box was added to the system for the needs of the experiment. Its purpose was to mix the expired gases to send a representative expired sample from the box to the carbon dioxide analyzer.

Two parallel water cooled soda-lime absorbers eliminate by chemical reaction the expired carbon dioxide from the system. An automatic water cooling system (Absorberkühlsystem II) reduces the heat of reaction in the absorbers and the heat of expired air to a preset temperature on a second thermostat further away in the circulation system.

The heater could be used to raise the air temperature if the latter were found to be too far from the thermostat setting. The heater will not operate automatically when the actual temperature is near the desired temperature.

The second contact thermometer (Kontaktthermometer II) controls the soda-lime absorbers' automatic cooling system. Temperature readings are not given on this contact thermometer; the thermostat only can be set.

The throttle valve (Drosselklappe) allows a ventilation adjustment in the spirometer system.

The oxygen bell stores oxygen which serves to replace the oxygen consumed by the subject so that the system's oxygen concentration remains constant. The volume of oxygen sucked from the bell by the blower is controlled by the amount of opening of a manually operated oxygen regulator (Sauerstoffregler). This is accomplished by the spirometer operator. A string leads from the bell to a pen recording the volume of oxygen introduced into the system. This bell is also linked by a light chain to a third

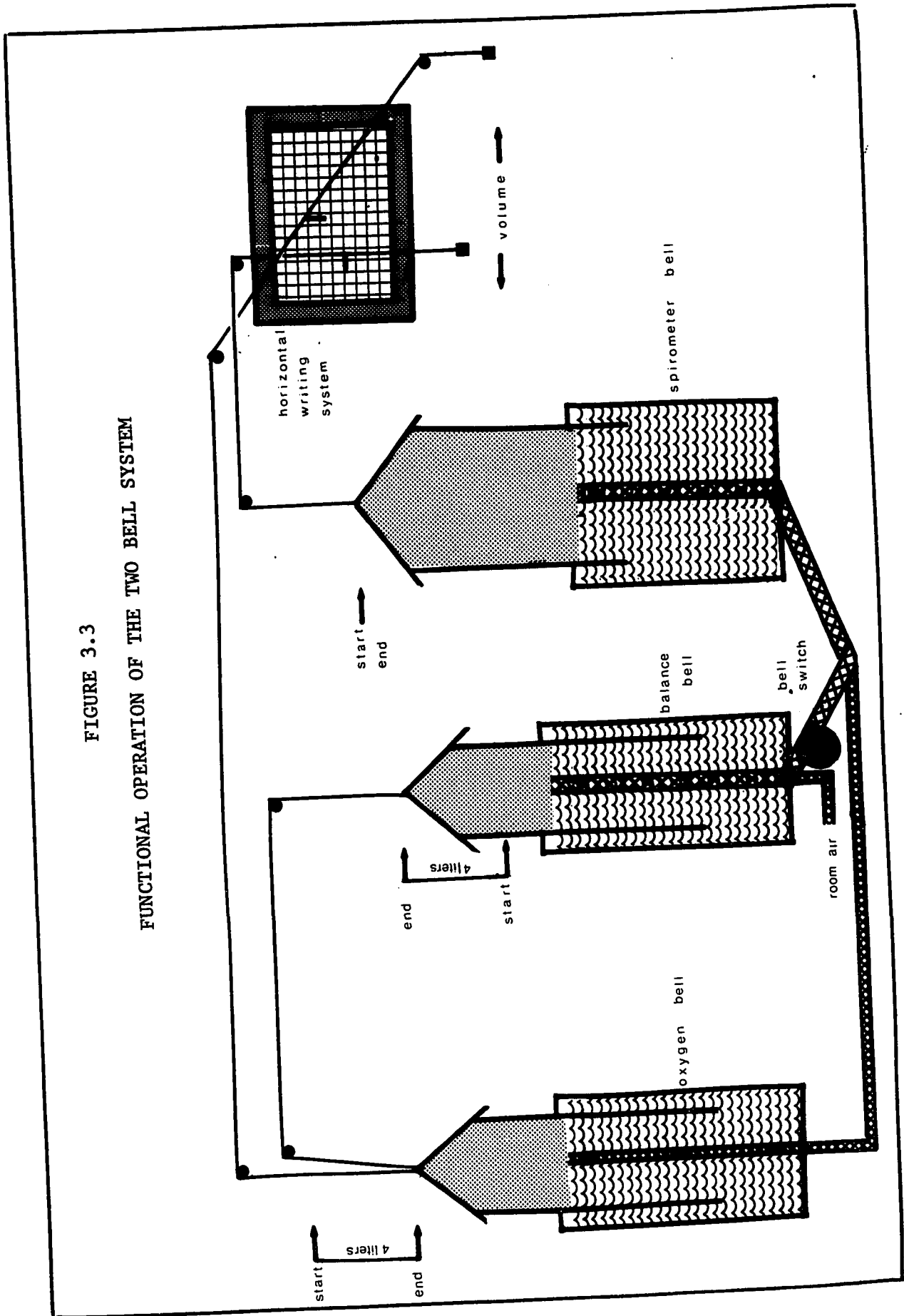
bell in the system.

The latter bell is the balance bell (Stabiglocke). It is linked to the spirometer bell by wide tubings allowing air transfer from one bell to the other. It can be cut off the system by a balance bell switch (Stabischalterwalze) which opens it to room air. A two bell instead of three bell system is thus obtained.

The two bell system. This system is obtained by opening the balance bell to room air by means of the balance bell switch. As already mentioned, it should be used only with the automatic restoration of the oxygen concentration. Figure 3.3 illustrates the functional operation of each part of this system when four liters of oxygen are consumed over a given period of time; the initial and final positions of the bells are indicated by arrows. It should be noticed that the position of the spirometer bell is identical at the start and at the end of the period. As to the balance bell, it drew four liters of air from the room as it was pulled upward by the oxygen bell. In this system the oxygen consumption volume is obtained indirectly by measuring the volume of oxygen added into the system.

The three bell system. This system is obtained by opening the balance bell to the spirometer bell by means of the balance bell switch. The system must be used when the oxygen is restored through a manually operated regulator. Figure 3.4 illustrates the functional operation of each part of this system when four liters of oxygen are consumed in a given period of time; the initial and final positions of the bells are indicated by arrows. The oxygen and balance bells behaved in the same manner as in the two bell system. The spirometer bell volume however decreased by four liters, which was not the case in the other system.

FIGURE 3.3  
FUNCTIONAL OPERATION OF THE TWO BELL SYSTEM



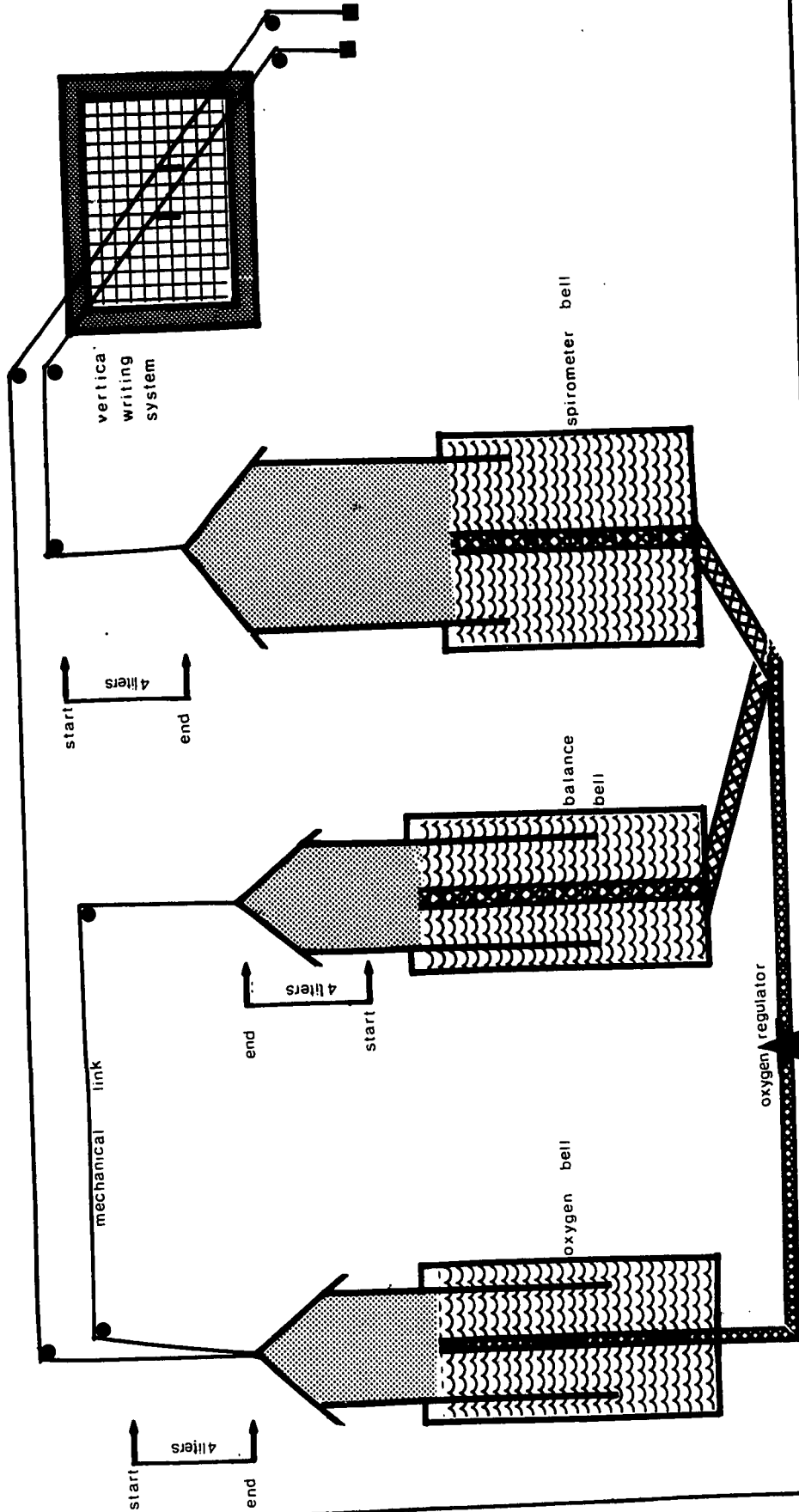
Since the balance bell was opened to the spirometer bell, it drew four liters from it as it was pulled by the oxygen bell. In other words, as four liters of oxygen were added into the spirometer bell to replace the four liters consumed, another four liters were drawn from the bell by the balance bell which filled itself as it moved upwards.

The balance bell was so called because its function is to balance the volume of oxygen added into the system in such a way that the spirometer bell volume reflects the amount of oxygen consumed. The balance bell will always draw from the spirometer bell a volume of air equal to the volume of oxygen added. Even though, therefore, a maladjustment occurs in the oxygen restoration, the oxygen consumption measure is not affected.

The recording system. The ordinate of the spirographic paper is calibrated in liters where 100 ml is the smallest division drawn. The abscissa is calibrated in millimetres where 5 mm is the smallest division. The paper speed ranges from 30 to 1500 millimeters per minute.

The writing unit (Schreiber) has two pens: one usually containing red ink records the spirometer bell movements caused by the respiration of the subject. It will also register spirometer volume changes resulting from such things as air leaks, temperature modifications, introduction of foreign gases like helium, carbon dioxide, etc. In the three bell system it records the volume change corresponding to the oxygen consumption. The second pen, usually filled with blue ink, records the oxygen bell volume changes brought about when pure oxygen is sucked by the blower into the system, either to replace the oxygen consumed or to substantially increase the oxygen concentration in the spirograph.

FIGURE 3.4  
FUNCTIONAL OPERATION OF THE THREE BELL SYSTEM



Two methods are available for recording graphically the volume changes in the spirometer bell. The horizontal writing (figure 3.3, far right) is characterized by a respiration curve which is kept parallel to the abscissa, or to the volume division lines. On the other hand the oxygen refilling curve moves diagonally across the paper. The oxygen consumption must be read from the refilling curve. This type of writing is obtained by removing the balance bell from the system. The two bell system thus obtained should be used only when the oxygen concentration can be automatically restored.

The vertical writing (figure 3.4, far right) is characterized by a respiration curve which moves diagonally across the paper along with oxygen refilling curve. The oxygen consumption must be read from the respiration curve. This type of writing is obtained with a three bell system which must be used when the oxygen concentration must be restored through a manual oxygen regulator. This writing can also be obtained when the oxygen is automatically restored but in such a case it is much more advantageous to use the two bell system.

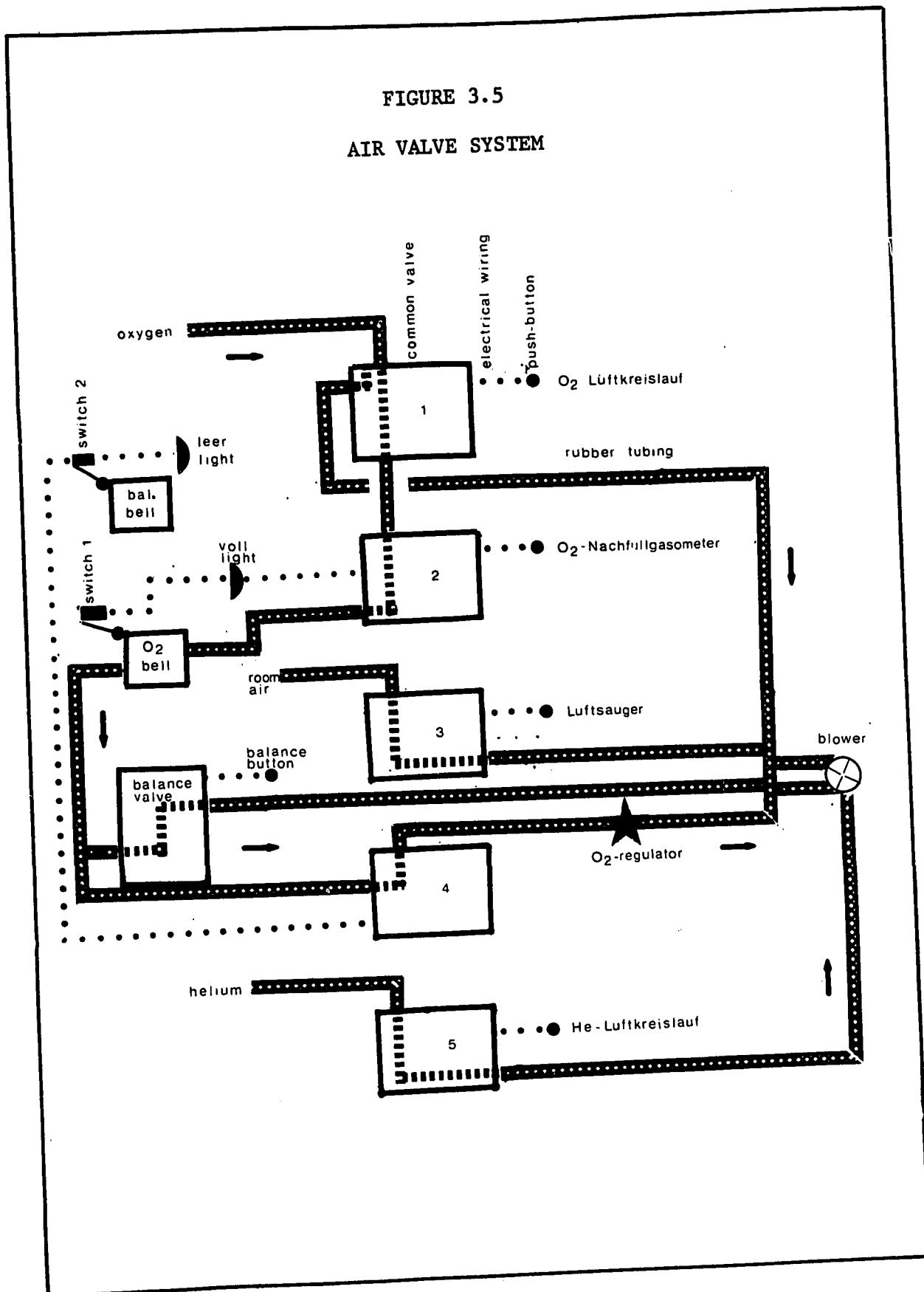
The air valve system. The system serves to introduce, under control, certain amounts of gas into various parts of the spirometer system (figure 3.5).

The common air valve<sup>2</sup> can be divided into a bottom, mid and top portion (figure 3.6). The alphabetical letters P, A, and R printed on the diagram actually correspond to openings named in the same manner on the valve.

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<sup>2</sup> Burkert valve, Type 315 C, made in Germany.

FIGURE 3.5  
AIR VALVE SYSTEM



From the top view of the bottom portion it can be seen that there is a direct air line between the corresponding side-openings (P-P, R-R) as well as between the end-openings. The small circles on these lines represent the air lines coming from the valve's mid portion.

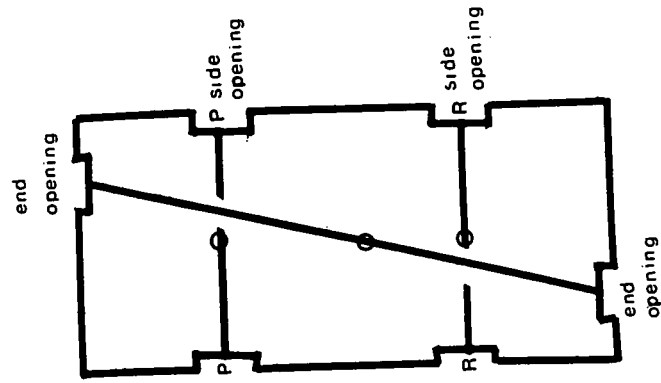
If a gas enters a side opening, it must pass through the mid portion to get out by an end opening and vice versa. The mid portion lines PA and AR can be cut off alternately by the action of the top portion's electromagnet on an interrupter or by the manipulation of an exterior lever. The activity of the magnet is controlled by push-buttons. A continuous spring action on the interrupter results in a blocked PA line when the magnet is not activated. When it is so, the magnet's force overcomes that of the spring, pulling the interrupter across the AR line. The suction of the blower is the force moving the air through the valves.

In figure 3.8, a straight air line across a valve, as in valve 1, indicates that the bottom portion only of the valve is used; a bended air line, as in valve 2, indicates that the mid and bottom portions of a common valve are used.

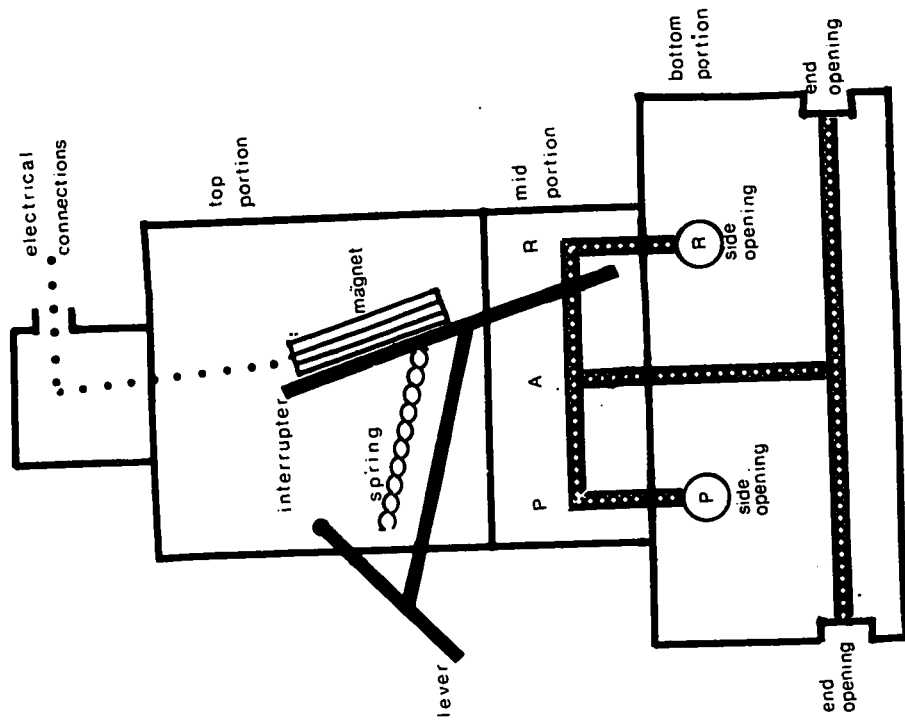
Valve 1 is activated by the "O<sub>2</sub> Lüftkreislauf" push-button. It introduces oxygen directly into the main circuit from a commercially obtained oxygen gas cylinder.

Valve 2 is controlled by the "O<sub>2</sub> Nachfüllgasometer" push-button. It serves to refill the oxygen bell with fresh oxygen. It is also used to indirectly refill an empty spirometer bell during an experiment where three bells are used. Referring to figure 3.5, it can be seen that as the oxygen bell rises, the balance bell lowers while its content is transferred into the spirometer bell.

FIGURE 3.6  
COMMON AIR VALVE



TOP VIEW OF  
BOTTOM PORTION



Valve 3 is operated by the "Lüftsauger" push-button. It sucks in room air and is mainly used with the mouth piece system where the back soda-lime container is removed from the circulation. In such conditions the spirometer bell's refilling rate through the air locks is reduced. It is increased with the action of valve 3.

Unlike the others, valve 4 is constantly activated unless switch 2 comes in contact with the balance bell in which case the oxygen bell would be empty. This mechanism prevents the creation of a vacuum in the bell by the sucking action of the blower. The volume of oxygen sucked into the system by the blower depends on the opening of the oxygen regulator placed in between the blower and valve 4.

Valve 5 is activated by the "He-Lüftkreislauf" push-button to add helium into the main circulation system.

Switch 1 is connected to the indicating light "voll" (full) which goes on when the oxygen bell is full. It is also linked with valve 2 through which oxygen is fed under pressure into the oxygen bell. Switch 1 cuts the circuit between valve 2 and "O<sub>2</sub> - Nachfüllgasometer" push-button when the oxygen bell is raised up to the switch. This arrangement prevents a high pressure build up in the bell.

An empty oxygen bell causes the balance bell to close switch 2 which allows the electrical current to activate the indicating light "leer" (empty). When this switch is closed by the balance bell, the activation of the balance valve is impeded. This arrangement prevents the creation of a vacuum in the oxygen bell.

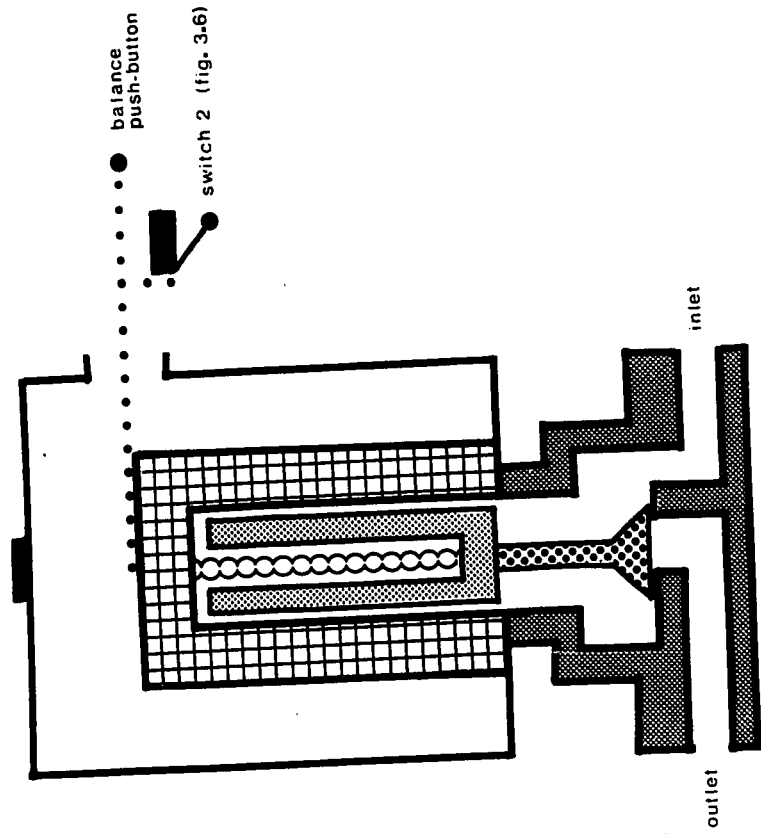
The balance valve<sup>3</sup> (figure 3.7) allows into the main air circulation

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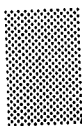
<sup>3</sup>Burkert valve, Type 4801 M, made in Germany.



FIGURE 3.7  
BALANCE VALVE



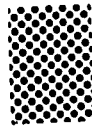
center cylinder



valve base



rubber stopper



electromagnet



coil spring



system, per unit of time, much larger volumes of oxygen than would the common air valve. It serves to increase rapidly the oxygen concentration in the system. It would also be used to simply empty the oxygen bell in order to clean it and refill it with fresh oxygen.

To increase the oxygen concentration in the system, the balance push-button is pressed down (figure 3.5, 3.7).

To wash out the oxygen bell the balance and "O<sub>2</sub> - Nachfüllgasometer" push-buttons are pressed down simultaneously. The latter controls valve 2 (figure 3.5). Since the air flow is greater through the balance valve, the oxygen bell empties itself. When it is so, the balance bell closes switch 2 (figure 3.5) which automatically cuts the current to the balance valve. Valve 2 remains open and the oxygen bell starts refilling until switch 2 is released by the balance bell which lowers as the oxygen bell rises. This goes on as long as the push-buttons are pressed down. To refill the oxygen bell completely the O<sub>2</sub> - Nachfüllgasometer push-button only is pressed down.

The balance electromagnetic valve has a large inlet and outlet. The latter can be closed by the action of a spring on a rubber stopper at the end of a hollow center steel cylinder. Then the blower suction creates a force acting in the same direction as that of the spring. When the electromagnet is activated, its force overcomes that of the spring to pull upward the center cylinder and the rubber stopper attached to it.

This valve is designed to operate with an inlet pressure of approximately one atmosphere. If it were connected to an oxygen gas cylinder or a water tap, the forces exerted on the sloped sides of the stopper could not be overcome by the electromagnet forces with the result that the valve would not open.

The central water system. By means of the force of gravity, the oxygen and balance bell containers, the U-shaped safety delivery tube and the immersion cooler are filled with water arriving in a distributor box placed above them (figure 3.8).

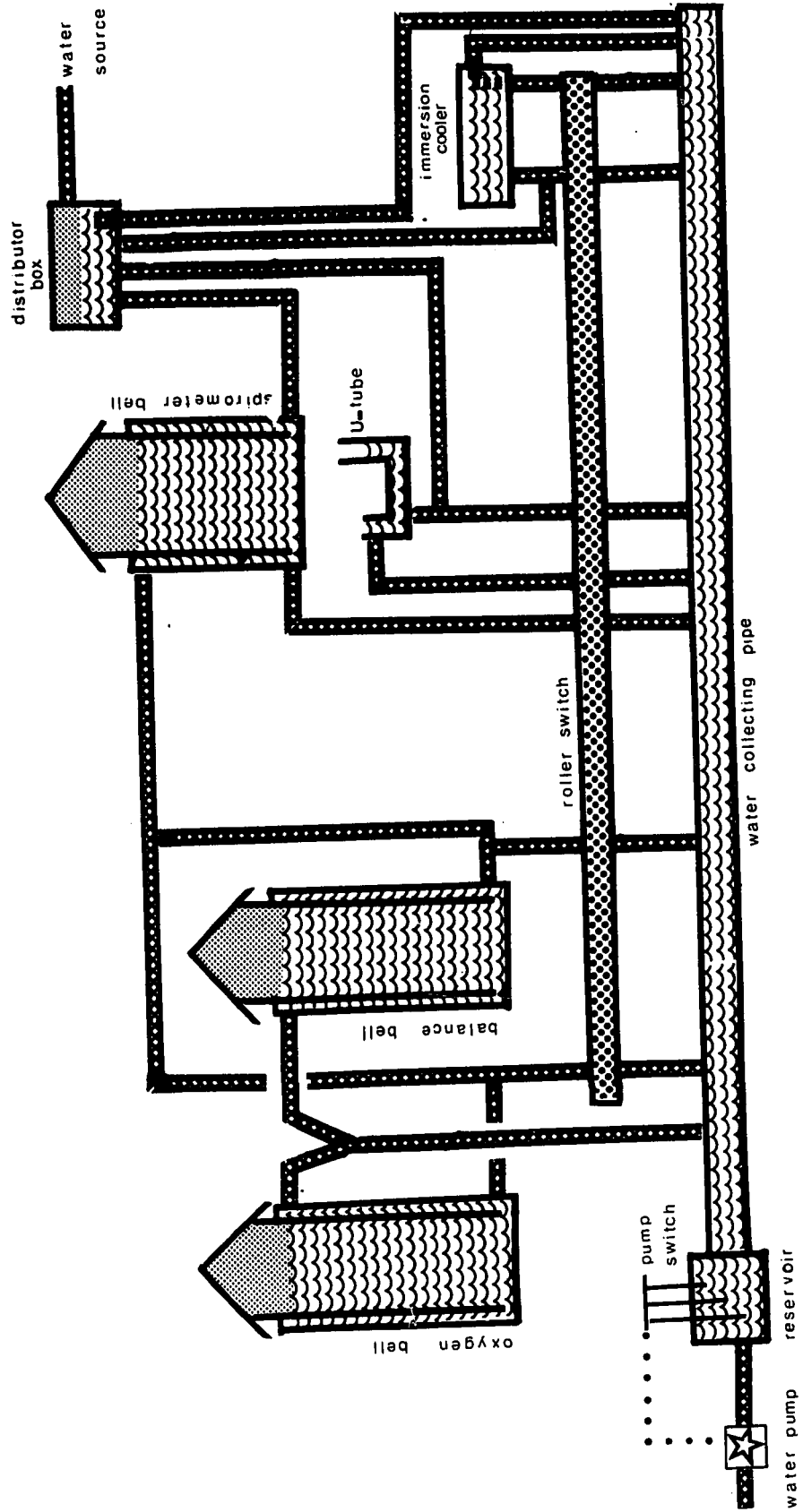
To drain all the containers, a roller switch is pivoted; water flows into a collecting pipe leading to a reservoir. When the water reaches a certain level in the reservoir a pump switch activates a water pump which empties the reservoir.

The central water system is controlled by valve 6 (figure 3.9) connected to a timing switch. This is a common valve (figure 3.6) as utilized in the air valve system.

The cooling water system. The soda lime and the immersion cooler's cooling systems have already been described. The latter system is controlled by valve 7 (figure 3.9) which is also a common valve (figure 3.6). The valve will open according to the inspired air temperature and the thermostat setting on contact thermometer 1 (figure 3.1).

A special water valve (figure 3.10) is used with the soda lime cooling system which requires a larger water flow than the first cooling system or central water system. The valve's top and mid portions operate in the same manner as in the common air valve's top and mid portions (figure 3.6). The electromagnet is activated if the soda-lime container's temperature is higher than the thermostat setting on contact thermometer II (figure 3.1). Tap water arrives under pressure at inlet P. If PB line is blocked, a pressure is exerted under the piston head which is pushed upward until the piston's end seals the R exit. Then water flows through PA line into the soda-lime cooling system.

FIGURE 3.8  
CENTRAL WATER SYSTEM



If, on the other hand, PB line is opened some water will flow into it and exert a pressure over the head of the piston. Since the surface area over which the pressure is exerted is larger over the piston head than under it, the piston will be pushed down until PA line is blocked, cutting the water flow to the cooling system. Exit R is branched on the water collecting pipe (figure 3.9).

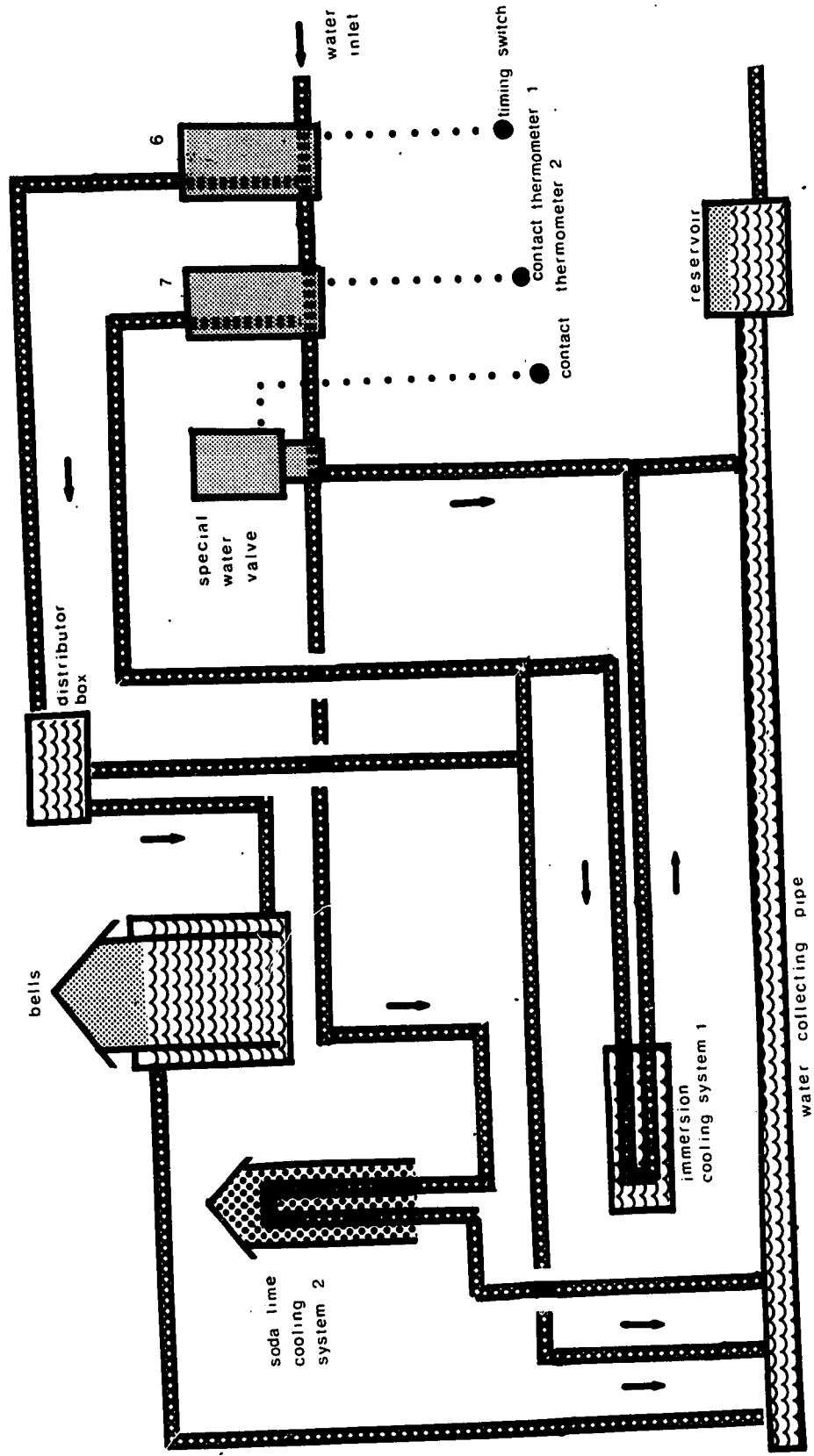
The spirometer volume. The spirometer volume was estimated by three methods. In the first one, the volume of some parts of the spirometer was determined by the volume of water it could hold while the volume of other parts was determined in function of their length and diameter. With the spirometer bell at its highest point and the balance bell at its lowest, as it is usually the case at the start of an experiment, the volume of the spirometer was fifty three liters. It must remain very nearly the same during experiments since the balance bell rises as the spirometer bell lowers when the consumed oxygen is properly replaced.

In the second method the temperature inside the spirometer was varied. As stated in the first chapter, a gas volume varies by  $1/273$  of its volume for every change of one degree centigrade. Therefore the increase in volume caused by an increase of one degree was multiplied by 273. By this method the estimated total spirometer volume was fifty five liters.

In the third method the volume was estimated according to the change in the oxygen concentration caused by the addition of a known volume of pure oxygen. The estimated volume was approximately sixty liters.

The magnitude and significance of gas concentration and relative volume changes caused by temperature variation that can be observed in

FIGURE 3.9  
WATER VALVE AND COOLING SYSTEMS



specific conditions were judged obviously always related to the total gas volume inside the closed circuit system.

### Ergometer

A Godart-Lanooy bicycle ergometer was used. The load on the bicycle was constant and independent of the revolutions per minute between 40 and 85 rpm.; the error was expected to be less than 1 percent for total evaluated work.<sup>4</sup>

### Gas Analyzers

Oxygen. A Beckman paramagnetic analyzer, Model F 3M3-1AA, was coupled to the spirometer system to monitorize the oxygen concentration in the inspired air. The 0-25 percent range was used. The downscale and upscale calibrations were made with 16.6 and 23.8 percent oxygen, respectively.

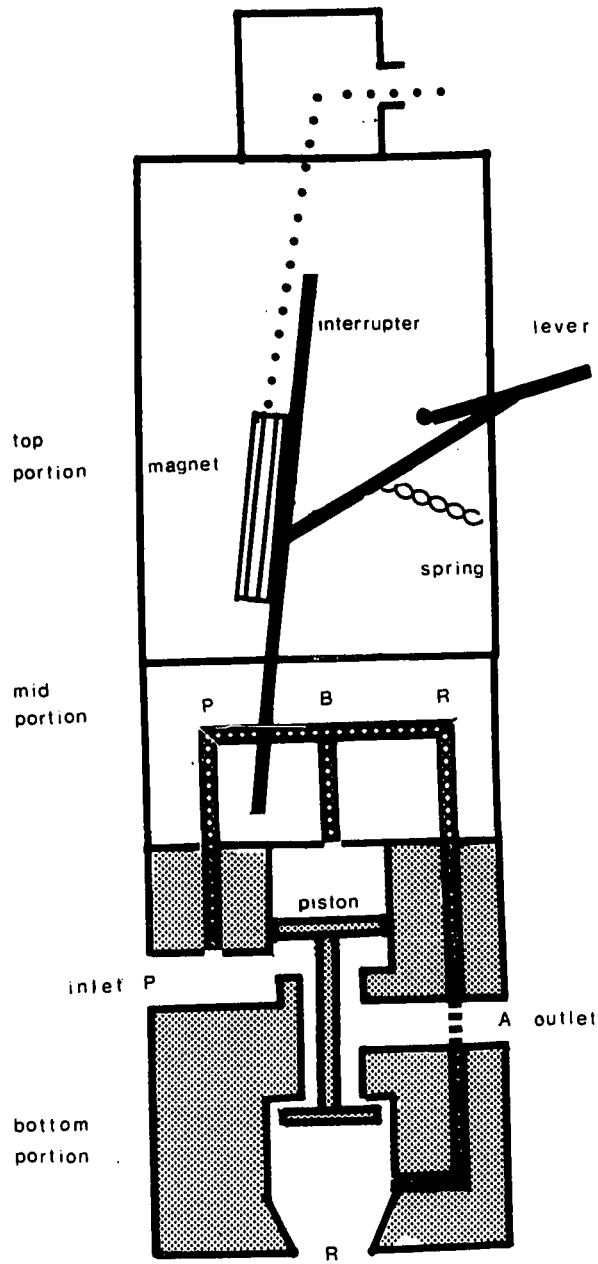
The air flow through the analyzer was kept at 200 ml/min. A ninety percent response was obtained in forty seconds. The accuracy for all ranges was  $\pm 1$  percent of full scale.

Carbon dioxide. A Beckman infra-red analyzer model 215A was also coupled to the spirometer system to measure the carbon dioxide concentrations in the mixing box as well as in the inspired air. The 0-10 percent by volume range was used. The downscale and upscale calibration points were determined with nitrogen and 2.01 percent carbon dioxide, respectively. These values corresponded to 0 and 29.1 on the arbitrary scale. The apparatus had a sensitivity of 0.5 percent of full scale and an accuracy of  $\pm 1$  percent. A ninety percent response was obtained in 0.5 second. The flow rate through the apparatus was kept at 400 ml./min.

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<sup>4</sup>Instruction Manual: Directions for Use for Godart Ergometer, Holland.

FIGURE 3.10  
SPECIAL WATER VALVE



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### Flowmeters

One Brooks Sho-rate flowmeter was connected at the input orifice of each gas analyzer to control the air flow rate through them.

### Dessicant

Anhydrous  $\text{CaSO}_4$  dessicant called Drierite was inserted in between the flowmeters and the gas analyzers.

### Polyethylene Tubes

The polyethylene tubes consisted of a tubular body 5/8 in. I.D., and separate serrated tips 7/8 in. long with a 3/32 in. bore. The length of the tube was 100 mm. Color changes of the interior indicating substances were easily observed through the tube. Glycerine was used to seal the tips. These tubes held dessicant or soda-lime.

### Soda-Lime

USP "Wilson", 4/8 mesh, 2 percent moisture, self-indicating soda-lime was placed in polyethylene tubes to absorb the carbon dioxide in the air leaving the carbon dioxide analyzer. "Carbosorb" soda-lime, distributed by British Drug Houses Ltd., was used in the spirometer carbon dioxide absorbers.

### Timers

Two Galab Universal Timers, Model 165-S, were used. One was placed on top of the spirometer in front of the Dargatz operator; the other was placed in front of the Dynograph operator. The latter timer was connected to the first in such a way that it automatically started or stopped with the first one.

### Tele-thermometers

YSI Thermistemp Tele-thermometers were used to measure the temperature of the air in the oxygen and balance bells, and the temperature

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of the inspired air. The manual selection switchboard of YSI Model 44 was plugged directly into a Beckman Dynograph thermistor coupler, type 9858. The YSI thermistor probes, no. 409, used were designed to measure surface temperatures. Their time constant<sup>5</sup> was 1.1 second. Two of the probes used provided exactly the same readings when placed in a water bath at various temperatures. The third one used gave readings one tenth of a degree centigrade higher than the two others. No corrections were made for this divergence.

### Thermometers

A partial immersion thermometer graduated in tenths of degrees from 1 to 51°C was used as the standard thermometer. Although it was not calibrated with regards to the melting point of ice and melting point of a highly purified organic compound, it was considered as giving acceptable absolute readings after comparisons with two uncalibrated thermometers. The results of these comparisons are shown in table 3.1.

### Bladders

Rubber bladders used with the Kofrany-Michaelis Respirometer were connected to the calibration gas cylinders since there were no constant flow regulators on these. The bladders were kept partially filled.

### Dynograph

An eight channel Beckman type R Dynograph recorded oxygen and carbon dioxide concentrations, temperatures registered by the three YSI probes, and the length of time the cooling systems were in operation.

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<sup>5</sup> Time constant, the standard measure of probe response time is the time required for a probe to read 63 percent of newly impressed temperature. Approximately five time constants are required for a probe to read 99 percent of the total change. Leaflet entitled, YSI Thermistor Probes, published at Yellow Springs, Ohio, by Yellow Springs Instrument Company.

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**TABLE 3.1**  
**STANDARD THERMOMETER READINGS IN RELATIONSHIP TO**  
**SIMULTANEOUS READINGS ON UNCALIBRATED THERMOMETERS**

<b>READINGS</b>	<b>STANDARD THERMOMETER</b>	<b>THERMOMETER 1</b>	<b>THERMOMETER 2</b>
<b>READING 1</b>	18.7	18.7	18.6
<b>READING 2</b>	21.1	21.1	21.1
<b>READING 3</b>	28.1	28.1	28.1
<b>TOTAL</b>	67.9	67.9	67.8
<b>MEAN</b>	22.63	22.63	22.60

All the Dynograph amplifiers and pre-amplifiers were of the type 482 and 481B respectively. Table 3.2 summarizes the characteristics and the functions of the couplers used on the Dynograph which was equipped with the 501F/R zero weave paper drive and an ink curvilinear recording system. The event marker on the Dynograph was in operation, marking every first 55 seconds of the minute.

### Valves

B-D MS10 luer lock valves were employed in the sampling and calibration systems.

### Sampling System

The oxygen and carbon dioxide sampling systems are described in figure 3.11.

Oxygen. A sample of oxygen was continuously flowing through the oxygen analyzer. It was taken by  $\frac{1}{4}$  in. I.D. tygon tubing from the large spirometer hoses (Kupplungsrohr) leading to the mask. On the line in between the sampling point and the oxygen analyzer were a luer lock valve, a Brooks Sho-Rate flowmeter and a tube containing dessicant. The total length of this sampling line was 36 inches (91 cm) while its volume was approximately 70 cubic centimeters. It took about five to seven seconds for the sample to reach the analyzer. In order not to alter the volume of the closed system, this sample was returned to the system by a tygon tubing linked to the back of the spirograph pump. This return line was 70 inches long.

The air was brought to the analyzer by the suction of the spirograph pump. The flowmeter control knob was well opened; the flow rate through the analyzer was set with a Hoffman clamp placed on the return line. This procedure prevented the possible creation of a partial

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TABLE 3.2  
DYNOGRAPH COUPLERS

TYPE	VARIABLE RECORDED	RECORDING MODE	AMPLIFICATION
O <sub>2</sub> concentrations	continuous	9806A, A-C	1 mv/cm
CO <sub>2</sub> concentrations	alternating from box to system	9806A, A-C	1 mv/cm
temperatures	alternating from probe 1, 2, 3	9858, thermistor	2 mv/cm
cooling system I	continuous	9826, integrating, direct mode	50 v/cm
cooling system II	continuous	9801, straight-through	50 v/cm

vacuum in the analyzer.

Carbon dioxide. Two samples were alternately introduced through the infra-red analyzer.

To switch the samples on the analyzer a Becton-Dickenson five stopcock manifold was used in the following manner: the center stopcock conducted either sample to the analyzer input through a  $\frac{1}{2}$  in. I.D. tygon tubing. A Hoffman clamp, a flowmeter and a dessicant tube were inserted in between the center stopcock and the analyzer. The total length of this sample line was 30 inches (76 cm.) while its volume was about 60 cubic centimeters. The Hoffman clamp between the stopcock and the flowmeter served for minor flowrate adjustments during calibration.

A sample arrived at each stopcock adjacent to the center one. These adjacent stopcocks could either be opened toward the center or end-stopcocks.

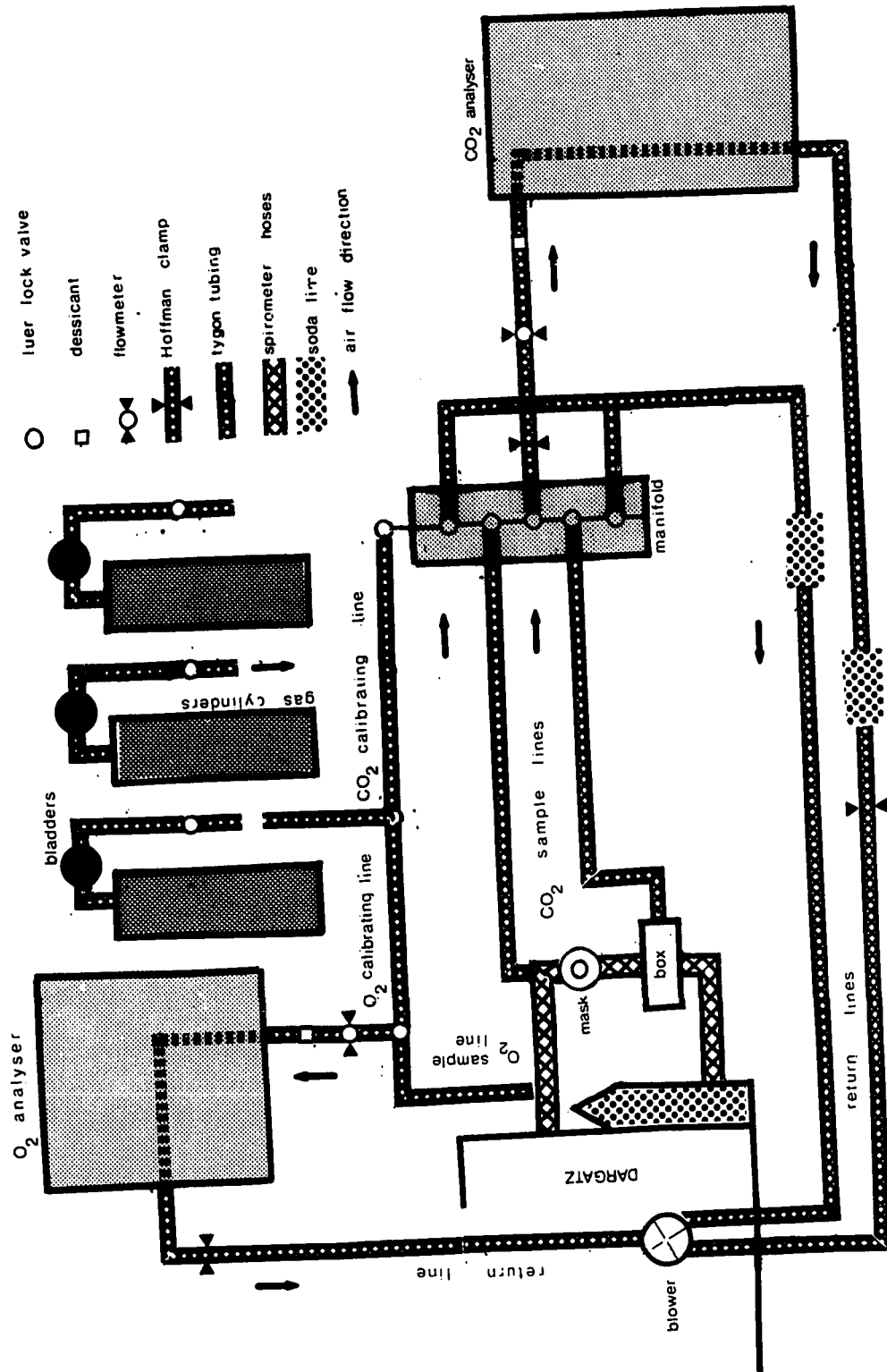
When an adjacent stopcock was opened towards the center one, its sample was directed towards the analyzer. When an adjacent stopcock was opened towards the end-stopcock, its sample was returned to the spirometer system. During experiments, the adjacent stopcock that was not opened towards the center stopcock was so towards the end one.

The purpose of this sytem was to prevent "dead air" situations in a sample line that was not opened to the analyzer. A "fresh" or representative sample was always flowing right up to the center stopcock.

The tygon tubings leaving the end-stopcocks were connected to a plastic "T" at one foot from the manifold. From there the 50-inch (127 cm.) return line was connected on the spirometer tube feeding pure oxygen into the system. This connection was two feet away from the pump and did not reduce the maximal volume of oxygen that could be sent into the

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FIGURE 3.11  
SAMPLING AND CALIBRATING SYSTEM



system. A polyethylene tube containing soda-lime was inserted into this line to absorb carbon dioxide. There was no need to control the flow rate on this return line.

The sample analyzed was returned to the back of the pump by a 55-inch (140 cm.) long tygon tubing, passing through soda-lime in a polyethylene tube. A Hoffman clamp on this line was used to regulate the air flow rate through the analyzer while the flowmeter control knob was well opened. This procedure prevented the possible creation of a partial vacuum in the analyzer.

The first of the samples to be analyzed originated from a five-liter, gas mixing box inserted into the closed system between the soda-lime bottles and the hoses returning the air from the mask. This analysis gave information on the relative amount of carbon dioxide going through the soda-lime bottles for absorption. An 18-inch tygon tubing brought the sample to an adjacent stopcock.

The second sample oriented towards the carbon dioxide analyzer originated from the large hoses (Kupplungsrohr) conducting air to the mask. An 18-inch tygon tubing brought the sample to an adjacent stopcock.

#### Calibration System

Three gas cylinders were used to calibrate the analyzers. Scholander analyses were performed<sup>6</sup> on two of cylinders. The third one contained commercially pure nitrogen. The results of the analyses are displayed in table 3.3. Rubber bladders with luer lock valves on their end were directly attached on the cylinders.

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<sup>6</sup> Analyses were made at the Biokinetic laboratory of the University of Ottawa, on November 4, 1970.

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TABLE 3.3

GAS CONCENTRATIONS IN CYLINDERS USED FOR  
THE CALIBRATION OF THE BECKMAN ANALYZERS

ANALYSIS	CYLINDER 1		CYLINDER 11	
	CO <sub>2</sub> %	O <sub>2</sub> %	CO <sub>2</sub> %	O <sub>2</sub> %
1	2.0238	16.5770	7.8986	23.8681
2	1.9377*	16.6732*	7.8856	23.8017
3	1.9940	16.6912	7.8856	23.8048
4	2.0152	16.6440	7.8874	23.8302
5	2.0138	16.5646	7.9318*	23.8299*
MEAN	2.0117	16.6192	7.8978	23.8282

\* These values were dropped because they differed the most from the others

A luer-lock valve added at the end of the manifold allowed room air and calibrating gases to reach the carbon dioxide analyzer. A stopcock on the oxygen sampling line allowed the calibrating gases to reach the oxygen analyzer.

#### STATISTICAL METHOD

The nature of the experiment required that repeated measurements be made on the same subjects, that is, each subject was measured under all treatments. The factors were treated one by one. The analysis of variance model is referred to as a single-factor experiment having repeated measures on the same elements.<sup>7</sup> The mathematical calculations were all made with an IBM - no. 360 Computer using Winer's method.<sup>8</sup> The estimation of the mean squares and of the F ratio as a test of significance was made for each variable according to the model also described by Winer.<sup>9</sup>

In order to determine which means were significantly different from others when the over-all F ratio was statistically significant, multiple comparisons on treatment means were effected with the Duncan new multiple range test as described by Edwards.<sup>10</sup> The calculation of the within-treatment mean squares was made with an IBM no. 360 computer. The remaining calculations were made with a Munroe Epic 3000.

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<sup>7</sup>B.J. Winer, Statistical Principles in Experimental Design, (Toronto: McGraw-Hill Book Company, 1962), Chapter 4, p.105.

<sup>8</sup>B.J. Winer, op. cit., pp. 105-110.

<sup>9</sup>B.J. Winer, op. cit., pp. 106-110.

<sup>10</sup>A.L. Edwards, Experimental Design in Psychological Research, (3d ed.; Toronto: Holt, Rinehart and Winston, Inc., 1968), pp. 130-135.

Main Hypothesis (Ho). There is no significant difference between minutes in a work period, from the point of view of the variables measured.

Other Hypotheses. There is no significant difference between work loads, from the point of view of the variables measured.

There is no significant difference between thermometers from the point of view of the variable measured.

There is no significant difference between bell temperatures, from the point of view of the variable measured.

## CHAPTER IV

## PRESENTATION AND DISCUSSION OF RESULTS

The object of this study of the Dargatz Magna Test 510 spirometer was to observe firstly the variables that could alter the expected physiological behavior of a subject using the apparatus and, secondly, the variables that could falsify the oxygen consumption slope.

In the first case, it was thought that the subject's behavior could be altered by an increase or a decrease of oxygen concentration and/or the presence of carbon dioxide in the inspired air. In the second case, it was thought that the consumption slope could be tempered by the presence of carbon dioxide and/or a difference of temperature between the oxygen and spirometer bells.

The results will be presented and discussed along the following lines. A first section will focus on the oxygen concentration changes within each of the five work periods; a second section, on the carbon dioxide concentration changes within each of the five work periods; a third section, on temperature differences between the bells; a fourth section, on the Dargatz thermometer accuracy; a fifth section, on the oxygen and carbon dioxide concentration differences among the work periods.

In each section will be grouped the observed variables that could help to explain the changes observed in the variable focussed upon.

## OXYGEN CONCENTRATION

Introductory Comments

In each of the five work periods will be grouped the following variables: oxygen concentration, carbon dioxide concentration in the system and in the box, ATPS ratio, STPD ratio, cumulative ATPS ratio, cumulative STPD ratio. The following paragraphs will specify how each of these variables will be used in the discussions of this section.

The addition of carbon dioxide in the system leads to a decrease in the nitrogen and oxygen concentrations. Since approximately twenty-one percent of the gas mixture in the apparatus is oxygen and seventy-nine is nitrogen, oxygen will absorb twenty-one percent of a concentration change brought about by the addition of carbon dioxide, while nitrogen will absorb seventy-nine percent of that change. For example, if carbon dioxide is added to the two gases so that it forms one percent of the mixture, the total change of the two original gases will be of one percent; the oxygen concentration will decrease by 0.21 percent while that of nitrogen will decrease by 0.79 percent. In other words, since the ratio of nitrogen to oxygen is 3.77, the nitrogen concentration change will be 3.77 times greater than that of oxygen. In the discussion, it will therefore be possible to estimate the influence of carbon dioxide presence on the oxygen concentration.

The ATPS ratio was established to reflect the degree of parallelism between the oxygen consumption slope and the added oxygen slope over a period of one minute, when both volumes involved are kept at their respective ATPS conditions. The volume stabilization method used to maintain the proper oxygen concentration required that both slopes be kept parallel,

or at least that the straight line that would join both ends of the added oxygen curve be parallel to the oxygen consumption slope. An ATPS ratio smaller than one will indicate an insufficient amount of added oxygen while a ratio greater than one will indicate a surplus of added oxygen. This line of discussion would come to an end here if both volumes were at the same temperature. Because different temperatures do exist, both volumes must be compared at identical or standard conditions to verify if the amount of added oxygen was adequate. Then, the problem is considered in terms of number of molecules per unit volume rather than only space occupied.

Therefore the STPD ratio was established to reflect the degree of parallelism between the two slopes over a period of one minute, when both volumes involved are brought to STPD conditions. Its purpose is the same as that of the ATPS ratio; in addition it accounts for the difference between the temperatures of the oxygen and spirometer bells. This ratio is really the measure that will indicate if the number of molecules consumed were completely replaced.

The interactions of both ratios are given in table 4.1 when the ATPS ratio is equal to or greater than one, and in table 4.2 when the ATPS ratio is smaller than one.

The cumulative ATPS ratio and the cumulative STPD ratio serve the same purpose as the ATPS ratio and the STPD ratio, respectively, except that the volumes involved can cover more than a one minute period but must always be cumulated from the start of a given period of work. In fact, they are obtained by averaging the means of the ATPS and STPD ratios from the first minute of a given period of work to a defined moment in that period. Their interactions are the same as those of their counterparts.

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TABLE 4.1  
 INTERACTION EFFECTS OF ATPS AND STPD RATIOS WHEN THE ATPS RATIO IS EQUAL TO OR GREATER THAN ONE

TYPE	EFFECTS		
	CONDITION 1	CONDITION 2	CONDITION 3
1	ATPS RATIO = OR > 1	STPD RATIO > ATPS RATIO	---
2	ATPS RATIO > 1	STPD RATIO < ATPS RATIO	STPD RATIO = OR > 1
3	ATPS RATIO, = OR > 1	STPD RATIO < 1	---
4	ATPS RATIO = OR > 1	STPD RATIO = ATPS RATIO	---

the effect of the difference between them adds to the ATPS ratio effect: increased O<sub>2</sub> concentration

STPD ratio effect counteracts but does not reverse the increased O<sub>2</sub> concentration effect of the ATPS ratio

STPD ratio effect reverses the ATPS ratio effect to yield a decreased O<sub>2</sub> concentration

only the ATPS ratio has an effect if it is greater than 1: increased O<sub>2</sub> concentration; no changes when it is equal to one

TABLE 4.2  
 INTERACTION EFFECTS OF ATPS AND STPD RATIOS WHEN THE ATPS RATIO IS SMALLER THAN ONE

TYPE	CONDITION 1	CONDITION 2	CONDITION 3	EFFECTS
5	ATPS RATIO < 1	STPD RATIO < ATPS RATIO	---	the effect of the difference between them adds to the ATPS ratio effect: decreased O <sub>2</sub> concentration
6	ATPS RATIO < 1	STPD RATIO > ATPS RATIO	STPD RATIO < 1	STPD ratio decreases but does not reverse the decreased O <sub>2</sub> concentration effect of the ATPS ratio
7	ATPS RATIO < 1	STPD RATIO = OR > 1	---	STPD ratio effect reverses the ATPS ratio effect maintaining (STPD = 1) or increasing (STPD > 1) the O <sub>2</sub> concentration
8	ATPS RATIO < 1	STPD RATIO = ATPS RATIO	---	only the ATPS ratio has an effect: decreased O <sub>2</sub> concentration

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The ATPS and STPD ratios were given a value of 1.00 at the start of each period in order to find out by statistical analysis if a significant change had occurred during the first minute of the period. For example, if the STPD ratio of a first minute of work was 1.00, it would mean that the oxygen consumed was completely replaced and that the oxygen concentration would be the same at the end of the first minute as it was at the start of the minute, all other things being equal.

#### Period I (resting values)

While the subjects remained at rest on the bicycle ergometer during this period, the oxygen concentration increased every minute by approximately 0.20 percent (table 4.3, figure 4.1). From 20.60 percent, it rose to 21.88 percent; the corresponding standard deviations were 0.25 and 0.82. The F ratio was significant at the 0.001 level. The Duncan multiple range test revealed significant differences between each minute.

At no time were carbon dioxide traces found in the system. It therefore exerted no influence on the oxygen concentration.

The ATPS ratio was 2.22 for the first minute but then decreased progressively each minute, down to 1.64. The F ratio was significant at the 0.001 level and the Duncan multiple range test revealed that there were no significant differences within any group of three consecutive minutes. The fact that the ratio was never smaller than 1.00 means that the oxygen consumption curve and the added oxygen curve were not kept parallel and that they always tended to approach each other. It can be seen from figure 4.1 that the oxygen consumption changed very little from minute to minute; the fact that the ATPS ratio decreased every minute indicates that the supply of oxygen was reduced from minute to minute, probably in an attempt to bring to two curves parallel to each other.

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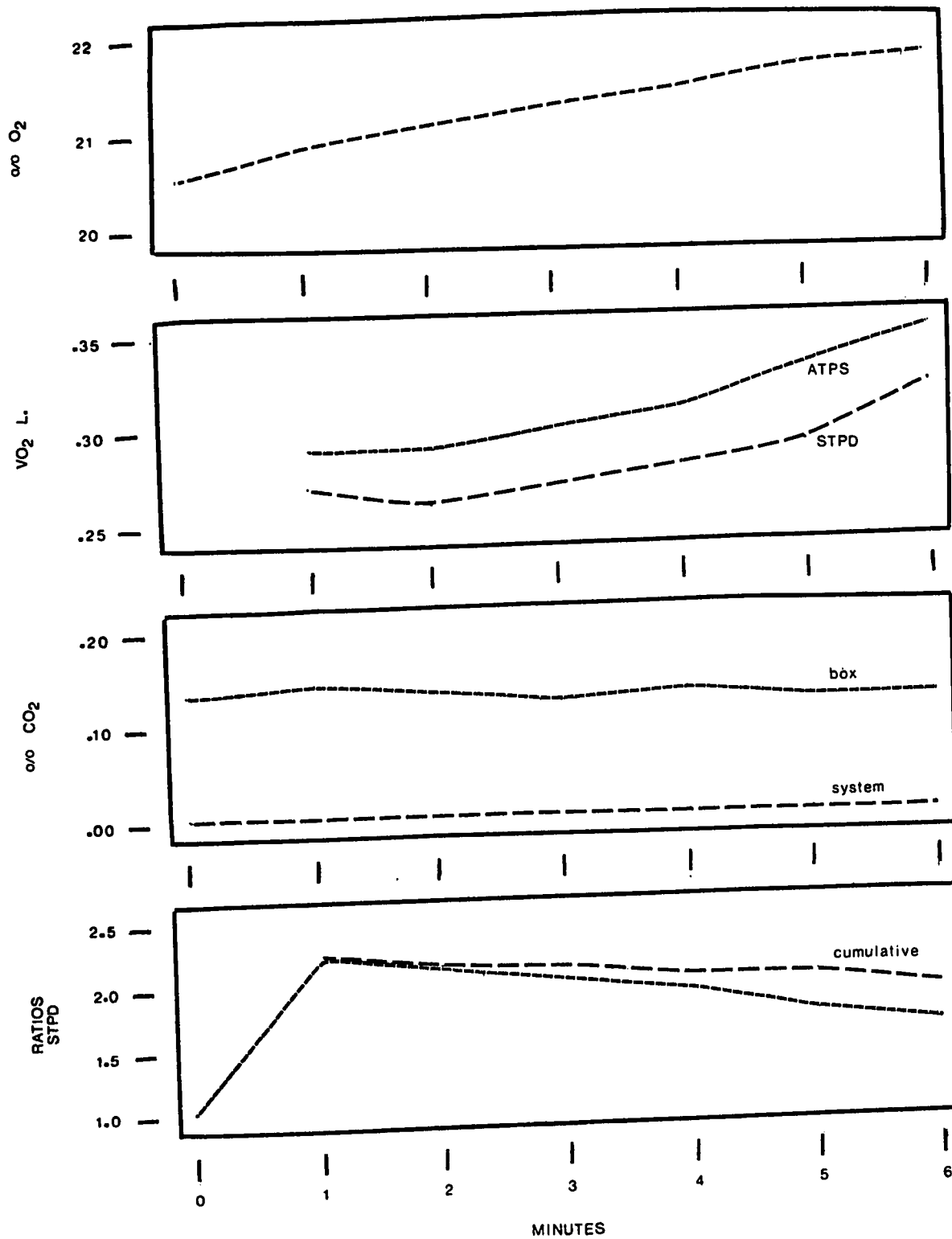
TABLE 4.3  
PERIOD I (REST) MEAN VALUES AND ANALYSIS OF VARIANCE RESULTS

VARIABLES	MINUTES						MEAN	F RATIO	SIGNIF. LEVEL	
	0	1	2	3	4	5				6
O <sub>2</sub> %	20.60	20.86	21.10	21.31	21.50	21.68	21.88	21.27	58.9	.001
$\dot{V}O_2$ L. ATPS	---	0.29	0.29	0.30	0.31	0.33	0.35	0.31	4.93	.001
$\dot{V}O_2$ L. STPD	---	0.27	0.26	0.27	0.28	0.29	0.32	0.28	5.03	.001
BOX CO <sub>2</sub> %	0.13	0.14	0.13	0.12	0.13	0.12	0.12	0.13	2.37	.05
SYSTEM CO <sub>2</sub> %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N.S.
ATPS RATIO	1.00	2.22	2.08	1.99	1.90	1.73	1.64	1.93*	17.5	.001
STPD RATIO	1.00	2.20	2.06	1.97	1.88	1.72	1.61	1.91*	18.1	.001
CUMULATIVE ATPS RATIO	---	2.22	2.15	2.10	2.05	1.98	1.93	1.93	---	---
CUMULATIVE STPD RATIO	---	2.20	2.13	2.08	2.03	1.97	1.91	1.91	---	---

\* mean of the last six minutes

FIGURE 4.1

PERIOD I. (REST) MEAN VALUES OF SEVEN VARIABLES



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The STPD ratio curve follows its corresponding ATPS ratio curve, progressively decreasing every minute from 2.20 to 1.61. Their respective standard deviations were 1.00 and 0.61. The F ratio was significant at the 0.001 level. The multiple range test yielded results identical to those of the ATPS ratio. The fact that the ratio was always greater than 1.00 means that the volume of oxygen consumed was always replaced with a larger volume of oxygen. During the first minute, more than twice the volume needed was added, while during the last minute 61 percent of the volume added was in excess. Except for the sixth minute it can be seen that the smaller the STPD ratio is, the smaller is the oxygen concentration increase for corresponding minutes. In other words the closer to 1.00 the ratio is, the smaller is the oxygen concentration increase.

Since the STPD ratio values were always smaller than the corresponding ATPS ratio values, the added oxygen was at a higher temperature than that of the consumed oxygen. Referring to table 4.1, we have a type two situation for every one of the six minutes in this period. This means that the oxygen concentration would have been slightly higher had the added and consumed oxygen temperatures been equal. In the present case the STPD ratio effect counteracts but does not reverse the increased oxygen concentration effect of the ATPS ratio.

The cumulative ATPS ratio ranged from 2.22 in the first minute to 1.93 in the last one which means that on the whole period the added oxygen volume (ATPS) was 1.93 times greater than the consumption volume (ATPS).

The cumulative STPD ratio followed the same pattern as the cumulative ATPS ratio but its values were slightly lower, ranging from 2.20 to 1.91. This means that on the average the added oxygen volume was 1.91 times greater than the volume consumed.

TABLE 4.4  
 PERIOD I (REST) DUNCAN MULTIPLE RANGE TEST RESULTS

MINUTES NOT SIGNIFICANTLY DIFFERENT (WITHIN PARENTHESES)

PROTECTION LEVEL:  $\alpha = 0.001$

PROTECTION LEVEL:  $\alpha = 0.05$

(0, 1) (1, 2) (2, 3) (3, 4) (5, 6)

(1, 2, 3, 4, 5) (3, 4, 5, 6)

(1, 3, 4, 5, 6) (1, 2, 3, 4, 5)

(0, 1, 2, 4) (0, 2, 3, 4, 5, 6)

(0, 1, 2, 3, 4, 5, 6)

(1, 2, 3, 4, 5) (2, 3, 4, 5, 6)

(1, 2, 3, 4) (2, 3, 4, 5, 6)

VARIABLES

O<sub>2</sub> %

$\dot{V}O_2$  L. ATPS

$\dot{V}O_2$  L. STPD

BOX CO<sub>2</sub> %

SYSTEM CO<sub>2</sub> %

ATPS RATIO

STPD RATIO

We have a type two situation (table 4.1) for the interaction of the cumulative ratios. When temperature differences of both oxygen volume are taken into account, the volume added according to the curve on the spiographic paper is reduced by two percent.

Throughout the period therefore the oxygen concentration was high enough to maintain arterial blood normally saturated.

#### Period II (100 watts)

At a work load of one hundred watts the oxygen concentration dropped of 0.68 percent during the first two minutes, from 20.49 to 19.86. The corresponding standard deviations were 0.41 and 0.56. Then, similar values were observed during the second and third minutes, after-times the concentration progressively increased until the sixth minute, reaching 20.31 percent, which is 0.18 percent lower than the initial value. The average concentration was 20.14 percent, which is 0.35 percent below the starting concentration. The F ratio was significant at the 0.001 level (table 4.5, figure 4.2).

At a protection level where  $\alpha$  is equal to 0.05, the Duncan multiple range test revealed that there was no significant difference between the concentration at the start of the period and that at the end of the period. There was also no significant difference among minutes one, five and six, between minutes four and five, and among minutes two, three and four. Where  $\alpha$  is equal to 0.001, the test revealed significant differences between the middle values of the period and the two values observed at each one of the extremities of the period (table 4.6).

No traces of carbon dioxide were observed during the entire period.

All ATPS ratios were above 1.00 except the 0.73 ratio of the first minute. From the second to the sixth minute they ranged from 1.06 to 1.10.

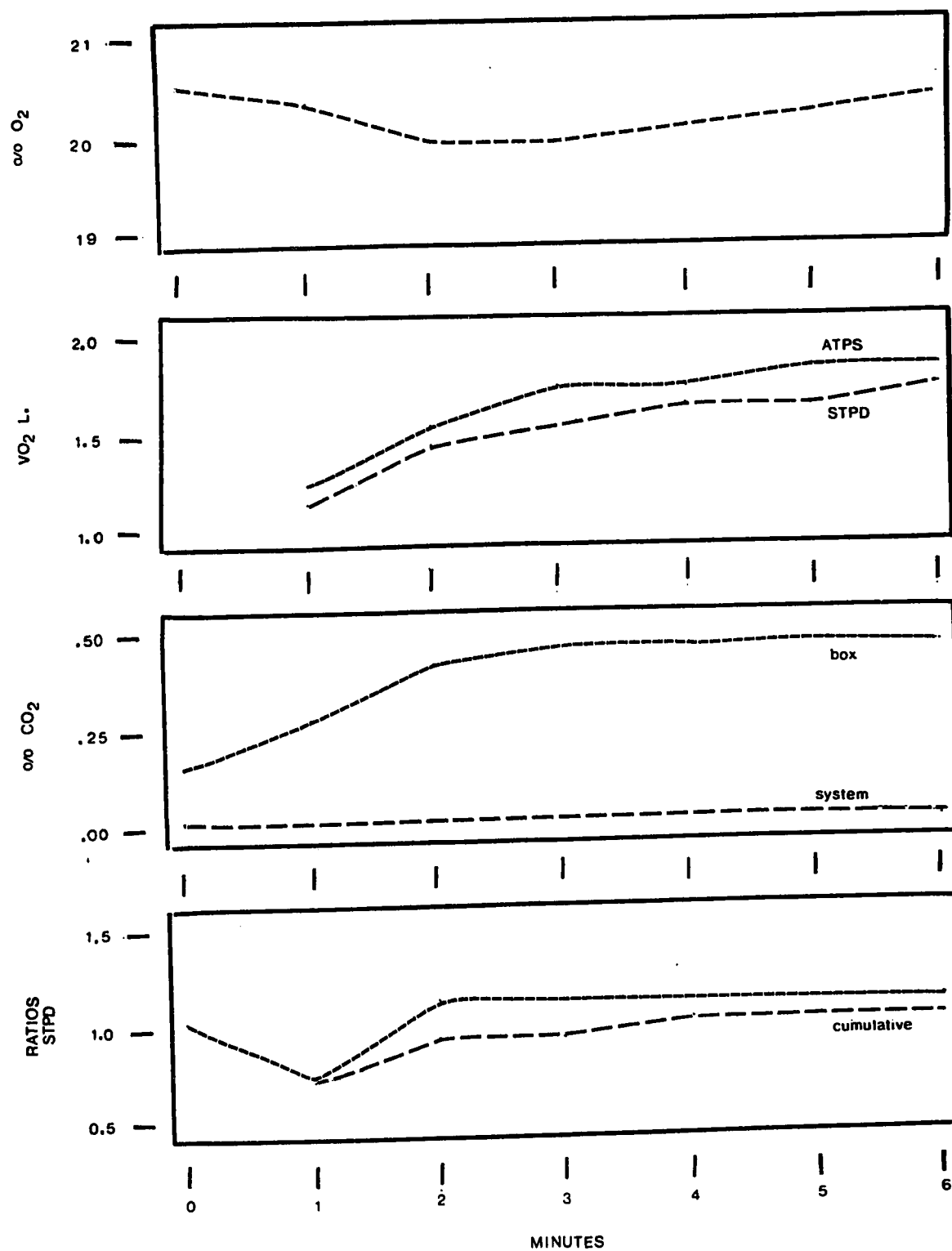
TABLE 4.5  
PERIOD II (100 WATTS) MEAN VALUES AND ANALYSIS OF VARIANCE RESULTS

VARIABLES	MINUTES							MEAN	F RATIO	SIGNIF. LEVEL
	0	1	2	3	4	5	6			
O <sub>2</sub> %	20.49	20.27	19.86	19.87	20.01	20.14	20.31	20.14	10.6	.001
$\dot{V}O_2$ L. ATPS	---	1.20	1.53	1.68	1.73	1.77	1.83	1.62	125.2	.001
$\dot{V}O_2$ L. STPD	---	1.09	1.39	1.52	1.57	1.60	1.66	1.47	127.6	.001
BOX CO <sub>2</sub> %	0.14	0.26	0.40	0.44	0.45	0.46	0.45	0.37	252.4	.001
SYSTEM CO <sub>2</sub> %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.43	N.S.
ATPS RATIO	1.00	0.73	1.08	1.06	1.08	1.10	1.08	1.02*	32.3	.001
STPD RATIO	1.00	0.73	1.07	1.06	1.08	1.06	1.07	1.01*	44.6	.001
CUMULATIVE ATPS RATIO	---	0.73	0.905	0.956	0.987	1.010	1.021	1.021	---	---
CUMULATIVE STPD RATIO	---	0.73	0.900	0.953	0.985	1.000	1.011	1.011	---	---

\* mean of the last six minutes

FIGURE 4.2

PERIOD II (100 WATTS) MEAN VALUES OF SEVEN VARIABLES



The F ratio was significant at the 0.001 level. According to the multiple range test, minutes zero and one differed significantly from each other and from the remaining minutes at a protection level where  $\alpha$  equals 0.05. When  $\alpha$  equals 0.001 the same results were obtained with the same grouping; furthermore, there was no difference among minutes 0, 2, 3, 4 and 6 (table 4.6).

The added and consumed oxygen curves were not kept parallel. Except for the first minute the added oxygen slope was always greater: the quantities added ranged from 1.06 to 1.10 liters (ATPS) of oxygen were added for every liter (ATPS) consumed. The low ratio of the first minute reveals that the oxygen supply was not increased as the consumption increased with the start of work. The adjustment made for the second minute seems to have been maintained during the third minute since a slight consumption increase was accompanied by a slight ratio decrease. The supply was then increased during the fourth and fifth minute a little more than the consumption increase (table 4.5, figure 4.2).

The STPD ratio curve is similar to the ATPS ratio curve. Its values are slightly lower, ranging from 0.73 to 1.08 with respective standard deviations of 0.14 and 0.08. The F ratio was significant at the 0.001 level. The multiple range test results were similar to those of the ATPS ratio except that the fifth minute was included in the group of minutes not significantly different ( $\alpha = 0.001$ ); therefore only the first minute was different from the others; in the analysis of the oxygen concentration, it was the second minute that was different from all other minutes. This reflects the time lag in the analysis of the oxygen sample.

During the first minute only seventy-three percent of the volume consumed was replaced. The situation was well corrected for the remaining

TABLE 4.6  
 PERIOD II (100 WATTS) DUNCAN MULTIPLE RANGE TEST RESULTS

MINUTES NOT SIGNIFICANTLY DIFFERENT (WITHIN PARENTHESES)

PROTECTION LEVEL:  $\alpha = 0.001$

PROTECTION LEVEL:  $\alpha = 0.05$

(0, 1, 5, 6) (1, 4, 5, 6) (2, 3, 4, 5)

(2, 3, 4) (4, 5, 6)

(3, 4, 5) (4, 5, 6)

(3, 4, 5, 6)

(0, 1, 2, 3, 4, 5, 6)

(2, 3, 4, 5, 6) (0, 2, 3, 4, 6)

(0, 2, 3, 4, 5, 6)

VARIABLES

O<sub>2</sub> %

$\dot{V}O_2$  L. ATPS

$\dot{V}O_2$  L. STPD

BOX CO<sub>2</sub> %

SYSTEM CO<sub>2</sub> %

ATPS RATIO

STPD RATIO

of the period as every minute an excess of six to eight percent of oxygen was added. It can be seen from figure 4.2 that every minute's excess contributed in raising the oxygen concentration back towards its initial value after it had decreased to 19.86 percent in the second minute. Although the STPD ratios did not differ significantly, that of the first minute excepted, the oxygen concentration levels were significantly different from the initial value until the fifth minute.

Considering the interaction of both ratios we have a type eight situation (table 4.2) for the first minute since both were equal and inferior to one. The decreased oxygen concentration can be attributed to a lack of oxygen supply only since the temperatures of the added and consumed oxygen were measured equal. The third and fourth minutes are type four situation while the second, fifth and sixth minutes are type two situations (table 4.1).

The cumulative ATPS ratio which ranged from 0.73 to 1.02 indicates that an excess of twenty milliliters of oxygen were added for each liter of oxygen consumed.

The cumulative STPD ratio which ranged from 0.73 to 1.01 indicates that an excess of oxygen as little as ten milliliters per liter consumed was sent into the system. This amount being smaller than the error of measurement, the consumed volume can be considered to have been well replaced on the average. Although the final concentration is lower than the initial one, it was not significantly different from it.

The interaction of the cumulative ratios is described in the type two situation of table 4.1. When temperature differences of both oxygen volumes are taken into account, the volume added according to the curve on the spiographic paper is reduced by one percent.

Even at the lowest concentrations observed in the second and third minutes the arterial blood's saturation was derived as being above ninety-four percent. The ventilation and the heart rate are therefore believed not to have been affected by a significant amount.

#### Period III (150 watts)

The experimental and statistical analysis results of period three are given in table 4.7 and 4.8 and in figure 4.3. At a work load of one hundred and fifty watts the oxygen concentration markedly decreased from the start of the period to the third minute, passing from 20.60 to 19.50 percent. Further smaller decreases were observed during the fourth and fifth minutes, the lowest concentration being 19.42 percent. The total drop was 1.18 percent. The oxygen concentration increased to 19.56 in the sixth minute. The mean was 19.80 percent, 0.80 percent below the starting value. The standard deviations ranged from 0.17 to 0.86. The F ratio was significant at the 0.001 level.

At a protection level where  $\alpha$  equals 0.001 the multiple range test results indicate that the first two observations were not statistically different from each other, but differed from the last five observations; these five did not differ from one another.

The concentration of carbon dioxide was 0.01 in the first three minutes, 0.02 in the fourth minute and 0.03 in the fifth and sixth minutes. The F ratio was significant at the 0.001 level. According to the multiple range test when  $\alpha$  equals 0.05, only identical concentrations did not differ significantly from one another; when  $\alpha$  equals 0.001, minutes with a difference of 0.01 were not considered significantly different.

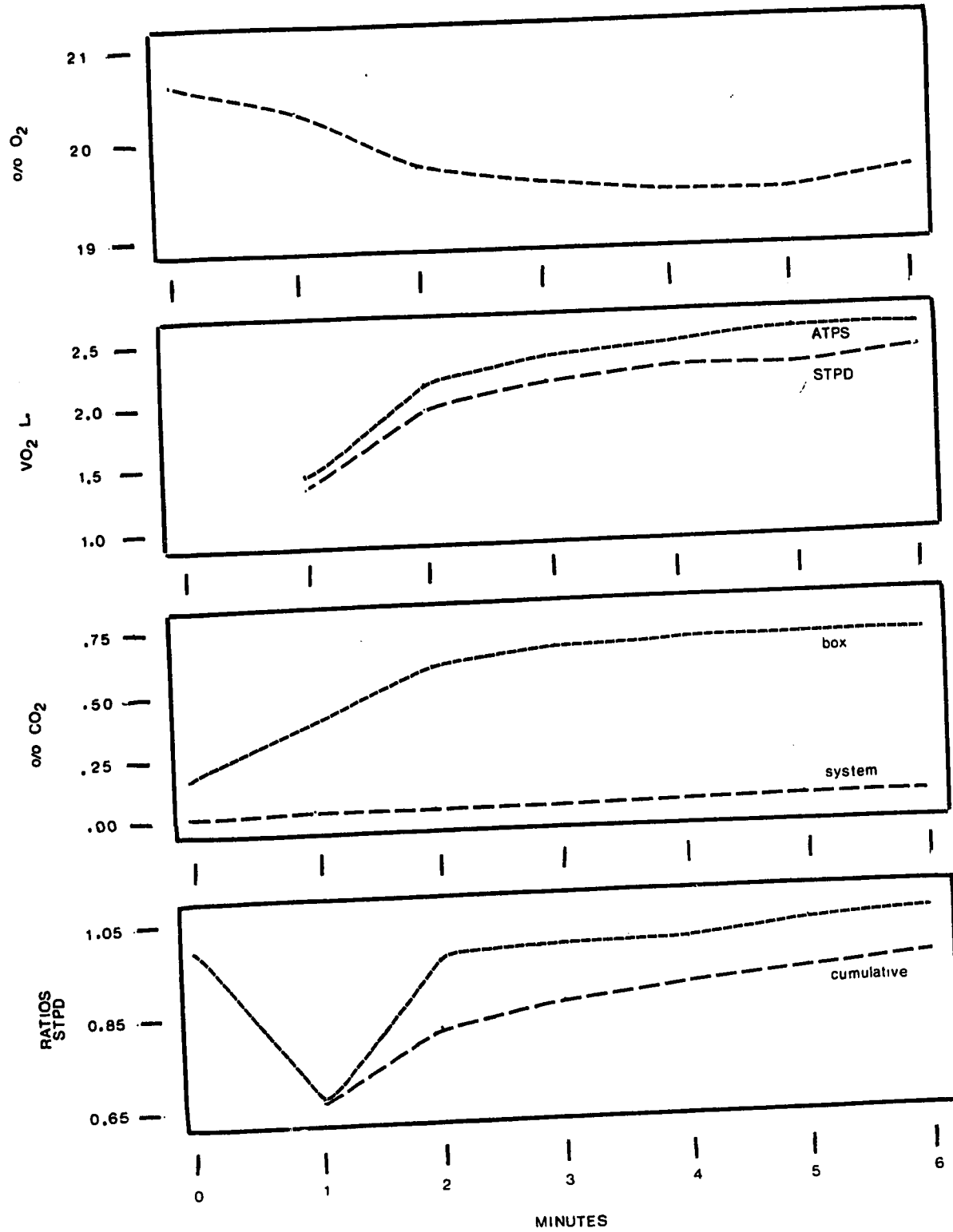
Even the highest percentage of carbon dioxide in the period had practically no influence on the oxygen concentration. Since the latter

TABLE 4.7  
PERIOD III (150 WATTS) MEAN VALUES AND ANALYSIS OF VARIANCE RESULTS

VARIABLES	MINUTES							MEAN	F RATIO	SIGNIF. LEVEL
	0	1	2	3	4	5	6			
	O <sub>2</sub> %	20.60	20.35	19.74	19.50	19.44	19.42			
$\dot{V}O_2$ L. ATPS	---	1.41	2.06	2.29	2.39	2.45	2.50	2.18	242.9	.001
$\dot{V}O_2$ L. STPD	---	1.28	1.86	2.07	2.16	2.23	2.26	1.98	242.1	.001
BOX CO <sub>2</sub> %	0.15	0.37	0.58	0.65	0.67	0.68	0.68	0.54	429.2	.001
SYSTEM CO <sub>2</sub> %	0.0	0.01	0.01	0.01	0.02	0.03	0.03	0.016	15.8	.001
ATPS RATIO	1.00	0.77	0.99	1.00	1.01	1.04	1.05	0.98*	26.3	.001
STPD RATIO	1.00	0.76	0.98	1.00	1.00	1.03	1.04	0.97*	27.3	.001
CUMULATIVE ATPS RATIO	---	0.77	0.88	0.92	0.94	0.96	0.98	0.98	---	---
CUMULATIVE STPD RATIO	---	0.76	0.87	0.91	0.93	0.95	0.97	0.97	---	---

\* mean of the last six minutes

FIGURE 4.3  
 PERIOD III (150 WATTS) MEAN VALUES OF SEVEN VARIABLES



changed by about twenty percent of the amount of carbon dioxide present, it was only altered by 0.006 percent, a change too small to be detected by the oxygen analyzer.

Except for the 0.77 ATPS ratio of the first minute the others were very close to 1.00, ranging from 0.99 to 1.05. The F ratio was significant at the 0.001 level. The results of the multiple range test indicated no significant difference among minutes 0, 2, 3, 4, 5 and among minutes 0, 3, 4, 5, 6.

In the first minute there was an important gap between the added and consumption oxygen curves; they were kept almost parallel in the second, third and fourth minutes; finally, the added oxygen volume was 1.04 and 1.05 times greater than the consumption volume in the fifth and sixth minute respectively.

Except for the first minute, the ratios revealed that the oxygen supply was increased as the oxygen consumption increased. The last two ratios revealed a tendency to keep on increasing regularly the supply even though a relative steady state was reached. According to the multiple range test when  $\alpha$  equals 0.001, the oxygen consumption values (ATPS) did not differ in the last three minutes. The three ratios above 1.00 in this period were obtained at these times.

The STPD ratio values were in general slightly lower than those of the ATPS ratio. They ranged from 0.76 to 1.04 with respective standard deviations of 0.16 and 0.06. The F ratio was significant at the .001 level. The multiple range test results were identical to those of the ATPS ratio.

During the first minute, only seventy-six percent of the volume consumed was replaced; during the second, ninety-eight percent was replaced;

TABLE 4.8  
 PERIOD III (150 WATTS) DUNCAN MULTIPLE RANGE TEST RESULTS

VARIABLES	MINUTES NOT SIGNIFICANTLY DIFFERENT (WITHIN PARENTHESES)	
	PROTECTION LEVEL: $\alpha = 0.05$	PROTECTION LEVEL: $\alpha = 0.001$
O <sub>2</sub> %	(2, 6) (3, 4, 5, 6)	(0, 1) (2, 3, 4, 5, 6)
$\dot{V}O_2$ L. ATPS	(5, 6)	(4, 5, 6) (3, 4)
$\dot{V}O_2$ L. STPD	(5, 6)	(4, 5, 6) (3, 4)
BOX CO <sub>2</sub> %	(3, 4, 5, 6)	(3, 4, 5, 6)
SYSTEM CO <sub>2</sub> %	(1, 2, 3) (5, 6)	(0, 1) (1, 2, 3, 4) (4, 5, 6)
ATPS RATIO	(0, 2, 3, 4, 5) (0, 3, 4, 5, 6)	(0, 3, 4, 5, 6) (0, 2, 3, 4, 5)
STPD RATIO	(0, 3, 4, 5, 6) (0, 2, 3, 4, 5)	(0, 3, 4, 5, 6) (0, 2, 3, 4, 5)

in the third and fourth minutes the consumed volume was completely replaced without excess as it was the case in the fifth and sixth minutes. The major drop in the oxygen concentration was observed in the second minute. It can be associated with the low ratio of the first minute since a close look at the results seem to indicate a lag in the sampling and analyser response time. In fact, the drop of 0.61 percent in the oxygen concentration observed in the second minute is much too big to be attributed to the 0.98 ratio of that minute, as the drop of 0.24 percent in the third minute is too important to be attributed to the ratio of 1.00. Similarly, the slight excess of oxygen sent during the fifth minute was perceived, in terms of oxygen concentration, in the sixth minute only.

Considering the interaction of both ratios, we had a type five situation in the two first minutes where the temperature difference between the two oxygen volumes contributed to decrease the oxygen concentration; it remains difficult to quantify this effect. In the third minute both ratios were equal to 1.00. The last three minutes were type two situations.

The cumulative ATPS ratio which ranged from 0.77 to 0.98 indicates that the added oxygen curve parted from the consumption curve by about twenty milliliters per liter of oxygen consumed.

The cumulative STPD ratio indicates that on the whole period ninety-seven percent of the volume consumed was replaced. During the six minutes a total of 11.86 liters were consumed. The three percent of this volume that was not replaced represents approximately 360 milliliters. Meanwhile the oxygen concentration decreased by approximately one percent.

The interaction effect of the cumulative ratios is identical to that of period II.

The oxygen concentrations were within acceptable physiological limits as in the previous periods.

Period IV (200 watts)

The experimental and statistical analysis results of period four are presented in table 4.9 and 4.10 and in figure 4.4. At a work load of two hundred watts a remarkable oxygen concentration decrease was observed during the three first minutes where it dropped of 1.48 percent, from 20.53 to 19.05. Thereafter the concentration progressively increased up to 19.73 in the sixth minute, 0.80 percent below the starting value. The mean concentration of 19.63 was 0.90 percent lower than the initial value. The standard deviation of the initial concentration was 0.32, that of the third minute was 0.62 and that of the sixth was 1.09.

The F ratio was significant at the .001 level. At a protection level where  $\alpha$  equals 0.05 the multiple range test revealed that minutes zero and one were significantly different and that they were different from all other minutes. Minute five was not different from two and four but was different from six. When  $\alpha$  equals 0.001, minute zero and one were not different from each other but were different from all the other minutes. Two, five and six did not differ, as did not two, three, four and five.

During the first minute the carbon dioxide concentration passed from zero to 0.04 percent, thereafter increasing by 0.02 percent in the second as well as in the third minute. The concentration of the fourth which was identical to that of the third increased by .01 percent in the fifth and in the sixth minute. The F ratio was significant at the 0.001 level. When  $\alpha$  equals 0.05, only minutes three and four were not different from each other. When it equals 0.001, the third, fourth and fifth were not different, nor were the fifth and sixth.

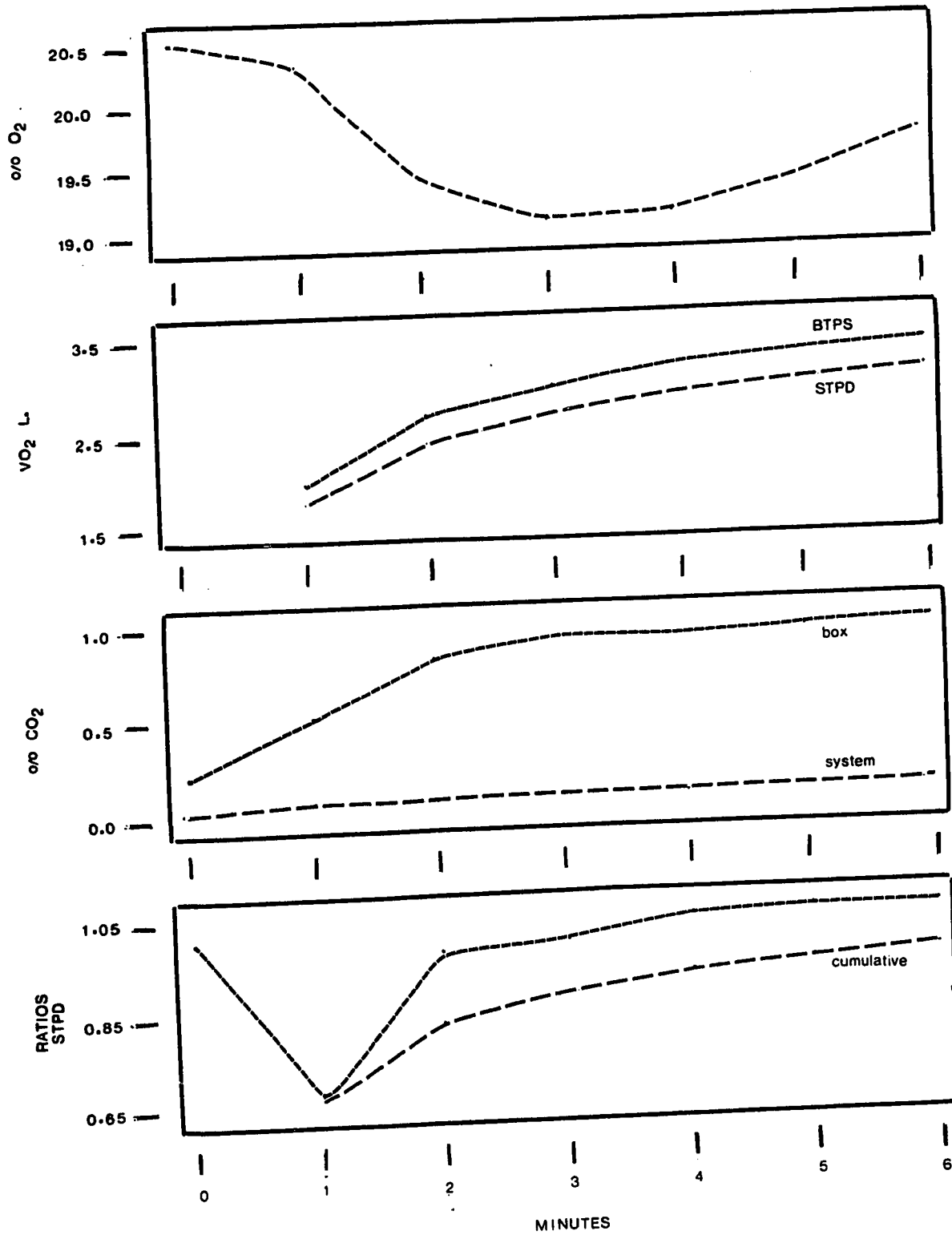
Had the final oxygen concentration been twenty percent, the highest carbon dioxide concentration observed would have caused a drop of only 0.02

TABLE 4.9  
PERIOD IV (200 WATTS) MEAN VALUES AND ANALYSIS OF VARIANCE RESULTS

VARIABLES	MINUTES							MEAN	F RATIO	SIGNIF. LEVEL
	0	1	2	3	4	5	6			
	$O_2$ %	20.53	20.25	19.35	19.05	19.11	19.37			
$\dot{V}O_2$ L. ATPS	---	1.87	2.56	2.94	3.09	3.24	3.32	2.84	214.6	.001
$\dot{V}O_2$ L. STPD	---	1.70	2.32	2.66	2.80	2.94	3.01	2.58	211.8	.001
BOX $CO_2$ %	0.17	0.45	0.80	0.91	0.93	0.95	0.96	0.74	699.1	.001
SYSTEM $CO_2$ %	0.00	0.04	0.06	0.08	0.08	0.09	0.10	0.64	88.8	.001
ATPS RATIO	1.00	0.67	0.97	0.99	1.04	1.06	1.06	0.96*	80.5	.001
STPD RATIO	1.00	0.67	0.97	0.99	1.04	1.05	1.05	0.96*	82.7	.001
CUMULATIVE ATPS RATIO	---	0.67	0.82	0.88	0.92	0.95	0.96	0.96	---	---
CUMULATIVE STPD RATIO	---	0.67	0.82	0.88	0.92	0.94	0.96	0.96	---	---

\* mean of the last six minutes

FIGURE 4.4  
PERIOD IV (200 WATTS) MEAN VALUES OF SEVEN VARIABLES



percent in the oxygen concentration. The mean effect would have been a decrease of 0.003 percent per minute. Since the final concentration was slightly lower than twenty, the effects were slightly lower than the above mentioned ones.

Following a low first ATPS ratio of 0.67 were ratios of 0.97 and 0.99 in the second and third minutes. That of the fourth minute was 1.04 while those of the fifth and sixth equalled 1.06. The F ratio was significant at the 0.001 level. The Duncan multiple range test revealed no difference among minutes zero, two and three, between minutes zero and four and finally among minutes four, five and six ( $\alpha = 0.05$ ). When the higher protection level was used no difference was obtained among 0, 2, 3, 4 nor among 0, 3, 4, 5, 6.

The mean ratio indicates that the consumption curve was four percent greater than the added oxygen curve. Except for the first minute, the oxygen supply was adjusted every minute in function of the consumption increment. Until a certain form of plateau was neared the supply was slightly insufficient while it exceeded the demand afterwards, that is, the supply was increased as if no form of plateau were reached. In this regard, period three was identical to this one.

The STPD ratio values differed from those of the ATPS ratio in the fifth and sixth minutes only. They ranged from 0.67 to 1.05 with corresponding standard deviations of 0.08 and 0.05. The F ratio was significant at the .001 level. The multiple range test results were identical to those of the ATPS ratio.

The first minute ratio means that only sixty-seven percent of the volume consumed was replaced. It must be the main cause of the relatively large oxygen concentration drop in the period. The effect of this oxygen

TABLE 4.10  
 PERIOD IV (200 WATTS) DUNCAN MULTIPLE RANGE TEST RESULTS

VARIABLES	MINUTES NOT SIGNIFICANTLY DIFFERENT (WITHIN PARENTHESES)	
	PROTECTION LEVEL: $\alpha = 0.05$	PROTECTION LEVEL: $\alpha = 0.001$
O <sub>2</sub> %	(2, 3, 4) (2, 4, 5)	(0, 1) (2, 5, 6) (2, 3, 4, 5)
$\dot{V}O_2$ L. ATPS	(5, 6)	(3, 4) (4, 5) (5, 6)
$\dot{V}O_2$ L. STPD	(5, 6)	(3, 4) (4, 5) (5, 6)
BOX CO <sub>2</sub> %	(4, 5, 6) (3, 4)	(3, 4, 5, 6)
SYSTEM CO <sub>2</sub> %	(3, 4)	(5, 6) (3, 4, 5)
ATPS RATIO	(0, 2, 3) (0, 4) (4, 5, 6)	(0, 2, 3, 4) (0, 3, 4, 5, 6)
STPD RATIO	(0, 2, 3) (4, 5, 6)	(0, 2, 3, 4) (0, 3, 4, 5, 6)

lack on the oxygen concentration was recorded mainly in the second minute because of the time lag in the sampling and analysing systems. To an STPD ratio greater than one corresponded an increase in the oxygen concentration.

Analysing the interactions of both ratios, type eight situations were found up to the fourth minute, the remaining minutes being type two situations (table 4.1). The temperature of both oxygen volumes were approximately equal most of the time; they could therefore be compared at their ATPS conditions to determine whether or not the consumed molecules were replaced.

The cumulative ATPS ratio was 0.96 at the end of the sixth minute. It indicates that throughout the period the average lack of added oxygen was approximately thirty-five milliliters per added liter when the volumes are kept at their ambient temperatures.

The cumulative STPD ratio of 0.96 reveals that the oxygen supply should have been increased by approximately forty milliliters STPD for each one of the fifteen liters consumed on the average in this period. The deficit was about six hundred milliliters.

Although the subjects breathed air with a mean oxygen concentration of 19.6 percent throughout the period, the arterial blood saturation may have decreased by an estimated two percent; this is an acceptable reduction of oxygen from a physiological point of view.

#### Period V (250-325 watts)

The experimental and statistical analysis results of period five are presented in table 4.11 and 4.12 and in figure 4.5. Significant differences were observed within the period for all variables (0.001).

As the work load progressively increased from 250 to 325 watts during the period, the oxygen concentration progressively decreased from

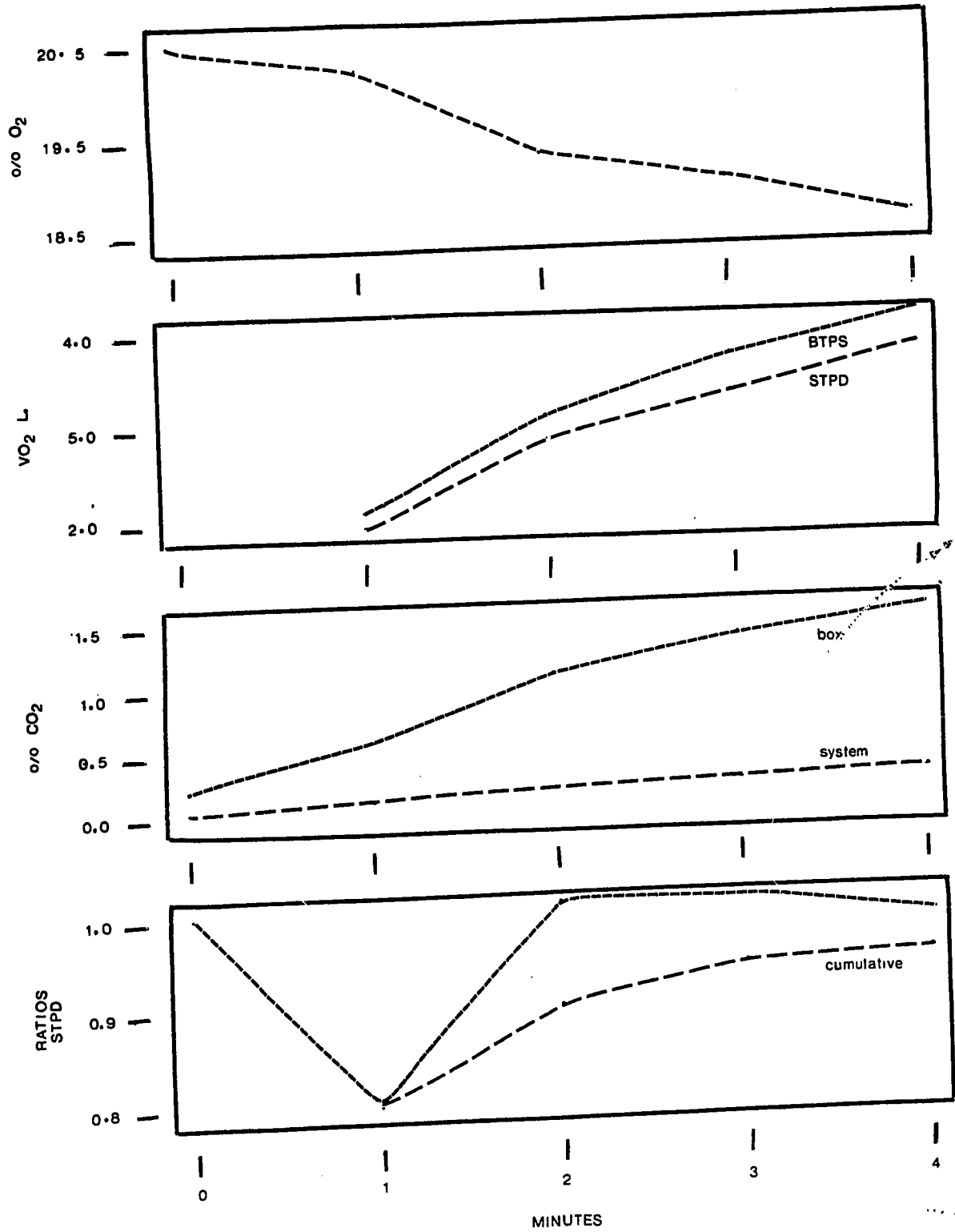
TABLE 4.11  
 PERIOD V (250-325 WATTS) MEAN VALUES AND ANALYSIS OF VARIANCE RESULTS

VARIABLES	MINUTES					MEAN	F RATIO	SIGNIF. LEVEL
	0	1	2	3	4			
O <sub>2</sub> %	20.45	20.20	19.32	18.99	18.56	19.56	46.1	.001
$\dot{V}O_2$ L. ATPS	---	2.12	3.12	3.67	4.15	3.26	416.9	.001
$\dot{V}O_2$ L. STPD	---	1.92	2.83	3.32	3.76	2.96	408.2	.001
BOX CO <sub>2</sub> %	0.19	0.56	1.08	1.36	1.55	0.95	656.3	.001
SYSTEM CO <sub>2</sub> %	0.01	0.09	0.16	0.20	0.25	0.14	115.0	.001
ATPS RATIO	1.00	0.80	1.00	1.02	1.00	0.95*	16.1	.001
STPD RATIO	1.00	0.80	1.01	1.01	0.99	0.95*	17.0	.001
CUMULATIVE ATPS RATIO	---	0.80	0.90	0.94	0.95	0.95	---	---
CUMULATIVE STPD RATIO	---	0.80	0.90	0.94	0.95	0.95	---	---

\* mean of the last four values

FIGURE 4.5

PERIOD V (250-325 WATTS) MEAN VALUES OF SEVEN VARIABLES



20.45 to 18.86 percent, with respective standard deviations of 0.35 and 1.12. Although it was the shortest period of work its oxygen concentration drop of 1.59 percent was the greatest observed during a period. The mean concentration of 19.56 was 0.89 percent lower than the initial concentration.

At the protection level obtained with an  $\alpha$  of 0.05 there was no significant differences between the initial and first minute concentrations and between those of the third and fourth minutes. With an  $\alpha$  of .001 the results were the same; in addition the second minute is included with the third and fourth. Therefore the two first observed concentrations were statistically different from the three last ones.

The major increase in the carbon dioxide concentration was observed after the first minute as it reached 0.09 percent. Thereafter the increment was about 0.05 percent per minute. The only two values not considered different were those of the second and third minutes ( $\alpha = 0.001$ ). The concentration of 0.25 percent (S.D. 0.11) caused an oxygen concentration decrease of about 0.05 percent during the period. Without the presence of carbon dioxide the final oxygen concentration would have been approximately 18.90 instead of 18.86 percent.

Following a low first minute ATPS ratio of 0.80 were ratios of 1.00, 1.02 and 1.00. The first one was significantly different from all others. Its standard deviation was 0.16 while that of the fourth was 0.06.

Although the added oxygen and consumption curves were kept parallel during the last three minutes the mean ratio of 0.95 indicates that the added oxygen slope was five percent smaller on the whole. During the last three minutes the minute consumption increments were accompanied by adequate minute oxygen supply increments.

TABLE 4.12  
 PERIOD V (250-325 WATTS) DUNCAN MULTIPLE RANGE TEST RESULTS

VARIABLES	MINUTES NOT SIGNIFICANTLY DIFFERENT (WITHIN PARENTHESES)	
	PROTECTION LEVEL: $\alpha = 0.05$	PROTECTION LEVEL: $\alpha = 0.001$
O <sub>2</sub> %	(0, 1) (3, 4)	(0, 1) (2, 3, 4)
$\dot{V}O_2$ L. ATPS	-----	-----
$\dot{V}O_2$ L. STPD	-----	-----
BOX CO <sub>2</sub> %	-----	-----
SYSTEM CO <sub>2</sub> %	-----	(2, 3)
ATPS RATIO	(0, 2, 3, 4)	(0, 2, 3, 4)
STPD RATIO	(0, 2, 3, 4)	(0, 2, 3, 4)

Compared to those of the ATPS ratio, the STPD ratio values were equal in the first minute, greater by one percent in the second and smaller by one percent in the third and fourth. The first minute ratio was significantly different from all others. As for the oxygen concentration, minutes two, three and four were not different.

Eighty percent of the oxygen consumed in the first minute was replaced. As previously explained, it is believed that the oxygen concentration reading made at the end of the first minute did not correspond in time to the actual concentration at the end of that minute. The drop between the first and second minutes was large in regard of the 1.01 ratio of the second minute. Further away in the period slight concentration decreases were observed in spite of the 1.01 ratios of the second and third minutes.

The interactions of both ratios are described in the type eight situation for the first minute, in the type one for the second, in the type two for the third and in the type three for the fourth (table 4.1 and 4.2). In general the temperature differences between the added and consumed oxygen cannot have affected much the oxygen concentration.

In fact both cumulative ratios were equal at the end of the period. They reveal that the oxygen supply should have been increased by approximately fifty milliliters STPD for each of the thirteen liters consumed on the average in this period. The total deficit amounted to about six hundred and fifty milliliters.

In this period the oxygen concentration was closer than in the other periods to the eighteen percent level below which physiological reactions normally appear because of a lowered blood oxygen pressure. Such could be the case at work loads nearing four hundred watts per minute if the trend observed in the period persisted.

## CARBON DIOXIDE

The experimental results are presented in table 4.13 and figures 4.6 and 4.7. Although they were described at each period in the discussions on the oxygen concentration they are grouped hereunder for ease of interpretation.

No traces of carbon dioxide were observed in the system during the two first periods (figure 4.8) while the highest percentage recorded in the box was 0.46 (figure 4.7). The oxygen consumption at the end of the one hundred watt period was 1.6 liters per minute.

During the third period the concentration progressively increased up to 0.03% (figure 4.6) in the system and 0.68% (figure 4.7) in the box. The oxygen consumption was then 2.2 liters per minute. At the end of period III (200 watts) requiring a minute consumption of three liters the concentration reached 0.10% (figure 4.6) in the system and 0.96% (figure 4.7) in the box. The fifth period final concentrations were 0.25% (figure 4.6) in the system and 1.55% (figure 4.7) in the box. The minute oxygen consumption was 3.76 liters.

As in Roskamm's study, no carbon dioxide was found in this study for work loads up to one hundred watts. At one hundred and fifty watts he reported an average value of 0.08 while ours was 0.03. At two hundred and fifty watts we observed 0.10% while he recorded 0.165%. At three hundred watts the carbon dioxide in their system accounted for 0.40% of the inspired air while our corresponding value was 0.20%. Therefore, except at lighter work loads, Roskamm observed higher carbon dioxide concentrations in the system than we did in this study.

TABLE 4.13  
BOX AND SYSTEM MEAN CARBON DIOXIDE CONCENTRATIONS FOR EACH MINUTE OF EACH PERIOD

LOCATION	PERIODS	MINUTES						MEAN	
		0	1	2	3	4	5		6
SYSTEM	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3	0.0	0.01	0.01	0.01	0.02	0.03	0.03	0.016
	4	0.0	0.04	0.06	0.08	0.08	0.09	0.10	0.064
	5	0.01	0.09	0.16	0.20	0.25	---	---	0.14
BOX	1	0.13	0.14	0.13	0.12	0.13	0.12	0.12	0.13
	2	0.14	0.26	0.40	0.44	0.45	0.46	0.45	0.39
	3	0.15	0.37	0.58	0.65	0.67	0.68	0.68	0.54
	4	0.17	0.45	0.80	0.91	0.93	0.95	0.96	0.74
	5	0.19	0.56	1.08	1.36	1.55	---	---	0.95

FIGURE 4.6  
SYSTEM CARBON DIOXIDE CONCENTRATIONS FOR EACH MINUTE OF EACH PERIOD

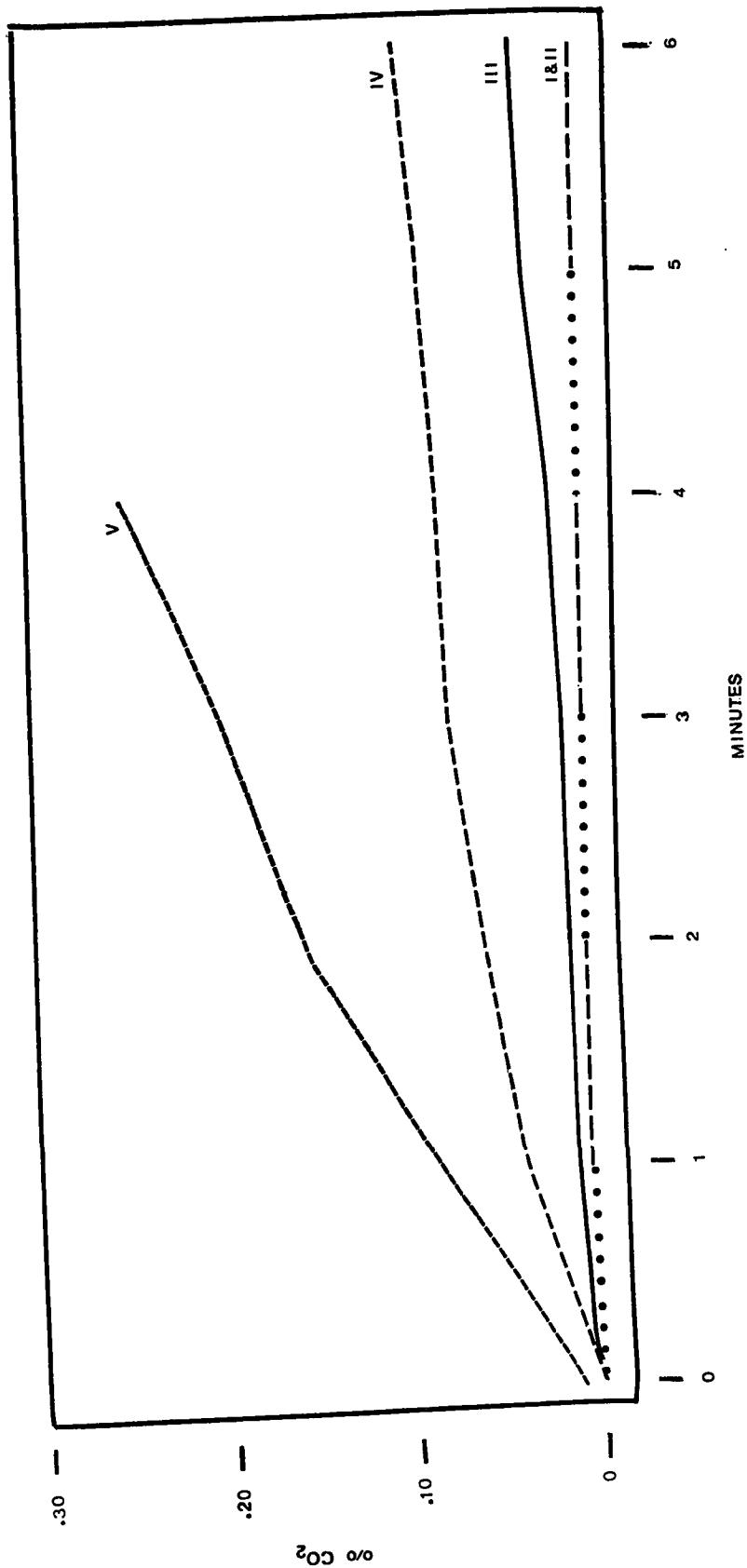


FIGURE 4.7  
BOX CARBON DIOXIDE CONCENTRATIONS FOR EACH MINUTE OF EACH PERIOD

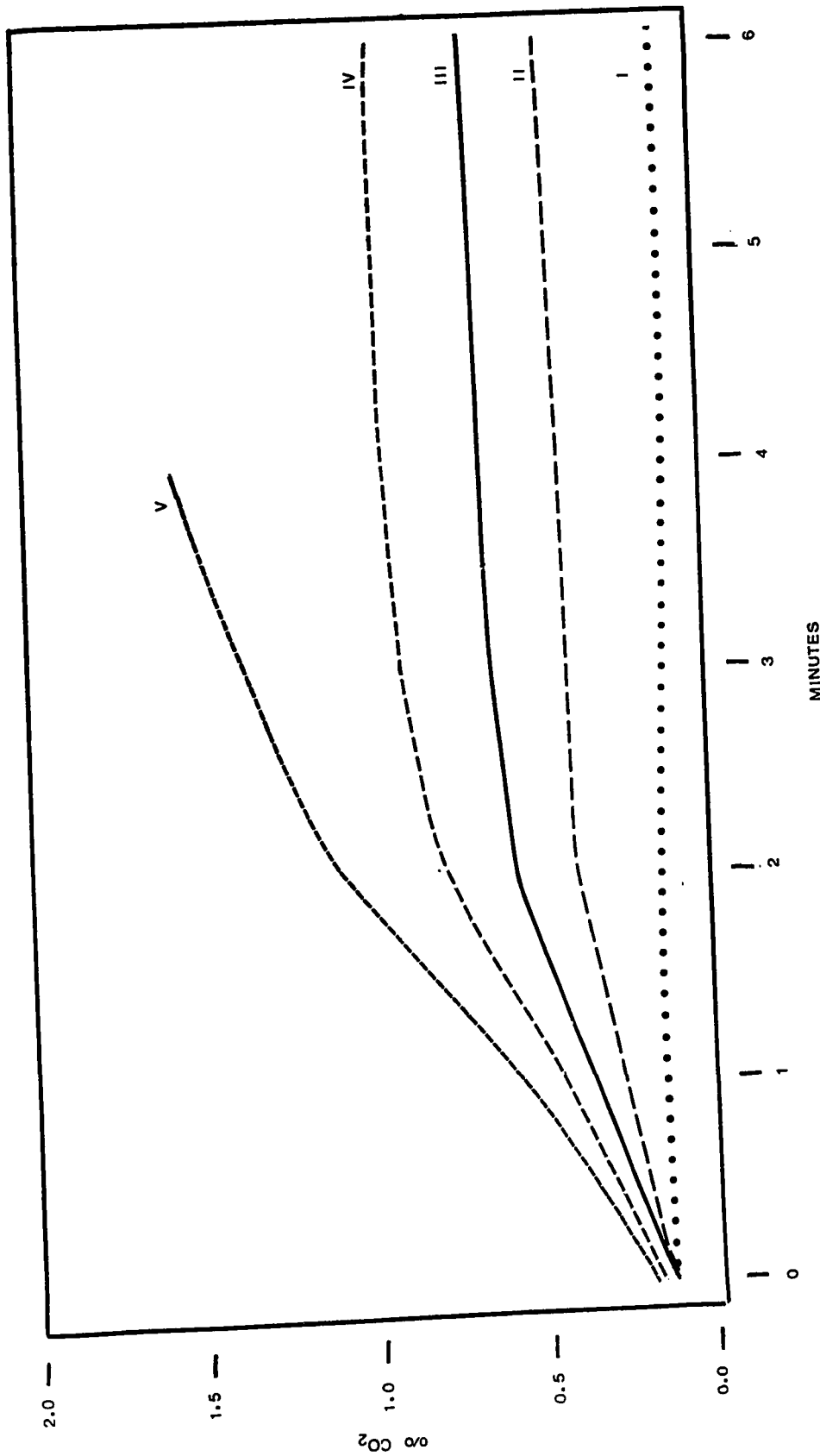


Table 4.14 summarizes the percentage of carbon dioxide absorption for every minute of each period. At the end of the third, fourth and fifth period the percentages of carbon dioxide not absorbed were 4.4, 10.4 and 16.1, respectively.

A certain error is introduced in the computation of oxygen consumption when carbon dioxide is introduced into the system since the consumption is thought to be equal to the total system volume decrease. When the spirometer volume and carbon dioxide concentration are known, the subestimation of oxygen consumption can be found from figure 4.8. The writer has quantitatively estimated that the spirometer volume, without the balance bell, is at least fifty liters. Had the oxygen consumption been computed for the last minute of each period, the subestimation would have been negligible at the end of period three while it would have been of fifty milliliters at the end of the fourth. Subestimations of consumptions at loads of 275, 300 and 325 watts would have been of 75, 100 and 125 milliliters, respectively. In spirometer systems of sixty and seventy liters, the error would have been of 150 and 175 milliliters, respectively.

Even though carbon dioxide was detected in the third period (table 4.13), its concentration was that normally existing in ambient atmospheric air. The subjects' ventilatory response to work was not therefore abnormally influenced by the presence of carbon dioxide.

The 0.1 percent concentration at the end of the fourth period (table 4.13) probably just barely affected the mean ventilation per minute commanded by the two-hundred watt load. The increase in ventilation caused by the breathing of some carbon dioxide would most probably be less than one liter since a one percent concentration raises the  $P_{A_{CO_2}}$  by only one

FIGURE 4.8  
UNDERESTIMATION OF  $\dot{V}O_2$  AT VARIOUS  $CO_2$   
CONCENTRATIONS IN DIFFERENT SIZES OF SPIROMETER

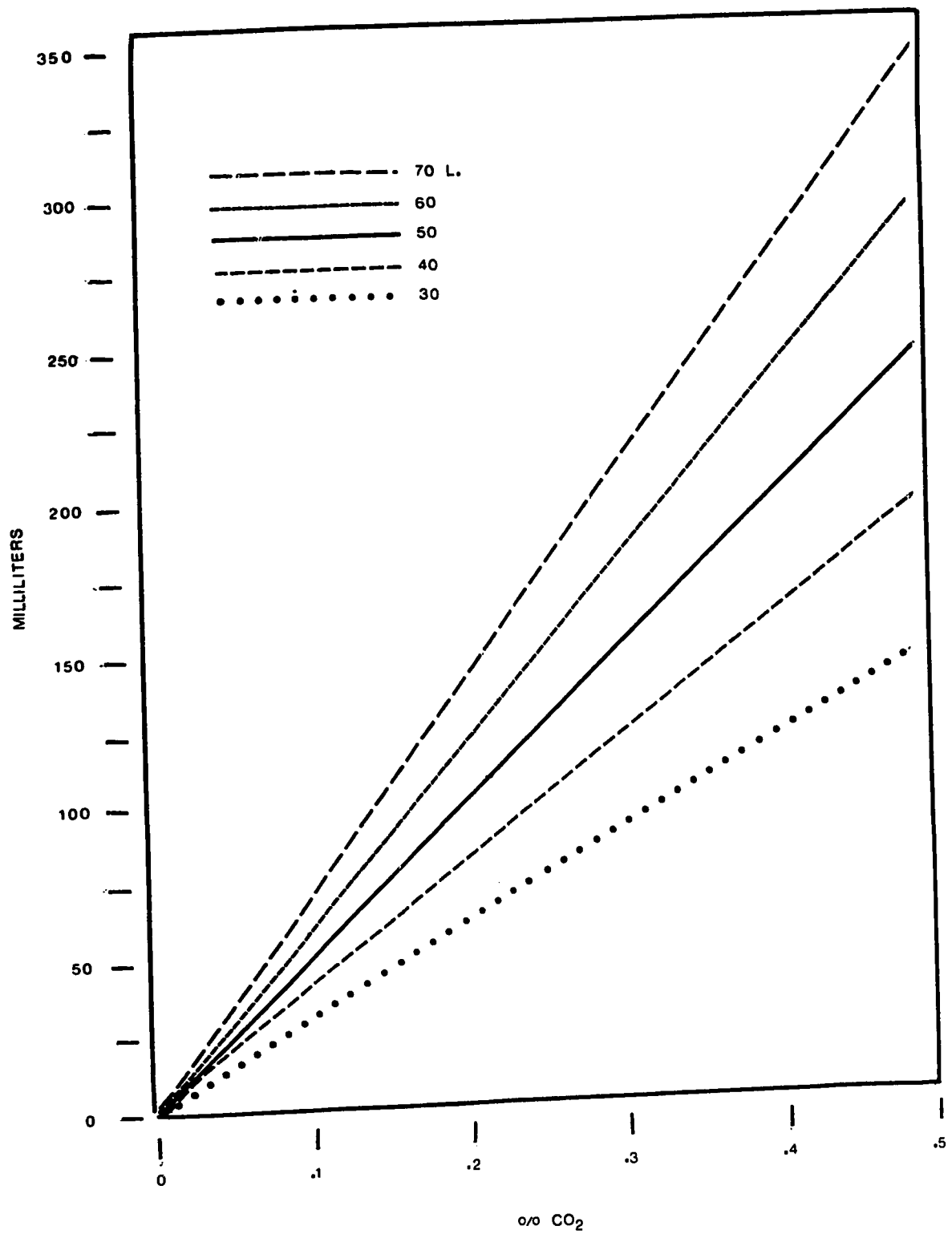


TABLE 4.14  
 PERCENTAGE OF CARBON DIOXIDE ABSORPTION

PERIODS	MINUTES						MEAN*	
	0	1	2	3	4	5		6
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3	100.0	97.3	98.3	98.5	97.1	95.6	95.6	97.1
4	100.0	91.2	92.5	91.3	91.4	90.6	89.6	91.1
5	94.8	84.0	85.2	85.3	83.9	---	---	84.6

\* mean excludes minute zero

mm.Hg., and since the ventilation increase is about two liters per mm.Hg. increase.

As ventilations reached 160 liters per minute at 325 watts, the carbon dioxide rose to 0.25 percent. In view of the foregoing statements the ventilation could have increased by one to two or three liters as an effect of carbon dioxide in the inspired air; that would be less than two percent of the minute ventilation.

#### TEMPERATURE DIFFERENCES BETWEEN THE BELLS

If the added oxygen is warmer than the spirometer air, the volume of the latter decreases as the former's temperature equilibrates with the colder air. In such a case the oxygen consumption is overestimated. When the oxygen temperature is lower than that of the spirometer air the consumption is underestimated.

To find out the magnitude of the overestimation which occurred in the present study, the temperature of the added oxygen volume was brought to the base of the temperature of the spirometer bell; the difference between the initial volume and the final volume therefore corresponded to that of the overestimation.

Since the oxygen consumption is usually computed for the last minute of work at a given load, the values of the last minute of each period were retained in this discussion. The results are given in table 4.15.

There was almost a two degree difference between the oxygen and spirometer bells at each period. The difference was statistically significant at the .001 level. As the added oxygen volume augmented from period to period the overestimation became increasingly apparent. In the

TABLE 4.15  
 OXYGEN AND SPIROMETER BELL TEMPERATURE DIFFERENCES AND THEIR EFFECTS ON THE  $\dot{V}O_2$  SLOPE

LOAD (WATTS)	$T_1$ : O <sub>2</sub> BELL (°C)	$T_2$ : SPIRO. BELL (°C)	DIFFERENCES IN TEMP. (°C)	ADDED O <sub>2</sub> VOL. AT $\bar{T}_1$ (L.)	ADDED O <sub>2</sub> VOL. AT $\bar{T}_2$ (L.)	$\dot{V}O_2$ OVER- ESTIMATION (ML.)
000	20.2	18.3	1.9	0.53	0.53	00
100	20.1	18.3	1.8	1.98	1.97	10
150	20.1	18.2	1.9	2.63	2.61	20
200	20.0	18.2	1.8	3.52	3.50	20
325	20.1	18.4	1.7	4.18	4.15	30

first two periods it was inferior to ten milliliters (ATPS). It was in the order of twenty milliliters (ATPS) in the third and fourth periods and thirty milliliters (ATPS) in the fifth one. Assuming that the consumption equalled the added oxygen volumes the overestimation was about 0.5 percent.

#### THERMOMETER ACCURACY

The thermistor probe placed approximately twelve inches from the Dargatz exterior thermometer generally gave temperature readings of  $1.5^{\circ}\text{C}$  lower than the latter. Table 4.16 presents these differences for the last minute of each period. The differences were statistically significant at the .001 level. An accurate thermometer is important in that its readings are utilized to convert the ventilation and oxygen consumption volumes from ATPS to BTPS and STPD conditions. The last two columns of table 4.16 indicate that the oxygen consumption volume converted to STPD conditions (assuming an ambient barometric pressure of 760 mm.Hg.) was underestimated by approximately twenty milliliters when the Dargatz thermometer readings were relied upon.

#### OXYGEN AND CARBON DIOXIDE CONCENTRATIONS FROM PERIOD TO PERIOD

Table 4.17 presents the mean oxygen and carbon dioxide concentrations for eight work levels. The means for the first four loads were obtained from six concentrations recorded while twenty subjects worked during six minutes; the remaining means represent the concentrations recorded at the end of each minute of work at the progressively increasing work loads.

TABLE 4.16  
 DARGATZ THERMOMETER AND THERMISTOR PROBE TEMPERATURE READING  
 DIFFERENCES AND THEIR IMPLICATIONS ON THE STANDARDIZATION OF CONSUMED VOLUMES

LOAD (WATTS)	THERMOMETER (°C)	PROBE (°C)	TEMP. DIFF. (°C)	$\dot{V}O_2$ STPD (THERMOMETER) (L.)	$\dot{V}O_2$ STPD (PROBE) (L.)
000	19.84	18.31	1.53	0.318	0.321
100	19.82	18.30	1.52	1.66	1.68
150	19.79	18.24	1.55	2.27	2.29
200	19.78	18.24	1.54	3.02	3.04
325	19.83	18.39	1.44	3.78	3.80

The two hundred and fifty watt mean cannot be compared to the others without restrictions since the spiograph was washed out with room air prior to the minute of work.

The oxygen concentration progressively decreased as the work load increased. At rest it was above normal atmospheric concentration while at 325 watts it was approximately 2.5 percent lower. Generally there were no significant differences among combinations of three consecutive loads.

Carbon dioxide was not completely absorbed at one hundred and fifty watts. Thereon, it progressively increased as the work load increased. There were no significant differences among the first three loads, between the 200 and 250 watt load and between the 275 and 300 watt load.

According to the previous analysis of each period the fall in the oxygen concentration reflected a lack of added oxygen. Carbon dioxide and temperature differences between bells had but minor effects on the oxygen concentration.

The writer believes that the increasing concentrations of carbon dioxide may be due partly to a progressive saturation of the absorbing reagent. As the latter may progressively have lost its absorbing capacity, the volume expired in the system progressively increased with the work load. The air flow rate in the spiograph left little time for a reaction to occur between the soda lime and the carbon dioxide. Assuming that the ventilation in the spiograph is near 400 liters per minute, that the total length of the closed circuit is at least thirty feet and that the spiograph volume is fifty liters, the air circulates about eight times per minute in the circuit. Complete absorption of the  $\text{CO}_2$  molecule must therefore occur within half a second. In relationship to given conditions of the absorbing agent this duration may be too short to favor maximal absorption.

TABLE 4.17  
 OXYGEN AND CARBON DIOXIDE CONCENTRATIONS: MEAN VALUES,  
 AND NON SIGNIFICANT DIFFERENCES AMONG EIGHT WORK LEVELS

PARAMETER	VARIABLES	WORK LOAD (WATTS)								F RATIO	SIGNIF. LEVEL
		000	100	150	200	250	275	300	325		
MEAN VALUES	O <sub>2</sub> %	21.4	20.1	19.7	19.5	20.2	19.3	19.0	18.9	47.0	.001
	CO <sub>2</sub> %	0.0	0.0	0.02	0.07	0.09	0.16	0.20	0.25	113.6	.001
LOADS NOT DIFFERENT (IN PAR-RENTHESES)	O <sub>2</sub> %	(100, 150, 250) (150, 200, 275) (200, 275, 300) (275, 300, 325)									
	CO <sub>2</sub> %	(000, 100, 150) (200, 250) (275, 300)									

## CHAPTER V

## SUMMARY AND CONCLUSIONS

## SUMMARY

The object of this study was to point out and observe at various work loads the factors that could alter

1. the physiological behavior of the subjects working with the Dargatz Type 510 spirometer: these factors were oxygen and carbon dioxide concentrations,

2. the print-out of the oxygen consumption slope: these factors were presence of carbon dioxide and temperature differences between the spirometer and oxygen bells.

Twenty voluntary well-conditioned male subjects were selected on the basis of their capability to complete a 325 watt load on the Lanooy ergometer.

The working time was divided into five periods. In the first four which lasted six minutes each the work loads were of 0, 100, 150 and 200 watts. In the last period the loads were increased every minute; they were of 250, 275 and 325 watts. Each period was followed by a pause during which room air was circulated in the spirometer.

Observations were made at the beginning of each period and at the end of each minute of work. The variables observed were grouped into five categories. Respiratory category: ventilation, oxygen consumption. Gas concentration category: oxygen concentration in the inspired air, carbon dioxide concentrations in the inspired air and in

the mixing box. Temperature category: temperature of the inspired air registered with the Dargatz thermometer and with a thermistor probe, temperature in the oxygen and in the balance bell. Gas volume category: volume of oxygen added into the spirometer. Cooling system category: operation time of cooling system I and II.

The design used was that of a single factor experiment having repeated measurements on the same elements. The differences observed within parameters were tested for significance with the appropriate F test. When the over-all F was significant, multiple comparisons on treatment means were effected with the Duncan new multiple range test.

Significant differences were found within each period for oxygen concentrations, carbon dioxide concentrations in the mixing box, carbon dioxide concentrations in the system (the first two periods excepted), ATPS and STPD ratios.

In the first period when the subjects were at rest, there was no significant difference between any two consecutive measurements of oxygen concentration. The general trend in all other periods was that the initial and final observations were significantly different from the remaining observations within a period. The sixth minute observation was, at times, similar to that of the first minute.

In general the oxygen consumptions of two or three consecutive minutes were not different in the first four periods. In the fifth period all minutes were different with respect to the oxygen consumption.

The box carbon dioxide concentrations were not significantly different in the last four minutes of the periods except in the fifth where they were all different from one another.

In the first and second periods no carbon dioxide was observed in the system. In the third and fourth periods there was generally no difference between three or four consecutive observations. In the fifth period, the second and third minute observations were not significantly different.

Generally the ATPS and STPD ratios of the first minute were significantly different from the other ratios within a given period.

Significant differences were found between the spirometer and oxygen bell temperatures at the last minute of each period.

Significant differences were found between the temperature readings of the Dargatz exterior thermometer and a thermistor probe, at the last minute of each period.

Significant differences were observed between eight work loads in terms of oxygen concentrations and system carbon dioxide concentrations.

Generally there was no significant difference between the mean oxygen concentrations of three consecutive work loads.

The mean carbon dioxide concentrations in the system were not different at 0, 100 and 150 watts. There was also no difference between 275 and 300 watts.

### CONCLUSIONS

The following conclusions have been reached as a result of this study.

1. The decrease usually observed in the oxygen concentration was imparted mainly to an under-adjustment of the manual oxygen regulator in the first minute of work. This was revealed by a first minute STPD ratio

significantly different from all other minute ratios within a period. Care should be exercised at the beginning of a work load to avoid an oxygen lack; it could even be recommended to increase the oxygen supply before the need is clearly indicated by a decreased spirometer bell volume. If in the first minute of a load the volume of added oxygen slightly exceeded or at least equalled the consumed volume, the initial oxygen concentration would probably be more easily maintained throughout a working period.

The minute ventilation volumes might have increased very slightly as the oxygen concentration dropped below twenty percent, but the concentration was never below critical values such as seventeen or sixteen percent where marked increases in ventilation would result because of the low concentration.

2. Up to two hundred watts, the carbon dioxide concentrations were not high enough to produce noticeable changes in the minute ventilations of the subjects. At the higher loads, the concentrations observed could have increased the ventilation by one or two percent. A critical value is estimated at about 0.3 percent where the effects on ventilation should not be overlooked. Such concentrations can be attained when work loads reach the 350 and 400 watt levels, even if the saturation of the absorbing reagent was not advanced.

3. For all practical purposes the amounts of carbon dioxide had no effect on the oxygen concentration in the system.

4. Carbon dioxide concentrations greater than 0.1 percent lead to measurable underestimations of the oxygen consumptions. In maximal tests the underestimation can reach one hundred and thirty five milliliters when the carbon dioxide concentration has attained 0.3

percent inside the spirometer system, the volume of which was measured at about fifty liters.

5. Oxygen and spirometer bell temperature differences tended to yield, in this study, oxygen consumption overestimations which increased with rising oxygen consumptions. It was of thirty milliliters at 325 watts. It is recommended that the spiograph temperature be kept only slightly lower than room temperature in order to reduce the difference between the two bell temperatures.

Early and generous adjustment of the oxygen regulator at the onset of a test and careful setting of the spiograph thermostats according to the ambient room temperature have revealed themselves as the two factors necessitating special attention from the operator in order to improve the precision of the results. At moderately heavy and heavy work loads the saturation level of the CO<sub>2</sub> absorbing agent should never be underestimated.

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