# ENERGY METHODS AND MEASUREMENTS FOR A TWELVE-YEAR-OLD GIRL WALKING AND CLIMBING UP AND DOWN STEPS WITH AND WITHOUT BOOKS

by

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# CHAPTER I

## INTRODUCTION

A southern regional research project has been conducted over a period of years at the Virginia Agricultural Experiment Station on metabolic patterns of preadolescent girls. In these studies energy measurements have been made for the basal metabolic rate, calorie intake and energy lost in excretions. This work was planned as a pilot study for the southern regional research project in which energy measurements were made with girls doing four standardized activities.

A number of energy studies have been made with children for doctoral dissertations at Columbia University, using the respiration chamber, the Benedict's knapsack and Benedict's field apparatus for collection of expired air (1). Only a portion of these results have been published, however.

For this study, energy used in particular activities of children was measured with the improved Kofranyi-Michaelis respiration gas meter.

This meter measures the volume of expired air and collects aliquot samples for analysis, making it possible to calculate the energy required although the activity is performed for a very short period of time. The meter is relatively inexpensive, easily stored and is useful for short test periods with adults. To overcome the size and weight difficulty in using it with children an adult near by may wear the meter strapped to her back while the child is attached to the meter with large corrugated rubber tubing and a mask or mouthpiece. A third person is required to operate the controls and take readings.

Research on the energy cost of activities with children is needed before dietary standards for calorie intake can be properly determined. Rapid growth and body changes at different ages in children make it difficult to use height-weight scales or other criteria for evaluating energy needs of a given child.

# CHAPTER II

## REVIEW OF LITERATURE

### Historical Background

The progress of energy studies has come about through a long series of scientific experiments (1). In the early 17th century, Boyle demonstrated that animal life is dependent on the air that is breathed in. Later on, in the middle 17th century, Mayow recognized that breathing makes air contact the blood, and a century later, Joseph Black concluded that breathing changes "common air" into "fixed air." Scheele discovered that "fire air," given off by growing plants, when used by bees or a burning candle, gives off carbon dioxide. Lavoisier concluded from respiration studies that the carbon dioxide expired came from burning carbon in the body. At the beginning of the 19th century, Liebig showed that substances which can be oxidized in the body contain carbon and are compounds of protein, fat or carbohydrate. Rubner showed that starch and fat produce about the same energy when burned outside the body as in the body but the energy value of protein is different as it can not be completely burned in the body. In the middle of the 19th century, Regnault showed that eating different kinds of food makes a difference in the amount of oxygen used and the amount of carbon dioxide given off. In the early 20th century Lusk, Rose-Benedict, Armsby and Atwater were perfecting the different types of calorimeters, which involve the combustion of oxygen and elimination of carbon dioxide and the measure of the heat involved, whether in respiration or in burning foods. Today, in the middle 20th century, energy research is still progressing, using improved calorimeters and respirometers with the aid of automatic air analyzers.

Classification of Children for Energy Studies

In respiration studies with children some standard must be used in measuring nutritional status and in interpreting data. Height, weight, age tables are not always reliable guides as Meredith and Stuart (2) have pointed out:

> The appropriate weight for individuals of the same sex, age, and height, differs within very wide limits depending in large part upon the stockiness of the body skeleton.

They recommended five measurements for the classification of children: body weight, standing height, hip width, chest circumference, and leg girth. In their work with children 5-18 years of age, measurements were plotted on a graph, and interpreted in terms of percentiles—10th, 25th, 50th, 75th, and 90th (2).

The graph to be used in this study "weight-for-height classification of children" was based on 50th percentile values from Stuart-Meredith (1946). Concerning this graph, Sargent (3) says:

> . . . it is simply a means of classifying based on average height or weight for age. Children within the Stocky classification may have a large bony skeleton or may be more muscular than children in the Normal or Slender classifications but may not be overweight or approaching overweight; this classification also may include children who have a small bony skeleton but have adipose tissue. Similar comparisons may be made for the other classifications.

## Basal Metabolism

Any study of energy use by the body must begin with consideration of basal heat production. Basal metabolism is the amount of energy required by the body when awake and at complete mental and physical rest, at normal room and body temperatures and 12-13 hours after last intake of food. Basal metabolism measurements should be made on more than one day due to the fact that there is a daily variation ranging from 7.4 to 28.8 per cent, or an average of 13.2 per cent, which might cause erroneous conclusions to be drawn from a single test (4). In basal measurements reference is made either to body surface, as determined from height and weight, or to body weight alone. Some of the factors which affect basal metabolism are:

1. Body weight.—There is no direct relationship between the total body weight and the total heat production, although large bodies give off more heat than smaller ones (5).

2. Body composition.—The amount of active tissue and muscle tenseness or tone, rather than the total body mass, determines the basal heat production (6).

3. Age.—During growth of children the basal energy metabolism is proportionally higher than with adults per unit of active tissue. The greater the rate of growth the higher will be the basal metabolism (5).

4. Sex—Women have a lower basal rate of energy metabolism than men because of the greater proportion of inert body fat in women (5).

5. Height.—For a given weight the taller individual usually has the greater basal metabolism; due to the larger proportion of active protoplasmic tissue (5).

6. Prolonged fasting or starvation.—Fasting or starvation may cause a fall of 30 per cent in terms of metabolism per unit of body surface. A vegetarian diet over a long period of time will reduce basal metabolism (6).

7. Emotional excitation.—Emotional factors may raise the rate of basal metabolism 20 per cent or more, and are the greatest cause of error in basal metabolism determinations (7).

8. Fever.—"Du Bois has calculated that the increase in energy expenditure in fever amounts to 7.2 per cent for every degree Fahrenheit" (1).

9. Thyroid.—Thyroxine from the thyroid gland has a powerful effect in determining the rate of oxidation processes in the tissues. An abnormal secretion will greatly affect basal energy metabolism (6).

Values for Children: Basal metabolism values and ranges for children have been reported by Albritton (8) and follow. These values are based on three of the most authoritative sets of original data: (1) the Mayo Foundation Standards of Boothby, Berkson and Dunn, (2) the British measurements of Robertson and Reid and (3) the Carnegie Laboratory Data of Harris and Benedict. Ranges are calculated from an average coefficient of variation of 6.9 per cent.

Female

| Age yrs | Values Cal/sq m/hr | Range Cal/sq m/hr |
|---|---|---|
| 7 | 49.7 | 42.8-56.6 |
| 8 | 48.0 | 41.4-54.6 |
| 9 | 46.2 | 39.8-52.6 |
| 10 | 44.9 | 38.7-51.1 |
| 11 | 44.1 | 38.0-50.2 |
| 12 | 42.0 | 36.2-47.8 |
| 13 | 40.5 | 34.9-46.1 |
| 14 | 39.2 | 33.8-44.6 |

Albritton gives the following summary of basal calories per square meter per hour for studies made with girls 7-14 years of age.

| Age yrs | Robertson & Reid 1952 Cal/sq m/hr | Boothby 1952 Cal/sq m/hr | Boothby Berkson & Dunn 1936 Cal/sq m/hr | Lewis Duval & Iliff 1943 Cal/sq m/hr | Fleisch 1951 Cal/sq m/hr |
|---|---|---|---|---|---|
| 7 | 50.2 | 49.7 | 48.5 | 45.5 | 45.4 |
| 8 | 48.4 | 48.0 | 46.7 | 44.0 | 43.8 |
| 9 | 46.4 | 46.2 | 46.1 | 42.7 | 42.8 |
| 10 | 44.3 | 44.9 | 45.7 | 41.4 | 42.5 |
| 11 | 42.4 | 43.5 | 45.1 | 40.4 | 42.0 |
| 12 | 40.6 | 42.0 | 43.9 | 39.7 | 41.3 |
| 13 | 39.1 | 40.5 | 42.5 | 38.4 | 40.3 |
| 14 | 37.8 | 39.2 | 41.1 | 36.8 | 39.2 |

Albritton states that Robertson and Reid set the British Standard by repeated measurements on trained persons under rigorously basal conditions; Boothby, Berkson and Dunn established the basal standard for man that is commonly used in America; and Lewis, Duval and Iliff got their values by measurements on well trained children, and are the lowest of those given for children here (8).

## Activity Studies

Most activity studies reported in the literature have been made with adults to develop energy-saving methods connected with routine household operations. Studies on energy expenditures with children performing different activities are few. In this survey of literature, no reports were found for children walking, with or without a load, and only one report for children in stair climbing, where 9-11 year old girls averaged 1.47 Calories per kilogram per hour for basal metabolism and 4.65 Calories per kilogram per hour above basal for climbing up and down steps (1).

Taylor, et al., have reported activity studies with boys and girls 7 to 14 years of age, using a respiration chamber (9-12). Results of their studies may be summarized as follows:

| Activity | Age | Boys Cal/kg/hr | Boys Cal/cm/hr | Girls Cal/kg/hr | Girls Cal/cm/hr |
|---|---|---|---|---|---|
| Quiet play | 7-8 | 3.1 | 0.59 | | |
| | 9-11 | 2.6 | 0.58 | | |
| | 12-14 | 2.1 | 0.58 | | |
| Sitting listening | 9-11 | 2.07 ±0.06 | 0.54 ±0.01 | 1.80 ±0.04 | 0.45 ±0.01 |
| Sitting sewing | 9-11 | | | 1.85 | 0.47 |
| Sitting singing | 9-11 | 2.23 ±0.06 | 0.57 ±0.02 | 2.06 ±0.07 | 0.52 ±0.02 |
| Standing singing | 9-11 | 2.35 ±0.05 | 0.60 ±0.01 | 2.13 ±0.06 | 0.54 ±0.01 |
| Wash & wipe dishes | 9-11 | 2.92 | 0.75 | 2.61 | 0.67 |
| Standing drawing | 9-11 | 3.19 ±0.10 | 0.83 ±0.03 | 2.62 ±0.05 | 0.63 ±0.01 |
| Carpentry work | 9-11 | 3.58 | 0.87 | | |
| Dressing-undressing | 9-11 | 4.29 ±0.16 | 1.09 ±0.04 | 4.04 ±0.13 | |
| Cycling | 7-8 | 6.6 | 1.23 | | |
| | 9-11 | 5.1 | 1.15 | | |
| | 12-14 | 4.5 | 1.24 | | |

These activity studies were completed within a period of less than six months following the basal metabolism determinations. Each test was preceded by a ten minute rest period, during which the children sat quietly reading or playing with puzzles, games, or other activities involving only finger muscles.

Passmore and Durnin (13) have reviewed activity studies, made with adults in Germany, using a light portable respirometer developed at the Max-Planck-Institut fur Arbeitsphysiologie. This apparatus measures the volume of expired air directly and simultaneously diverts a small fraction of the air into a rubber bladder for analysis later. In their review of these studies they found that:

1) In level walking the energy expenditure was proportional to body weight and that increased speed caused greater energy expenditure.

2) Walking on an incline required appreciably more energy than walking on the level.

3) Descending stairs involved only about one-third of the energy used in going upstairs.

4) In carrying a load the position was important, energy expenditure was lowest for the load carried with a shoulder yoke and highest when carried on the hip, under the arm. Middle energy values were obtained for loads carried in trays, in hand bundles, on the head and over the shoulder.

A recent study has been reported by Richardson and McCracken (14) using women subjects aged thirty-six to forty-six years for measuring energy expenditure while lying, sitting, standing, walking at different speeds with and without loads, and performing trunk and knee bending exercises. Subjects were selected to be within height range of five feet two inches to five feet five inches; a weight range of 110 to 160 pounds, and having a basal metabolic rate, within 15 per cent of Aub and Du Bois standards. The energy expenditure was measured with a Muller-Franz respirometer and a paramagnetic oxygen analyzer (14).

The procedure used for the activity tests were as follows: (1) a pre-activity test during which the subjects sat or stood quietly; (2) activity tests; and (3) a postactivity test of sitting or standing quietly. Activity tests ranged from one to five minutes and experimental periods were alternated with rest periods of lying quietly for at least twenty minutes. Rest periods of measured duration were incorporated between high energy activities to minimize any effect of oxygen debt (14).

Average values and standard deviations for six women lying down were 34.1 ± 4.3 Calories per square meter per hour, sitting 37.6 ± 4.9 Calories per square meter per hour and standing 39.7 ± 4.0 Calories per square meter per hour. The mean energy cost of six women walking was at the subjects own pace 2.53 Calories per kilogram per hour and at 96, 108 and 120 steps per minute, respectively 2.19, 2.28 and 2.48 Calories per kilogram per hour (14).

## The Respiration Gas Meter

A light portable gas meter, made by Kofranyi and Michaelis in 1940 and improved by Muller and Franz in 1952, was designed for use in energy exchange studies during periods of light and moderate activity. It weighs 2.5 kilogram without accessories or 3.6 kilogram (eight pounds) with accessories and can be worn like a rucksack by the subject. The meter measures the total volume of expired air and samples of 0.3 per cent or 0.6 per cent of the expired air can be collected in rubber bladders for analysis. Montoye and coworkers (15) have shown in work with adults that reasonably accurate results are obtained with the meter using ventilation rates up to 40-50 liters per minute (moderate work) but for higher rates they recommend the Douglas bag or spirometer. They report that the resistance of the mechanical operation of the meter amounts to 20-25 mm water at about 50 liters per minute and to about 40-50 mm water at approximately 100 liters per minute. Resistances above 20 mm water would result in an increase in oxygen consumption (Matthews 1946) (15).

Calibration of the gas meter: Calibration tests were found to be necessary to determine correction factors for gas metered through a particular respirometer under operating conditions at different rates of flow. At least five different methods have been used for calibration as the meters must be periodically recalibrated in use.

Montoye and coworkers (15) reported calibration tests of the Muller-Franz apparatus against a calibrated wet-test meter. Their tests were made by pumping a known volume of gas through the wet-test meter into a Douglas bag at varying rates of flow. After recording the volume from the wet-test meter, the air was pumped out of the Douglas bag through the Muller-Franz respirometer. In their study the respirometers appeared to underestimate gas flow. They found if a correction factor is applied to account for this, the meter is accurate to approximately ± 3.0 per cent or ± 4.0 per cent between rates of flow of approximately 3 to 100 liters per minute (15).

Durnin and Brockway (16) made calibration tests using an air flow of the same pattern as that encountered with the meter in use. Their apparatus consisted of: a large 'standard' gas meter which is recalibrated by the makers; a blower capable of delivering a steady flow of up to about 500 liters per minute and a motor-driven interrupter fan. The fans have alternate regular segments cut out and cause the air stream to be interrupted 12, 24, 36, 48 or 60 times per minute. Calibration was carried out by connecting this apparatus with the Muller-Franz meter by one inch rubber tubing. Readings were taken on the 'standard' gas meter and on the 'test' meters. The correction factor was calculated as follows for different rates of flow:

$$\frac{\text{Volume passed through standard meter}}{\text{Volume recorded on respirometer}}$$

To find the corrected pulmonary ventilation, the volume recorded by the respirometer is multiplied by the correction factor appropriate for the particular recorded flow rate. This figure would then be adjusted to standard temperature and pressure or body temperature and pressure, saturated (16).

Insull, et al., tested the accuracy of the Muller-Franz meter first by forcing a stream of air from a Tissot spirometer through a laboratory dry gas meter and then through the Muller-Franz meter. This was not considered a valid test for operating conditions because it used a continuous rather than an intermittent flow of gas. For calibration, under the physiological conditions present in actual use, they collected expired gas alternately in a Douglas bag and from the

Muller-Franz meter from men in a steady state of work at various intensities. The ratio of the energy cost measured by the Douglas bag to that measured by the meter gave the calibration factor (17).

For calibrating the Muller respirometer, Harkness (18), at Ohio State University, constructed a piston type, positive displacement pump to be connected to the plastic valve on the face mask so that as the piston moves up on the pump, air is drawn in through the respirometer. The length of stroke and rate of operation of the pump could be varied to simulate any depth of breathing and rate of breathing that might be encountered. Through calibration the quantity of air drawn into the pump with each stroke was known and by taking the number of strokes per minute the calibration of the respirometer could be checked easily (18).

Calibration at Iowa State University has been carried out by using a Tissot Spirometer filled with room air which is metered from the spirometer to the respirometer by the operator, using rubber tubing, plastic adapter, mouthpiece and nose clamp. Different rates of flow are used to correspond to the values to be used in the test.

> Initial and final readings of volumes and temperatures of air in the Tissot and of air metered through the respirometer, and the ambient barometric pressure, provided bases for calculation of correction factors for various rates of gas flow through the respirometer (19).

## Collection of Air Samples

In collecting outside air samples Haldane (20) mentions there are two important things to consider: the collecting vessel and the collecting method. The collection bottle must be clean, dry, air-tight, easily handled, and one from which a sample can be passed into the gas analyzer. If the bottle is wet and dirty, carbon dioxide may appear, and oxygen disappear, by bacterial action. If the bottle is wet and clean the carbon dioxide gradually disappears, as it is absorbed by alkali dissolved out of the glass by the water. Haldane's method for collecting an outdoor sample was to use rubber tubing (2-3 feet long and 1/8-1/4" bore) introduced into a three ounce collecting bottle. The tube was placed in the mouth and a deep breath of air sucked in which washed the bottle with incoming air since ten times the capacity of the bottle will be sucked through. The tube was removed while the air was being sucked up to avoid the risk of breath passing backwards into the bottle. It was then sealed with a stopper greased with vaseline and held tight by a large elastic band.

Insull and coworkers (17) have reported their method for collecting an expired air sample into the rubber bladder and its transfer to a 30-50 ml glass syringe. The aliquot bladder in storage was kept full of expired air to saturate it with carbon dioxide. It was evacuated before use, closed with a pinch clamp and connected to the sample outlet of the meter. After collection the clamp was closed and the bladder removed. The bladder was immediately kneaded and the gas sample carefully transferred through a three-way Ayer stopcock to the glass syringe.

Three flushes of 5-10 ml of gas were taken and pushed out before the final sample was drawn in. Duplicate syringe samples were taken. The syringes were lubricated with mineral oil and sealed by a Hoffman screw clamp on a short piece of butyl rubber tubing wired to the syringe tip.

Bailey (21) designed a sampling bottle to collect and store air samples under mercury. This bottle is useful for sampling small volumes of gases, for flushing connecting tubing, for storage of air samples under positive pressure and is especially convenient for use with the Henderson modification of the Haldane gas analyzer. It consists of parallel glass cylinders connecting at the bottom through a small opening: a two-way stopcock joins the capillary tubes from each cylinder at the top to a third capillary tube which may be joined to the burette of a gas analyzer. The Bailey sampling bottle is flushed out with 1 per cent $H_2SO_4$ before use and is half filled with mercury. The principle of using the bottle is to displace the air in the gas compartment by tilting the bottle forward sending mercury in and forcing air out, and then by tilting it backward to draw the air sample into the bottle.

## Gas Analysis

Samples of expired air, collected from the respiration gas meter must be analyzed for its oxygen and carbon dioxide content. Haldane's chemical method of gas analysis was described in its original form in the Journal of Physiology in 1898 (20). Since that time many modifications of the procedure have been made. The principle of the Haldane-Henderson gas analyzer is the removal of carbon dioxide by potassium hydroxide absorption and of oxygen by pyrogallate absorption from a known volume of air under constant temperature and pressure, leaving a residue of gas that is essentially nitrogen. The gas volume readings after absorption of each and the final volume reading are used for calculating the percentage of oxygen, carbon dioxide and nitrogen in the sample (22).

A Pauling type electronic analyzer has been successfully used for analysis of expired air.

> This instrument determines the oxygen partial pressure of an air sample by measuring the magnetic susceptibility of the gas with a magnetic torsion balance. Since oxygen is relatively paramagnetic, accurate oxygen analyses can be made in the presence of practically all gases (14).

Gas chromatography is a recently developed method of gas analysis and there are now many different instruments available for this purpose. "In gas chromatography the compounds in a mixture migrate at differing speeds when carried along by an inert gas through a tube that has been packed or treated in a special way."(24) Here, the sample components are retarded by absorption or adsorption by the column filling material and as the carrier gas continually flows through this packed column, the individual sample components emerge (elute) from the column at different times. This stream emerging from the column is composed of carrier gas and dilute bands of components. As it passes through a thermal compartment it alters the transfer of heat from a heated filament. This change is recorded on a strip chart. The area of the recorded peaks provide a quantitative index of the sample components passing through and the retention time of the sample component can be used for identification (24).

Calculation of Energy Expenditure

"...Weir has shown the metabolic rate to be essentially a function of the pulmonary ventilation and oxygen content of expired air so the metabolic rate may be calculated after measurement of these two." (17) To determine the caloric equivalent for pulmonary ventilation the following formula (24) may be used:

$$K' = \frac{(O_i - O_e) \times 0.0504}{1 + 0.082\,p}$$

where:
$K'$ = Calories per liter of expired air
$O_i$ = per cent oxygen in inspired air (20.93 per cent)
$O_e$ = per cent oxygen in expired air
$p$ = per cent of calories from protein in the diet (normally 10-15 per cent of total calories from protein)

Heat production may then be calculated as:

$K'$ x liters per minute expired = calories per minute

Insull, et al, (17) reported a comparison of their data calculated with the Weir formula adjusted to a daily dietary protein intake of 10 per cent of the total calories, to the conventional method of Peters and Van Slyke accounting for protein metabolism and to the short method of Consolazio, Johnson and Marek ignoring protein metabolism by assigning five calories per liter of oxygen consumed. Their study showed the Weir method in close agreement (101.2 per cent) to the conventional method which corrected for protein metabolism. The short method was 105.6 per cent of the conventional method. With the Weir formula, if the average diet is 10-15 per cent of the calories from protein the maximum error from the 10 per cent calculation would be 0.36 per cent too high or from the 12 per cent calculation only 0.2 per cent too high.

# CHAPTER III

## PURPOSE

This research has been developed as a pilot study in energy measurement for the southern regional research project entitled "Requirement and Utilization of Selected Nutrients in Preadolescent Children" being conducted over a period of years at the Virginia Agricultural Experiment Station.

Past studies on this campus have included basal metabolic rate, analysis of food, feces and urine for calories with the calculated fuel value of the diet; however, in previous studies no effort has been made to determine the energy cost of activities of the preadolescent girls who served as subjects.

The purpose of the author in conducting the study was to determine in girls the energy cost of walking and stair climbing, with and without a load, at normal rates of speed. The over-all objectives for the study were:

1. To develop techniques, using the Kofranyi-Michaelis respirometer for measuring expired air in children and collecting an aliquot sample for analysis.

2. To develop a technique for analyzing expired air by the Haldane-Henderson method.

3. To determine energy expenditure for a given activity by use of experimental data in the Weir formula expressing results in terms of body weight and a standard time interval.

4. To determine energy cost of the following activities with girls.

   (1) Walking at normal rate of speed
   (2) Walking with load at normal rate of speed.
   (3) Walking up and down stairs at normal rate of speed.
   (4) Walking with load up and down stairs at normal rate of speed.

# CHAPTER IV

# METHODS OF PROCEDURE

The purpose of this study was to develop the necessary methods and to measre energy expended by girls in walking and stair climbing at normal rates of speed, with and without a load.

Three girls ranging in age from 10 to 14 served as subjects. Height was measured without shoes and weight taken in light clothing. These measurements were compared with a standard height-weight-age table (Baldwin and Wood) and with a weight-for-height classification grid for determination of body type (using Stuart-Meredith standards). Basal metabolism tests were given to assure that the girls selected could be regarded as normal in relation to energy metabolism and as a basis for determining energy used for activity alone.

Throughout this study, the three girls who served as subjects for basal metabolism tests lived at home, and ate the usual diet of the family. One of the subjects was chosen for the activity studies. Studies were made in the late afternoon after school for her convenience and to eliminate the necessity of controlling the diet. No food was taken between lunch and the activity period for the tests.

## Measurement of Basal Metabolism

Basal metabolism was measured on not less than two mornings for each subject using the McKesson Waterless Recording Metabolor. This machine measures oxygen consumed in a definite period of time and is an indirect method of measurement of basal metabolic rate.

Subjects were brought to the laboratory at 6:30 a.m. in the post-absorptive state and allowed to rest for thirty minutes before the test. The procedure used for the test is given in the appendix. Duplicate tests were made each morning for at least six minutes. After the test height and weight were taken and breakfast was served. The basal tests were repeated for a second or third morning to be reasonably sure the recordings were reliable.

## Calibration of the Gas Meter

The Kofranyi-Michaelis respiration gas meter was calibrated against a Tissot type spirometer, using a rubber stopper to close the exit to the outside air above the three-way valve on the Tissot. The two apparatuses were connected with a plastic adaptor and rubber mouthpiece between two lengths of one inch corrugated rubber tubing, with all connections tight. The operator (serving as air pump in the series) used a nose clamp and made an air tight connection between the two apparatuses when the mouthpiece was in place. Temperature and volume were recorded for both instruments just before and after the test and barometric pressure was recorded. A measured air volume was inhaled from the Tissot and the expired air was metered through the Kofranyi for a definite length of time as measured with a stopwatch. From the readings taken on both, a correction factor was calculated for the respiration gas meter. A series of these tests was done to establish a true calibration factor for the meter at different flow rates normally found when the meter is in use. Different rates of flow were secured by using different adult operators in these tests and by having them sit, stand or step in place to increase the rate of breathing. Procedure for calibration is given in the appendix.

## Calibration of the Rubber Bladder

Two rubber bladders were used in this study for collecting the aliquot air samples, these were calibrated against a Douglas bag. The bladders were kept filled with expired air and stored in a jar of expired air to keep them saturated with carbon dioxide. Before each calibration, they were taken out, emptied and rinsed three times with the operator's expired air.

To calibrate, a 0.6 per cent aliquot was collected in each rubber bladder while eight liters per minute of expired air was metered for six minutes from the Douglas bag through the Kofranyi respirometer. The air samples were then transferred from the bladders into Bailey gas sampling bottles for analysis. A sample was taken directly from the Douglas bag into a Bailey sampling bottle before and after metering through the Kofranyi. From analysis of these samples, calibration factors were established for each bladder. Calibration factors were determined by dividing the per cent oxygen from the Douglas bag sample by the per cent oxygen from the Kofranyi bladder sample. Detailed calibration procedure is given in the appendix.

## Procedure for the Activity Tests

Four activities performed by an eleven year old girl were tested in this study: walking at normal speed with and without school books and going up and down stairs at normal speed with and without school books.

A pocket-size Taktell metronome was used to gauge normal walking speed and a seven jewel Swiss non-magnetic, interrupted interval, stopwatch graduated in 1/5 seconds was used for timing the activities. All windows were opened wide before the tests as inspired air was assumed to be the same as outside air. A 3-way stopcock was attached to the Kofranyi so that expired samples might be collected into two bladders during the activity.

Complete energy determinations were made for activities tested in four afternoons. The first afternoon the subject walked at her normal rate of 104 steps per minute for exactly eight minutes up and down a hallway that was eighty-three feet long, turning at each end. The air expired during the activity was accurately measured by the respirometer. Two aliquot bladders of expired air were collected for four minutes each and immediately transferred to three Bailey gas sampling bottles under mercury. Samples were analyzed the following morning.

The second afternoon the subject walked up and down ten stair steps at her normal rate of 104 steps per minute for exactly eight minutes. Two aliquot bladders of expired air were collected for four minutes each and immediately transferred to four sampling bottles to be analyzed the next morning.

The third afternoon two activities were performed. The subject walked around a large room area (50' x 27') at her normal rate of 104 steps per minute for exactly four minutes. One aliquot bladder was collected and transferred into two sampling bottles. After resting for

FIGURE 1 - THE KEFRANYI-MICHAELIS RESPIROMETER IN OPERATING POSITION FOR THE WALKING AND STAIR CLIMBING TESTS MADE IN THIS STUDY.

at least ten minutes the same procedure was followed with the subject carrying three pounds and seven ounces of books with her right arm.

The fourth afternoon two activities were performed. The subject went up and down ten stair steps at 104 steps per minute for exactly four minutes. One sampling bladder was used. After resting at least ten minutes the test was duplicated with the subject carrying three pounds and seven ounces of books with her right arm. Two samples from each bladder were stored in Bailey sampling bottles for analysis next morning.

In the appendix are given the detailed procedure used in these activity tests with the Kofranyi-Michaelis respirometer followed by an activity Data Sheet showing the necessary calculations for one activity.

## The Collection and Storage of Air Sample

The rubber bladders were stored filled with expired air in a large jar of expired air to keep them saturated with carbon dioxide. Before use the bladder was evacuated with a vacuum pump and then rinsed with expired air three times and evacuated again, then closed with a pinch clamp and carefully connected to the sample outlet of the gas meter. After connecting the bladder, the pinch clamp was released. The air flowing into the bladder was carefully timed by the "on" and "off" tap. When two bladders were used the time was controlled by the stopcock between bladder and gas meter. The air sample was transferred immediately from the aliquot bladder to the Bailey sampling bottle. Details of the transfer procedure are given in the appendix.

## Analysis of Expired Air

The expired air was analyzed by using the Haldane-Henderson gas analyzer. The full method is given in the appendix. Samples were collected in rubber bladders and transferred immediately to the Bailey sampling bottles under mercury and kept until the next day.

The apparatus was flushed before each day's analysis to remove carbon dioxide and oxygen from the capillary tubes. Outside air samples were analyzed now and then to check the accuracy of the apparatus and the operator as it has a constant value of 20.93 per cent oxygen 0.03 per cent carbon dioxide and 79.04 per cent nitrogen.

## Calculating the Energy Expenditure

The metered volume of expired air is first corrected to standard conditions ($0^{\circ}C$ and 760 mm pressure) by using factors from appropriate tables and then multiplied by the meter calibration factor to give the adjusted volume (See appendix).

The expired air is analyzed for the percentage of oxygen and carbon dioxide. By using the per cent oxygen content and the Weir formula, the Calories per liter of expired air may be calculated:

$$K' = \frac{(O_i - O_e) \times 0.0504}{1 + 0.082\,p}$$

$K'$ = Calories per liter of expired air
$O_i$ = per cent oxygen in inspired air (20.93 per cent)
$O_e$ = per cent oxygen in expired air
$p$ = per cent of calories from protein in the diet (10-15 per cent in the average American diet)

For convenience a table was set up using this formula for oxygen concentration from 15.0 per cent to 16.0 per cent to simplify calculations.

The adjusted volume is then multiplied by the calories per liter to find the total calories expended for the activity in the test.

The total calories are divided by the activity time to get the calories per minute for this activity.

# CHAPTER V

## DISCUSSION OF RESULTS

### Activity Studies

This study was planned to determine the energy cost for girls in walking and stair climbing, with and without books, at normal rates of speed.

Three girls were selected as prospective subjects for this study. In January when basal metabolism was measured G. P. was ten years old, 55" tall and weighed 66 pounds. J. C. was 11 years and 5 months of age, weighed 73 pounds and was 59" tall. M. C. was 14 years old, weighed 104 pounds and was 64" tall.

Two methods were used to determine whether energy metabolism was normal. Subjects were compared with weight-for-height averages for children, based on the 50th. percentile values of Stuart-Meredith as shown in Figure 2. In plotting height and weight values for the subjects on the graph in Figure 2, subject M. C. was within the normal classification, slightly below the average line. G. P. was on the line between normal and slender. J. C. was in the slender classification in January but five months later was in the normal classification as shown.

Subjects were given basal metabolism tests to determine whether the basal metabolic rate was within the normal range. Results are shown in Table 1. The basal metabolic rates of the three subjects were within the normal range of ± 15 per cent, using the Du Bois standards as modified by Boothby and Sandiford.

FIGURE 2 - WEIGHT-FOR-HEIGHT CLASSIFICATION OF CHILDREN: Metric units (3).

Values used to establish the average line were as follows: For 100 cm., 16.1 kg.; for 130 cm., 27.3 kg.; and for 160 cm., 46.3 kg.

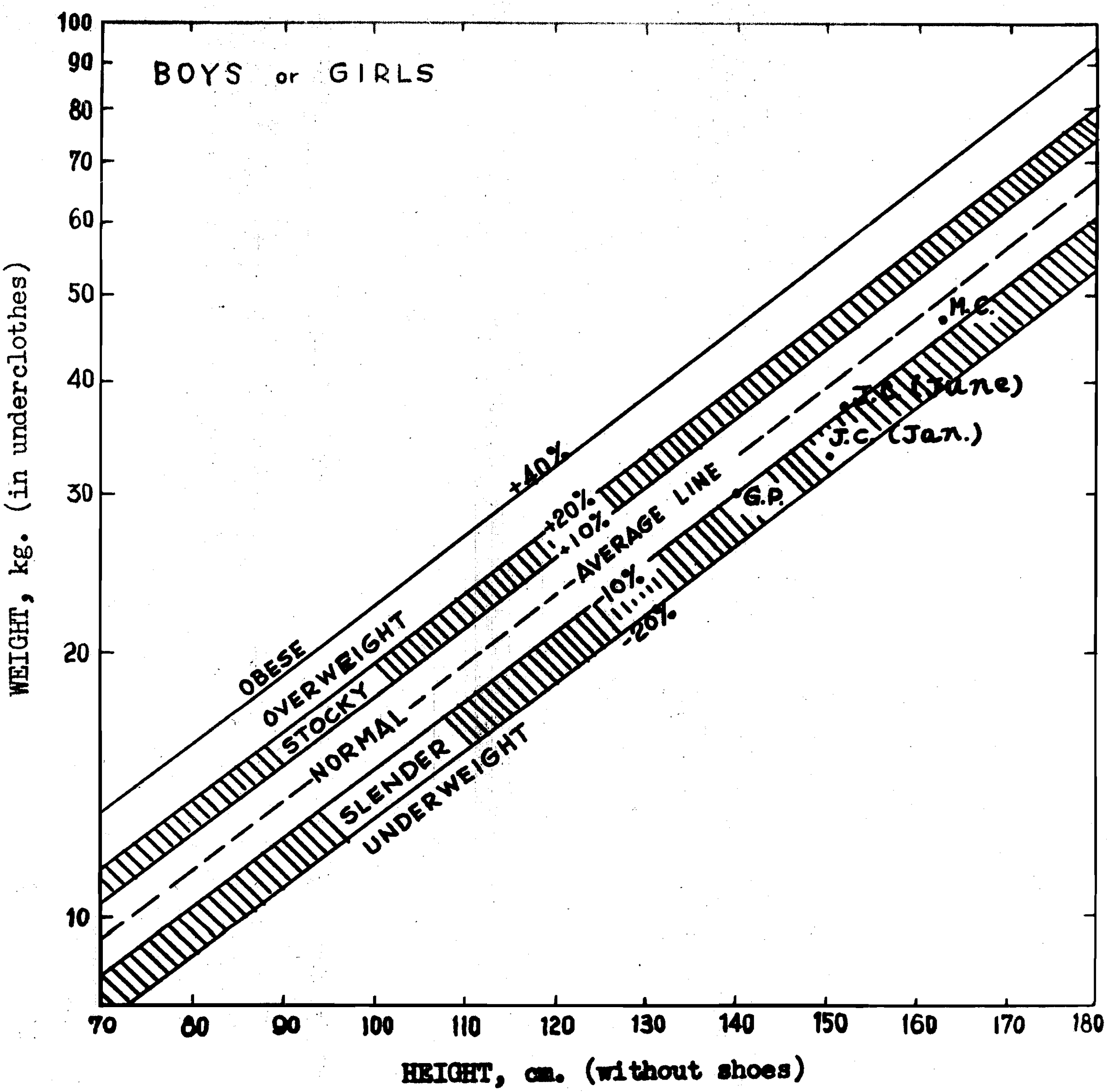

TABLE 1

BASAL ENERGY METABOLISM OF CHILDREN IN THIS STUDY

| Subject | Age | BMR Cal/sq.m/hr | Cal/kg/hr | Ave. Basal Calories 24 hr. | BMR Percent Deviation | Used |
|---|---|---|---|---|---|---|
| G.P. | 10 | 41.2 | 1.51 | 1088 | - 2.8 | Jan. 3rd day |
| J.C. | 11 yr 5 mo | 39.1 | 1.33 | 1060 | -13 | Jan. 2nd day |
| J.C. | 11 yr 10 mo | 49.4 | 1.55 | 1402 | +13 | June 1/ Only day |
| M.C. | 14 | 41.6 | 1.31 | 1478 | - 2 | Jan. Only day |

1/ Six days later a repeat test was made with a BMR of 11 per cent.

TABLE 2

BASAL ENERGY METABOLISM OF CHILDREN FROM OTHER LABORATORIES

| Age | Average of 3 Sources (8) Female Cal/sq.m/hr | Average of 3 Sources (8) Range Cal/sq.m/hr | Modified Du Bois (25) Cal/sq.m/hr | Taylor & MacLeod (1) Cal/sq.m/hr | Taylor & MacLeod (1) Cal/kg/hr |
|---|---|---|---|---|---|
| 10 | 44.9 | 38.7-51.1 | 45.8 | 37-46 | 1.50 |
| 11 | 44.1 | 38.0-50.2 | 44.6 | 38-45 | 1.42 |
| 12 | 42.0 | 36.2-47.8 | 43.4 | 38-44 | 1.33 |
| 13 | 40.5 | 34.9-46.1 | 42.0 | 37-43 | 1.29 |
| 14 | 39.2 | 33.8-44.6 | 41.0 | 37-43 | 1.54 |

In comparing BMR for the subjects at their last birthday with the ranges from other studies in Table 2, all subjects were within the ranges given. If J.C. is compared to values at her closest birthday her basal energy metabolism is higher than the range given, in both cases.

Subject J.C. grew one inch in height and gained ten pounds in weight within six months. She performed the activities for this study late in May and another basal metabolism measurement was taken early in June. Her basal metabolic rate increased from 39.1 to 49.4 Calories per square meter per hour or from -13 to +13 per cent compared with the modified Du Bois standard. No definite explanation can be offered for this change in metabolic rate. One week after this study was completed a second basal was made and J. C. had a BMR of +11 per cent. Sargent (3) in her review of basal studies states:

> From the age curves (plotted from longitudinal data) it was concluded that basal heat production increases during the prepubertal growth spurt...

Richardson and McCracken reported data for a 22 year old woman who in 9 months had weight fluctuation of 3 pounds and basal variations up to 24 calories per hour (14). The basal requirement for J.C. of 1.55 Calories per kilogram per hour corresponds to the value for 14 year old girls (1.54 Calories per kilogram per hour) as given by Taylor and MacLeod (1). Compared with height-weight-age tables of Baldwin and Wood (1) J.C. was 3 inches taller than average 12 year old girls for her weight or 12 pounds lighter than the average for her height and age. This may help to explain her higher basal rate.

It was necessary to limit the final activity studies to one subject due to difficulties encountered in developing the methods and techniques to be used.

Subject J.C. performed the four activities: walking at normal rate of speed, with and without school books, and climbing up and down steps with and without school books. Preliminary tests on single activities were made on two days in May to check the normal rate of walking and the sampling techniques with Bailey sampling bottles. Experimental tests were made on two activities in each of two afternoons after school. Late afternoon, with no food since lunch, was considered desirable to eliminate the metabolic influence of food in the digestive tract. Weir calculations in this study were made assuming the diet contained an average of 12.5 per cent of calories from protein. The general average is usually given as 10-15 per cent of the American diet. Insull et al reported the final effect in calories of protein variation from 10-15 per cent using the Weir formula is $\pm$ 0.02 per cent. Results of the experimental test for four activities are given in Table 3. The experimental tests showed the energy cost of activities, above basal, in calories per kilogram per hour to be 26 per cent for walking at normal speed, approximately 88 per cent walking with books, 168 per cent going up and down steps and 199 per cent when books were carried up and down steps at normal speed.

Above basal expenditure going up and down steps at the rate of 104 steps per minute, required more than twice as much energy for the 12 year old subject as walking on the level. Carrying 3½ pounds of

TABLE 3

ENERGY DATA OBTAINED FOR ONE SUBJECT PERFORMING FOUR ACTIVITIES

| | Walking | Walking[1/] with books | Going up & down stair steps | Going up & down stair steps with books |
|---|---|---|---|---|
| Vol. exp. air STP | 27.95 | 38.55 | 44.38 | 49.11 |
| Calib. factor | 1.1168 | 1.0697 | 1.0697 | 1.0697 |
| Adj. exp. air vol. | 32.22 | 41.24 | 47.47 | 52.53 |
| L/min STP | 8.06 | 10.31 | 11.87 | 13.13 |
| Ave. $O_2$% | 15.71 | 15.62 | 15.03 | 15.08 |
| Bladder Calib. | 0.9901 | 0.9901 | 0.9901 | 0.9901 |
| Ave. adj. $O_2$% | 15.46 | 15.46 | 14.88 | 14.98 |
| Ave. Cal/L | 0.273 | 0.273 | 0.302 | 0.296 |
| Ave. Cal/min | 2.20 | 2.81 | 3.58 | 3.89 |
| Ave. total Cal/hr | 132 | 168.6 | 214.8 | 233.4 |
| Ave. total Cal/min | 2.2 | 2.8 | 3.6 | 3.9 |
| Ave. Cal/kg/hr | 3.50 | 4.47 | 5.70 | 6.19 |
| Basal Cal/kg/hr | 1.55 | 1.55 | 1.55 | 1.55 |
| Activity Cal/kg/hr | 1.95 | 2.92 | 4.15 | 4.64 |
| Activity Cal/kg/min | 0.032 | 0.049 | 0.069 | 0.077 |
| Activity energy cost % over basal | 26 | 88 | 168 | 199 |

1/ By mistake, an "S" pattern replaced the usual "O" pattern once in walking around the room.

books increased the cost by approximately 50 per cent for walking on the level and about 12 per cent in stair climbing.

Excluding basal energy metabolism the energy cost in Calories per kilogram per minute was 0.032 for walking, 0.049 for walking with books, 0.069 for climbing up and down stairs and 0.077 for stair climbing with books.

In the experimental test the 12 year old subject in this study used 4.15 Calories per kilogram per hour above the basal metabolism calories for going up and down 10 steps at the rate of 104 steps per minute. Taylor and MacLeod reported 4.65 as an average value for girls 9-11 years of age in climbing up and down stairs. They stated that in their studies as age decreased the energy expenditure per unit of weight increased in any given activity.

Including the basal metabolism Calories, 2.2 Calories per minute were used by the subject (weighing 37.7 kilogram) in walking and 2.8 calories per minute when $3\frac{1}{2}$ pounds of books were carried. Going up and down 10 stair steps required 3.6 calories per minute, increasing to 3.9 calories per minute when books were carried.

## Methods

In order to make this energy activity study, it was necessary to develop methods for gas meter calibration and operation, gas sampling, gas analysis, calibration of rubber bladders and to perform basal metabolism tests.

The Kofranyi-Michaelis respirometer #61437 was calibrated in February 1962 using a Tissot type spirometer. In fifteen tests, calibration factors were determined for rates from 6-18 liters per minute. These calibrations were made using an aneroid barometer, later found to be incorrect, so it was necessary to re-calculate the values after consulting barometric pressure and temperature records for each from a recording barometer in another department on campus. This recording barometer was compared with a mercurial barometer and found to be correct. The average calibration values for the Kofranyi from thirteen tests were as follows:

| Rate L/min | Calibration Factor |
|---|---|
| 6 | 1.1678 |
| 7-8 | 1.1158 |
| 9-17 | 1.0697 |

The machine used here was new and these were the first calibration factors obtained here.

For this study a Fisher Company Haldane-Henderson gas analyzer stand had to be re-aligned to accommodate the larger Arthur H. Thomas glassware, except for water bath and mercury leveling bulb. The carbon dioxide values did not check as well as the oxygen values in this study. This was not considered too significant however since the oxygen values only were used in the calculations made. On the carbon dioxide side of the apparatus a mended control tube was used and the capillary tube could not be aligned perfectly to permit the most accurate readings. Carbon dioxide absorption was complete although readings between tests were not as close as desired.

Library research and laboratory experimentation finally produced operating directions that were good and relatively easy to follow.

These directions as used are given in the appendix. This chemical method though tedious and troublesome, appears to be quite accurate.

Two rubber bladders were calibrated against a Douglas bag giving an average value of 99.01 per cent for each.

# CHAPTER VI

## SUMMARY AND CONCLUSIONS

### Summary

Methods were developed for measuring energy expended by children in performing certain activities. The equipment used included a McKessoon waterless metabolor for basal metabolism tests, an improved Kofranyi-Michaelis respirometer for collecting expired air, a Tissot type spirometer for respirometer calibration, a Douglas bag for bladder calibration and the Haldane-Henderson gas analyzer for determining oxygen and carbon dioxide content of expired air. The Weir formula used employed the percentage of oxygen concentration in inspired and expired air with a correction factor for protein in the diet. An average value of 12.5 per cent of total calories for protein was assumed in this study.

Basal metabolism tests were made for three subjects. Energy measurements for four activities were made with one of the subjects. This subject was between 11 and 12 years of age, weighed 83 pounds and was 60 inches tall. Results of the activity studies may be summarized as follows:

1. Size and weight of the Kofranyi-Michaelis respirometer made it necessary for an adult to wear it while it was connected to the child.
2. Basal metabolic rate, as determined within two weeks of the activity studies, was 49.4 Calories per square meter per hour or 1.55 Calories per kilogram per hour for the experimental subject. Basal energy metabolism required about 1402 calories for 24 hours.

3. The per cent deviation from normal basal metabolic rate (modified Du Bois standard) was -13 per cent at age 11 years and five months and increased to + 13 per cent at age 11 years and 10 months, along with a gain of one inch in height and 10 pounds in weight.
4. Compared to a height-weight-age standard the girl was 3 inches taller, or 12 pounds lighter than average 12 year old girls. In a classification using height and weight measurements without consideration of age she was within the average range.
5. Total calories per minute, including basal metabolism calories for J.C. were 2.2 for walking, 2.8 for walking with books, 3.6 for going up and down steps and 3.9 for going up and down steps with books.
6. Walking at normal speed, 104 steps per minute, including basal metabolism calories required 1.95 Calories per kilogram per hour or 0.032 Calories per kilogram per minute. The calories required were 26 per cent more than basal.
7. Walking at normal speed with about $3\frac{1}{2}$ pounds of books excluding basal metabolism calories required approximately 2.92 Calories per kilogram per hour or 0.049 Calories per kilogram per minute. The calories required were 88 per cent more than basal.
8. The subject used 4.15 Calories per kilogram per hour for climbing up and down 10 steps, at the rate of 104 steps per minute, requiring 168 per cent more calories than basal.
9. Climbing up and down steps with books required 4.64 Calories per kilogram per hour or 0.077 Calories per kilogram per minute which was nearly 200 per cent more than basal.

10. Going up and down steps excluding basal metabolism calories required more than twice as many Calories per kilogram per hour as walking on the level at 104 steps per minute. When books were carried for each there was less difference between the values.

11. Pulmonary ventilation rates for the activities performed at the rate of 104 steps per minute were 8 liters per minute for walking on the level, 10 liters per minute for walking with books, 12 liters per minute in climbing up and down stairs and 13 liters per minute with books.

12. Average per cent of oxygen in expired air was 15.46 per cent for walking with or without books, 14.88 per cent for going up and down steps and 14.98 per cent for going up and down steps with books.

## Conclusions

The following conclusions were drawn from this activity study with one subject:

1. The Kofranyi-Michaelis apparatus may be successfully used with children if it is worn on the back of an adult beside the child.
2. More than one test should be used to establish the energy value for a particular activity with one child.
3. Basal metabolism tests should be made near the time that activity studies are to be made.
4. The actual protein content of the diet should be known and used in the Weir formula for accurate energy determinations.
5. Energy expenditure studies are expensive in terms of time, equipment, techniques to be mastered and the number of personnel required.

The conclusions that were drawn in developing the methods used for this study are:

1. It is desirable to have the stand designed for the Haldane-Henderson glassware from Arthur H. Thomas Company to permit proper alignment and closer readings from the carbon dioxide absorber.
2. That enough sampling bottles be available to hold duplicate samples from bladders made in two different activities if the Haldane-Henderson method of gas analysis is used.

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# VITA

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Sally D. Yu

# APPENDIX

# INSTRUCTIONS FOR MEASURING BASAL METABOLISM
# USING McKESSON RECORDING WATERLESS METABOLOR #185

Preliminary preparation of the patient:

1. 12-18 hours since last food was taken.
2. Awake, lying down relaxed for 30 minutes.
3. Record pulse and temperature (check pulse several times).
4. Comfortable room temperature.

Directions for basal metabolism test:

1. Charge the machine with soda lime if necessary.
2. Charge with oxygen.
3. Record room temperature and barometric pressure from the machine.
4. Fill and adjust the pen ready for use.
5. Plug in the machine.
6. Adjust the face mask, or mouth piece, and nose clamp to the subject and get machine in place.
7. Open the valve in the inhaler body to admit oxygen.
8. Ask the patient to breath regularly and relax as if she is going to sleep.
9. Set the pen against the paper at the base line.
10. Turn on the clock switch to start the chart running.
11. After 6-7 minutes remove the inhaler and let the patient rest for at least 10 minutes.
12. Repeat the test from step 6 through 11 for 6 minutes or longer.
13. Remove mask, etc. from the patient.
14. Turn off the chart and close the inhaler valve to prevent escape of oxygen.
15. Obtain age, height, and weight.
16. On the graph, draw the slope of the oxygen consumption and complete the calculations on the data sheet using the tables provided with the machine.

# BASAL METABOLISM TEST

## Report Form

Name ____________________

Age ____________________

Date __________ Time __________

Height ____________________

Weight ____________________

Surface Area (Table B) ____________________

Body temperature ____________________

Pulse: Before ____________________

After ____________________

Last food eaten ____________________

Mental Attitude: Calm, nervous, very nervous

Temperature of machine ____________ °C

Barometric pressure ____________ mm $H_g$

Graph No. ____________________

Liters $O_2$ used in 6 minutes ____________

Liters $O_2$ used per hour ____________

## Calculations

(1) Calories/hour = volume of $O_2$ per hour x Table A factor

(2) Calories/sq. meter/hour $= \frac{\text{Cal/hour}}{\text{Surface Area}}$

Correct Cal/sq.m/hr for each degree subnormal temperature by adding 7.2% or substracting 7.2% for each degree of fever

(3) Basal metabolic rate in per cent above or below normal from calories obtained in (2), using Table E.

NOTE:

Normal frequency of pulse in adults, after a few minutes of rest, is 75-85 beats per minute when lying down. Normal pulse rate of 75 usually goes with a BMR of 0%. Change in pulse rate up or down by one beat is consistent with change in BMR up or down by 1%. For example:
A pulse of 50 and BMR of 25% = hypometabolism
A pulse of 90 and BMR of 15% = appenhension (first test) overactive thyroid or due to toxic gorter (2nd test)

CALIBRATION OF THE KOFRANYI-MICHAELIS RESPIROMETER

WITH A TISSOT-TYPE SPIROMETER

1. The pulley of the Collins chain-compensated respirometer must be telescoped upwards to be in proper position for normal use.

2. Fill the Tissot with air by opening the two way valve to the outside with all valves closed, and carefully pulling the stick assembly downward until the bell is filled with room air. Close the valve by turning the handle down.

3. Adjust the water level in the gasometer, adding distilled water at room temperature, until it will barely drip from the side valve.

4. Adjust leveling screws on the casters so the spirometer is exactly vertical and the bell floats evenly, about 3/4 inch from each side.

5. Test for leaks by removing the weight and carefully pulling the stick assembly downward so the bell rises a few inches. If there are no leaks the reading will remain the same as before the stick was pulled. Replace the weight.

6. Connect Tissot and Kofranyi with a plastic adaptor and rubber mouthpiece between two lengths of one inch corrugated rubber tubing.

7. Close the pipe above the three-way valve of the Tissot with a tight stopper. This provides a reservoir of air which makes breathing easier and excludes room air, when the valve is opened (left).

8. On data sheet record barometric pressure and room temperature and then record temperature and initial stick reading for the Tissot and temperature and meter reading for the Kofranyi.

9. Adjust nose clamp and mouthpiece and check for leaks.

10. To begin the test, turn on the valves for the Kofranyi and Tissot simultaneously, time accurately with a stopwatch. At the end of the test, turn both valves simultaneously and then remove mouthpiece and nose clamp.

11. Immediately record temperature and volume readings for both Kofranyi and Tissot.

12. Calculate the correction factor for the Kofranyi as outlined on the data sheet.

KOFRANYI-MICHAELIS RESPIRATION GAS METER

Calibration Data Sheet

Date ______________

Barometric pressure ____________ mm Hg. ____________ °C

Bar. Pr. Adjusted for brass scale and °C ____________ mm (Table A*)

Time ______________________ min. Rate ____________ Liters/minute

| TISSOT - TYPE GASOMETER | | | KOFRANYI # __________ | | |
|---|---|---|---|---|---|
| Initial stick reading | ________ | cm | Final meter reading | ______ | L |
| Final stick reading | ________ | cm | Initial meter reading | ______ | L |
| Change in stick height | ________ | cm | | | |
| Tissot factor | ________ | | | | |
| Volume | ________ | L | Volume | ______ | L |
| Initial temperature | ________ | °C | Initial temperature | ______ | °C |
| Final temperature | ________ | °C | Final temperature | ______ | °C |
| Average temperature | ________ | °C | Average temperature | ______ | °C |
| Volume correction factor STPD (Table B**) | ________ | | Volume correction factor STPD (Table B**) | ______ | |
| Corrected volume STPD | ________ | L | Corrected volume STPD | ______ | L |

$$\text{Correction Factor} = \frac{\text{Tissot corr. vol. STPD}}{\text{Kofranyi corr. vol. STPD}}$$

* Table A: Enlarged from "Temperature Correction for Barometer Readings" (Brass Scale-Metric Units) pg. 2300-2301, Handbook of Chemistry and Physics, 39th Ed. (26).

** Table B: Enlarged from Table 43, pg. 139 in Tables, Factors, and Formulas for Computing Respiratory Exchange and Transformations of Energy by T. M. Carpenter, published by Carnegie Institution of Washington, D. C., 1939. (27).

## PROCEDURE FOR CALIBRATING RUBBER BLADDERS

I. Collect an initial sample of expired air directly from Douglas bag into Bailey glass sampling bottles.

1. Evacuate the Douglas bag by using a vacuum pump.

2. Fill the Douglas bag by wearing a nose clamp and breathing through a mouthpiece with adaptor into the corrugated rubber tubing attached to the bag. Turn valve on the adaptor to close the Douglas bag when it is full.

3. Knead the bag thoroughly and then transfer a sample of expired air into Bailey sampling bottle.

II. Collect sample of air from Kofranyi into rubber bladder.

1. Evacuate the rubber bladder with a vacuum pump.

2. Connect the Douglas bag to the respirometer with corrugated rubber tubing.

3. Rinse the connections and the gas meter by sending air from the Douglas bag through the meter, Then turn off valves to meter and Douglas bag at the same time.

4. Connect the evacuated rubber bladder to the 2-way glass stopcock on the respirometer. Remove the pinch clamp.

5. Record temperature and meter reading of the Kofranyi.

6. Turn on the stopcock to the sampling bladder. Then turn on the sampling valves for the Douglas bag and the respirometer and pinch the stopwatch.

7. Press Douglas bag by hand to simulate breathing motion. Force air out at a rate of eight liters per minute by checking the reading of the Kofranyi and the stopwatch.

8. At the end of six minutes, turn off both valves. Close the 2-way stopcock, and put a pinch clamp on the bladder. Carefully remove the bladder from the stopcock.

9. Knead the bladder thoroughly and then transfer two samples from this bladder to two different Bailey sampling bottles.

III. Collect a final sample of expired air directly from Douglas bag.

1. Knead the Douglas bag thoroughly.

2. Transfer a sample from the Douglas bag directly into a Bailey Sampling bottle.

IV. Analyze the air samples and calculate the calibration factor.

1. Determine the percentage of oxygen in the sample of expired air.

2. Calculate the calibration factor as follows:

Calibration of Rubber Bladder #2

| Source | | % $O_2$ |
|---|---|---|
| Douglas Bag | Before | 17.90 |
| | After | 18.02 |
| | Average | 17.96 |
| Kofranyi | | 18.23 |
| 8 L/min | | 18.21 |
| | Average | 18.22 |

$$\text{Calibration factor} = \frac{\text{Douglas Bag (Ave. \% } O_2)}{\text{Kofranyi (Ave. \% } O_2)}$$

$$\frac{17.96}{18.22} = 0.9857$$

V. Repeat the procedure several times from each bladder to determine an average calibration factor.

# PROCEDURE FOR ACTIVITY TESTS

# USING THE KOFRANYI-MICHAELIS RESPIROMETER

# MODEL 59

I. Preliminary preparation for activity tests:

1. Preparation of equipment and supplies needed.

   a. Assemble gas meter, mouthpiece, nose clamp, adaptor, stopwatch, metronome, magnifying glass, thermometer, 60% alcohol and tissues.

   b. Fill out the known information on the data sheet.

   c. Evacuate the bladders and close with a pinch clamp. Connect the closed bladder to the sample outlet of the meter with turn tap in "off" position. Then open clamp on rubber bladder. Have sampling tap turned to the 0.6% position.

2. Have the child rest for about ten minutes after her arrival.

3. Take temperature and pulse to be sure both are normal.

4. Connect the mouthpiece and adjust the nose clamp to the child, and allow her to sit and breathe through the meter for 1-2 minutes to fill the communication lines and collect air in each bladder for one minute for rinsing. Turn off the stopcock and the sampling valve.

5. Remove the two bladders carefully, with the pinch clamp on.

6. Repeat 1c.

7. Strap the meter to the adult who will walk beside the child during the tests.

8. Take the initial temperature and meter reading of the Kofranyi.

9. Set the metronome.

II. Procedure for the tests:

1. Turn the stopcock and the sampling valve at the same time that the stopwatch is punched and have the child walk for the designated testing time.

2. At end of test period turn the stopcock and the sampling valve off and record the final temperature and meter reading.

3. Carefully clamp rubber bladder before removing.

III. Follow-up procedure:

1. Analyze the aliquot sample immediately or transfer to a Bailey gas sampling bottle under mercury for later analysis.

2. Wash mouthpiece and nose clamp with hot soapy water, drain, and dip in 60% alcohol.

3. Determine the volume of expired air by substracting the initial from the final reading. Adjust the volume to standard conditions of temperature, pressure and dry.

4. Calculate the energy expenditure values as shown on the Activity Data Sheet.

KOFRANYI-MICHAELIS RESPIRATION GAS METER

Activity Data Sheet

Subject's name________________ Activity________________

____________________ Length of time__________min

Observed Bar. Pressure__________mm Temperature__________°C

Adj. Bar. Pressure__________mm Kofranyi meter #__________
(Table A 1/)

Final meter reading__________L Initial temperature__________°C

Initial meter reading__________L Final temperature__________°C

Volume (uncorrected)__________L Average temperature__________°C

Volume correction factor STPD (Table B 2/)__________

Volume of expired air STPD__________L Calibration factor__________

Final adjusted volume__________L Respiratory rate__________L/min

| Bladder Number | Sample Bottle | % $O_2$ | Bladder Factor | Adj. % $O_2$ | Cal/L 3/ | Cal/min |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| Average Cal/hr | Average Cal/hr/kg | Basal Cal/hr/kg | Activity Cal/hr/kg | Activity Cal/min/kg |
|---|---|---|---|---|
| | | | | |

1/ Table A, Handbook of Chemistry and Physics, 39th Ed., pg. 2300-2301.
2/ Table B, Computing Resporatory Exchange, Carpenter, T. M., 1939.
3/ Weir Formula.

## PROCEDURE FOR TRANSFERRING THE AIR SAMPLE INTO A BAILEY SAMPLING BOTTLE

1. Have the sampling bottle half filled with mercury.

2. Tilt forward until mercury completely fills the gas compartment and the barrel of the stopcock.

3. Close the stopcock and place the bottle on a level position and connect with the sample bladder.

4. Knead the bladder well.

5. Flush a small amount of sample through the upper connection to remove room air.

6. Turn the stopcock to connect gas sample with the gas compartment of the Bailey sampling bottle.

7. Tilt the Bailey sampling bottle backward as far as possible so that mercury is drawn out of the gas compartment and sample is drawn in.

8. Close the stopcock and sample is secured.

# HALDANE-HENDERSON GAS ANALYSIS

## I. Preparation of the Apparatus

General:

Have all parts absolutely clean, carefully aligned and in position without strain but rigid enough to prevent motion in joints. The rubber tubing to be used requires special treatment and the mercury must be cleaned when necessary (22). For aid in setting the control tube a leveling bulb as well as two screw clamps should be used. Mercury and water leveling bulbs should be covered with closely woven cloth to protect from dust.

Reagents:

a) Potassium hydroxide solution for $CO_2$ absorber:

Mix equal volumes of KOH and distilled carbonate free water. Dilute to specific gravity of 1.15 using a hydrometer (range 1.120 to 1.190).

b) Potassium pyrogallate solution for $O_2$ absorber: (20) (22) (28).

Prepare a stock solution of caustic potash having a specific gravity of 1.55 using a hydrometer (range 1.540-1.610). This will require a ratio of 200cc distilled water to 300 gm of KOH (85-88%) pellets. Weigh the KOH, add carbonate free water and mix until completely dissolved and the solution is clear. A current of air may be used to get the last crystals into solution. Check the specific gravity and add more KOH, dissolving completely, until desired specific gravity is reached.

Potassium pyrogallate solution is made using 10-15 gm pyrogallic acid crystals N.F. for every 100cc of KOH solution (specific gravity 1.55). Place the weighed acid crystals into a brown bottle and add the measured volume of KOH stock solution. Stopper with a greased glass stopper and shake vigorously until completely dissolved. Avoid unnecessary contact with the air. Small brown bottles with glass stoppers that contain enough for one filling are best for storing this solution. Seal with paraffin wax and store for one month before using. If larger bottle is used layer the solution with paraffin oil to prevent contact with air. Successful transfer to the absorber pipette is more difficult when the oil is used. For accurate results, using a freshly made solution, heat for an hour at about 100°C (20).

c) Acidulated water:

Using 1 ml concentrated sulfuric acid, reagent grade, make up to 100 ml with distilled water. This is used over the mercury and in the leveling bulb for the control tube.

Stopcock grease:

"Lubriseal," a commercial stopcock grease, may be used to grease the stopcocks. A mixture of vaseline, crude rubber and paraffin has been recommended for use in hot weather by Peters and Van Slyke (22). Stopcocks should be carefully greased so that they appear transparent when in place. They stick if not carefully covered with thin film of grease.

Water bath:

Fill with distilled water so that the bulbs of burette and control tube are well covered. Add a few crystals of copper sulfate as a bacteriacide.

Control tube with leveling bulb:

Grease stopcock carefully but lightly. Partly fill the leveling bulb with acidulated water and allow about 3cc to run into the control tube. Hang on hook.

Carbon dioxide absorber cylinder:

Before connecting the ball and socket joint slowly run KOH solution (specific gravity 1.15) into the cylinder up to the top of the bell. Expel air bubbles by raising and lowering cylinder. Then connect with control tube by turning stopcock to exclude outside air and adjust control tube by raising and lowering the leveling bulb until KOH is drawn into the capillary tube, then hang and close the second screw clamp on the rubber tube. Fill the $CO_2$ absorber cylinder so that fluid rises to desired etched mark and then clamp greased ball and socket joint.

Oxygen absorber cylinder:

Slowly introduce pyrogallol solution into the cylinder so that the small glass tubes in the bell are filled and the solution reaches the desired etched mark in the capillary tube. Be careful that no bubbles are caught in any of the small glass tubes in the absorber. Clamp lightly greased ball and socket joints together. Cover with a layer of paraffin to protect the solution from air (have enough to keep it covered when in operation).

Gas burette:

Have greased stopcock in place and open to outside only.

a) Lower mercury reservoir until its opening is opposite the bottom of the water bath.

b) Introduce clean mercury into the leveling bulb and then raise and lower it and to drive all air from the tubing.

c) Permit mercury to rise finally in the burette to the opening of the stopcock when the leveling bulb should be about 1/3 full.

d) Draw a few drops of acidulated water into the burette through the stopcock by lowering Hg leveling bulb.

e) Slowly lower the mercury so that water moistens the walls for the calibrated length of the burette, then slowly raise Hg and eject the excess water through the upper cock onto a piece of filter paper (do this slowly to avoid spilling water and Hg).

f) Have just enough water left in the burette to make a visible ring about the mercury surface when it is near the 10cc mark. (If burette becomes dry appreciable errors are produced - air will take up more $H_2O$ than it loses $CO_2$ when it goes into the KOH).

Note: Mercury is poisonous and is very hard to handle. Avoid spilling, but when spilled clean immediately and spread powdered sulfur on table or floor. Vapors from spilled Hg are injurious. Spilled mercury must be carefully cleaned before using again.

Adjust automatic pulley:

Have Hg into the bulb of the burette before the leveling bulb is attached to the automatic pulley. It must be so regulated that the motions of the mercury meniscus are confined entirely to the bulb portion of the burette; to prevent mercury or pyrogallol from being driven into stopcocks and capillary tubes.

# HALDANE-HENDERSON GAS ANALYSIS

## II. Setting the Apparatus

Each morning close the control tube. Rinse burette with fresh acidulated water and follow below for setting the apparatus:

1. Admit sample of room air:

   Draw 9.5 - 10cc of room air into the burette.

2. Absorb $O_2$ from air for 7 minutes:

   a) Force the air into pyrogallate by making stopcock turn ¼ counter-clockwise and at same time raise mercury leveling bulb. This makes positive pressure and prevents sucking pyrogallate into stopcock and burette.

   b) Carefully hang mercury leveling bulb on motor pulley, turn on switch and have air pushed back and forth for 7 minutes (about 21 times or 3 revolutions per minute) using a stopwatch.

   c) Lower mercury by hand until pyrogallate enters capillary tube then turn stopcock slightly counter-clockwise to close.

3. Absorb $CO_2$ from air for 3 minutes:

   a) Connect burette with KOH by ½ turn counterclockwise and at same time raise mercury reservoir (to prevent sucking KOH into stopcock and burette).

   b) Force air back and forth for 3 minutes with pulley device.

   c) Carefully lower mercury bulb until KOH in capillary is about ½ inch from the bend, then close stopcock by slight clockwise turn.

4. Absorb $O_2$ from air for 5 minutes:

   a) Connect burette with pyrogallate (clockwise turn) at same time slightly raise mercury bulb.

   b) Force air back and forth into pyrogallate for 5 minutes using pulley device.

5. Take first reading: (Permanent marks must make all capillary levels in a straight line).

a) Bring pyrogallol to permanent mark by lowering Hg carefully and hang on rack to make the fine adjustment then turn stopcock slightly counterclockwise to close.

b) Connect to KOH by $\frac{1}{2}$ turn counterclockwise at same time slightly raising Hg.

c) Adjust KOH level to permanent mark by hanging Hg and using fine adjustment.

d) Reset control tube to permanent mark by manipulation of screw clamps.

e) Pump hand bubbler to equalize temperature in water bath.

f) Read with magnifying glass. Check permanent marks of pyrogallol, KOH and control tube levels. Stir with bubbler and recheck reading.

6. Absorb $CO_2$ for 1 minute (into KOH)

7. Absorb $O_2$ for 3 minutes (pyrogallol)

8. Take second reading:

a) Bring pyrogallol to permanent mark by lowering Hg carefully hang on rack and use fine adjustment.

b) Connect to KOH by $\frac{1}{2}$ turn counterclockwise at same time slightly raising Hg, using fine adjustment.

c) Adjust KOH level to permanent mark, hang on rack and use fine adjustment.

d) Reset control tube to permanent mark by use of screw clamp.

e) Pump hand bubbler to equalize temperature in water bath.

f) Read with magnifying glass. Check pyrogallol, KOH and control tube levels to see they are in a straight line. Stir with bubbler and recheck reading.

g) If two successive readings agree, the apparatus is free of $O_2$ and $CO_2$ with $N_2$ remaining, which is necessary before it is used for analyzing gas samples. If two successive readings do not agree, check for leaks in stopcock and check bores to see that they are not plugged with grease or with a mercury ball.

# HALDANE-HENDERSON GAS ANALYSIS

## III. Analysis of Gas Samples

1. After the apparatus is "set" remove the nitrogen gas from burette:

   Turn stopcock ¼ turn counterclockwise from KOH absorber of burette to outside air and force nitrogen gas out by slowly raising mercury leveling bulb.

2. Rinse burette:

   Introduce a few drops of acidulated water into burette for rinsing. Remove excess acid with a piece of filter paper.

3. Reset control tube:

   Turn stopcock of control tube to outside air briefly, then close. Adjust KOH level to permanent mark by means of screw clamp below.

4. Mount gas sampling bottle:

   Use support made to hold the sample bottle securely. Connect sample bottle to burette with short rubber tubing firmly attached at either end. Turn stopcock of sample bottle to connect with outside air.

5. Remove atmospheric air from sampling connections:

   Raise Hg bulb and force Hg column up through the burette, and just a bit past the sample bottle stopcock into the outlet arm. Turn stopcock of sample bottle to connect with gas sample and lower Hg leveling bulb to draw sample down into the burette.

6. Admit the gas sample:

   Draw gas sample into burette by slowly lowering Hg bulb until mercury level is at approximately 10 cc marking. If less is admitted the volume of residual nitrogen remaining after $O_2$ absorption is too small to read in the calibrated portion of burette and results cannot be used.

   After about 30 seconds, turn burette stopcock about 1/8 turn clockwise. Be careful not to connect directly to KOH absorber.

7. Take the initial volume reading:

a) Adjust Hg in the leveling bulb and burette to the same level, as nearly as possible, using fine adjustment, so gas is under atmospheric or only slight positive pressure (use ruler to measure evenness).

b) Slowly connect gas burette to KOH absorber.

Note: Reasonable speed is necessary from here on until reading is established as $CO_2$ will eventually diffuse into KOH and each successive reading will be less and the analysis must be abandoned.

c) Adjust so that KOH levels are at permanent marks and both at the same level before any readings are taken.

d) Pump the bubbler to equalize temperature in water bath.

e) Take the initial reading.

f) Pump the bubbler and repeat the reading. A constant reading is needed to establish initial reading for volume.

8. Absorb $CO_2$

a) Force gas into KOH for 3 minutes (or 5 times to and from by hand) on pulley device.

b) Adjust KOH level to permanent mark, in capillary. Adjust control tube KOH to permanent mark.

c) Pump bubbler to equalize temperature.

d) Take reading.

e) Again force gas into KOH for 1 minute and then adjust KOH and control tube levels to permanent mark and pump bubbler.

f) Take second reading.

g) Repeat "e" until two successive readings agree.

Caution: Each time the top of the falling Hg column reaches the lower part of the burette bulb, and enters the smaller graduated section its rate of descent increases. If care is not taken at this point the mercury may fall so rapidly that it overshoots the mark, drawing alkali into the connecting capillary. When this happens, the analysis must be discarded and the apparatus cleaned before it is used again.

9. Establish connections with pyrogallate:

a) Carefully lower Hg bulb so that KOH level is within 1 inch of the bend in the capillary tube. Close stopcock by a slight clockwise turn.

b) Connect with pyrogallate by turning stopcock ½ clockwise turn and at the same time slightly raise the Hg reservoir.

c) Hang Hg leveling bulb on pulley device.

10. Absorb $O_2$:

a) Force sample back and forth into pyrogallate for 10 minutes. (If done by hand let it remain several seconds in the pyrogallate each time and have at least 10 exchanges to remove the major portion of oxygen).

<u>Caution:</u> Even greater care must be taken in lowering the leveling bulb after absorption of oxygen than after the absorption of $CO_2$ because of the smaller amount of gas which now remains. If Hg falls rapidly solutions will be drawn into the capillary tubes.

b) Bring pyrogallate level to a temporary mark (any level) by gently lowering the mercury bulb.

c) Connect gas burette to KOH absorber and at same time gently raise Hg bulb and force gas back and forth into the KOH for 1 minute to sweep out oxygen remaining in the connecting tubes.

d) Again establish connections with pyrogallate and force gas back and forth for another 5 minutes. <u>Caution again</u> in lowering the leveling bulb!

e) Adjust pyrogallate level to permanent mark.

f) Connect to KOH (at same time gently raise Hg bulb).

g) Pump bubbler to equalize temperature.

h) Take first reading.

i) Again absorb in KOH for 1 minute and then in pyrogallate for 3 minutes. Adjust pyrogallate, KOH and control tube to permanent marks and pump bubbler.

j) Take second reading.

k) Repeat "i" until two succeeding readings agree.

11. Take the water meniscus reading after the last of the Hg meniscus readings are made. Substract the difference obtained between Hg reading and water reading from the initial volume to correct it before calculation of the per cent $CO_2$ and $O_2$ in the sample analyzed. The water volume should be kept between 0.05 and 0.10 per cent for every 0.05 per cent of volume due to visible water, 0.01 per cent error would result in the determination.

12. Use correction factors to adjust all volume readings from the burette.

    Note: Apparatus is now ready for analysis of next gas sample as the remaining gas is nitrogen.

13. Care of apparatus at end of day's analyses:

    a) Turn the stopcock to outside air and send $N_2$ out by raising Hg.

    b) Carefully blot off the acidulated water on top of Hg.

    c) Draw in fresh acidulated water, rinse the full length of the burette several times.

    d) Have Hg level in the burette bulb and hang leveling bulb securely.

    e) Open the control tube to the outside air to prevent KOH from being sucked back into the capillary tubes.

14. Calculations of Results:

    With expired air duplicate determinations should not differ more than:
    0.03% for $CO_2$
    0.04% for $O_2$

$$\text{Percent } CO_2 = \frac{100(\text{Init. Vol. Read.}) - (\text{Vol. after } CO_2 \text{ absorb.})}{\text{Init. Vol. Read.}}$$

$$\text{Percent } O_2 = \frac{100(\text{Vol. after } CO_2 \text{ absorb.}) - (\text{Vol. after } O_2 \text{ absorb.})}{\text{Init. Vol. Read.}}$$

$$\text{Percent } N_2 = \frac{100 \times \text{Vol. after } O_2 \text{ absorbed}}{\text{Init. Vol. Read.}}$$

Note: Outdoor air should be analyzed periodically to establish accuracy of the apparatus and operator. Outside air should yield 0.03 per cent $CO_2$ and 20.93 per cent $O_2$. Henderson (29) says "If the apparatus is properly graduated and in good order the sum of the oxygen and carbon dioxide is uncontainmented atmosphere air should be found to be 20.96 per cent with an allowable error of ± 0.03 per cent."

## ABSTRACT

In this study methods were developed for measuring energy expended by children. The equipment used included a McKesson Waterless Metabolor for basals, an improved Kofranyi-Michaelis respirometer for expired air with a Tissot type spirometer for calibration, a Douglas bag for bladder calibration and a Haldane-Henderson gas analyzer. Energy calculations were made using the per cent of oxygen in expired air and an average value of 12.5 per cent of total calories from protein in the Weir formula. The Kofranyi respirometer was successfully used with children when worn by an adult near by.

The subject for this study was a girl, almost twelve years of age, weighing eighty-three pounds, sixty inches high, having a B.M.R. of 49.4 Calories per square meter per hour, or + 13 per cent of the modified Du Bois standard. She was classified as "average" by a height-weight scale but was three inches taller or twelve pounds lighter than average using a height-weight-age standard. Her basal in six months increased from -13 per cent to +13 per cent with one inch gain in height and ten pounds in weight.

Energy measurements showed her requirements above basal were 26 per cent for walking at normal speed, and 88 per cent when 3½ pounds of books were carried. Climbing up and down stairs required 168 per cent above basal and nearly 200 per cent if books were carried.

Oxygen in expired air was 15.46 per cent for walking with or without books, 14.88 per cent for stair climbing with books. Air was expired at 8, 10, 12, and 13 liters per minute during these activities.