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Manual of Techniques Used in Determining Human Energy Expenditures

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CONTENTS

* * *

Dry Gas Meter ---------- 3

The Oxygen Analyzer and Accessories ---------- 6

Procedure for Oxygen Analysis of
Expired Air Using Beckman Analyzer, Model E2 ---------- 8

Warm-up Period ---------- 8

Evacuation ---------- 9

Calibration ---------- 9

Sample Analysis ---------- 10

Development of Forms ---------- 11

Periodic Inspection of Respirometer ---------- 13

Testing Equipment ---------- 13

Selection and Preparation of Subjects ---------- 14

Standardization of Activities ---------- 15

Reporting of Data ---------- 16

Literature Cited ---------- 17

Appendix ---------- 18

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MANUAL OF TECHNIQUES USED IN DETERMINING HUMAN ENERGY EXPENDITURES[1]

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Research workers often spend considerable time in working out the details of a method and in assembling equipment during the initial stages of a project. Seldom are these experiences recorded in the final report of the project. As a result other research workers initiating similar work usually repeat these same time-consuming experiences.

These details may be valuable to other workers in another way. In comparing results obtained in one laboratory with those obtained in another, it is important to know in each instance the procedure followed and, in many cases, the particular equipment used in determining energy.

For these reasons this detailed report is being made of techniques used in energy expenditure studies in the Home Economics Department of the Ohio Agricultural Experiment Station.

Two pieces of equipment used, the Kofranyi-Michaelis respirometer and the Beckman oxygen (O_2) analyzer, were comparatively new at the time these studies were initiated. The respirometer was developed in Germany in 1940 and modified by Müller and Franz in 1952. It was introduced into the United States in the early 1950's. Specifications for both pieces of equipment may be found in the Appendix.

Dry Gas Meter

Figure 1 shows the respirometer as purchased except that the mouthpiece and nose clip have been replaced with a face mask. Specifications for the mask will be found in the Appendix. Experience in this laboratory has shown that, in most cases, the mask is more satisfactory than the mouthpiece and nose clip. The mouthpiece tends to simulate the flow of saliva which may be both annoying and unpleasant. On the other hand, the mask may interfere with normal vision. Subjects who ordinarily wear glasses find it difficult and often impossible to wear them and the mask at the same time. With some individuals, problems may arise in fitting the equipment to the face so there are no leaks. Cosmetics worn by women and oil in the skin tend to cause deterioration of the rubber cushion of the mask. Subjects

[1]A contribution from North Central Regional Project NC-9, "Farmhouse Requirements and Their Application in the Improvement of Farm Housing."

Fig. 1.—Kofranyi-Michaelis respirometer and accessories.

are asked to remove cosmetics at the beginning of the test. Both the mask and the mouthpiece must be thoroughly washed and rinsed after use. The rubber cushion of the mask may be dusted with either talcum powder or cornstarch after cleaning. Instructions are furnished by the manufacturer for inflating the cushion. It becomes a matter of judgment as to whether one uses a mask or a mouthpiece and clip. Either may be used satisfactorily if properly adjusted to the individual.

The manufacturer furnishes a factor (true volume in relation to actual volume metered) for each respirometer. This factor needs to be checked by calibrating the respirometer against a high precision gas meter. Durnin and Brockway (1) describe in detail a method of calibration. The calibration should be repeated frequently.

The respirometer and accessories weigh about 8 pounds. In most activities (an exception would be in the case where it is used to determine basal metabolic rate) the meter is worn on the back. It should be fastened securely so it does not move about on the subject's back. The harness is adjustable but additional support is sometimes necessary. A belt (man's pant or lady's dress) put through the loops in the harness and fastened around the waist gives added support. Figure 2 shows the belt in position. It may be observed in this figure that the corrugated tube is tied to the harness at the shoulder by a cord loop. When the straps of the harness are tightened to hold the respirometer in place they tend to press against the shoulder and may become uncomfortable. Foam rubber pads (approximately ¼ inch thick) placed under the straps at the shoulder help to relieve this pressure. During rest between activities, the respirometer should be removed.

The corrugated tubing should be inspected periodically and if there are signs of small breaks or cracks, a "dried out" appearance, or loss of elasticity, it should be replaced. The tubing should fit snugly at the connections to the respirometer and the plexiglass breathing valve.

The position of the aliquoting control needs to be checked routinely at the beginning and at the end of a test. If it has been accidently turned to "off" during the test, there will be no sample.

It is desirable to have at least two respirometers, complete with acessories, available and in working condition. Each should be iden-

Fig. 2.—Respirometer held in position by belt.

tified by the manufacturer's number (manufacturer's stamp) and noted on the record sheet for each test along with the determined correction factor. A sample data sheet used in this laboratory will be found in the Appendix.

The plexiglass breathing valve is fragile requiring careful handling. It needs to be cleaned after use for sanitary reasons and for proper functioning.

The inflatable rubber bags used for collecting samples of expired air should be inspected periodically for breaks and cracks. These bags are used only for short time storage. Insull (5, p. 5) has tested the effect of diffusion of gases across the walls of the bags and states that the error "should be individually evaluated where extreme accuracy is desired or where the diffusion characteristics of the aliquot bladder are not known." The bags should be filled with expired air, stored in a jar with a tight fitting cover and evacuated just previous to the collection. In this laboratory the sample is analyzed for O_2 immediately following the collection. In cases when this is not possible the sample can be transferred to mercury filled syringes. As the sample is drawn into the syringe the mercury is drained off. The syringes used had a capacity of 30cc and were equipped with metal clips and springs over the top of the plunger and a 3-way metal stopcock over the tip. Specifications for these syringes are given in the Appendix. Garry *et al.* (3) have reported that filling a sampling tube with 0.5 percent solution of sulphuric acid in water was as satisfactory as using mercury. This would be more convenient and less costly.

The Oxygen Analyzer and Accessories

The analyzer was developed by Pauling and coworkers (8) and the general principle of the instrument is described by them. The principle of operation and general characteristics of the analyzer are given in the manual supplied with the equipment. The specifications for the model used in this laboratory will be found in the Appendix. In addition to the analyzer itself certain accessories are needed. Figure 3 shows the complete arrangement as used in this laboratory. Specifications for the pump and gas cylinders complete with gauges are found in the Appendix. The manometer was constructed on this campus. Figure 4 is a line drawing of the close-up of the analyzer and connections to manometer, cylinders, sample bag and pump. The stopcock which connects the gas cylinder and/or the sample bag to the analyzer is a 3-way type with capillary tubing leading into the upper opening and 0.5 cm inside diameter tubing into the lower opening (Figure 5). The capillary tubing is used to control the flow rate into the analyzer.

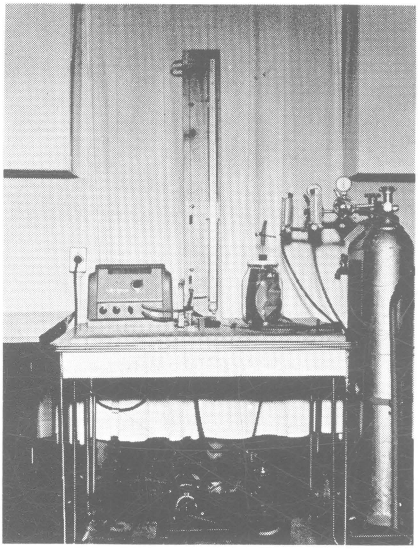

Fig. 3.—Arrangement of gas analysis equipment.

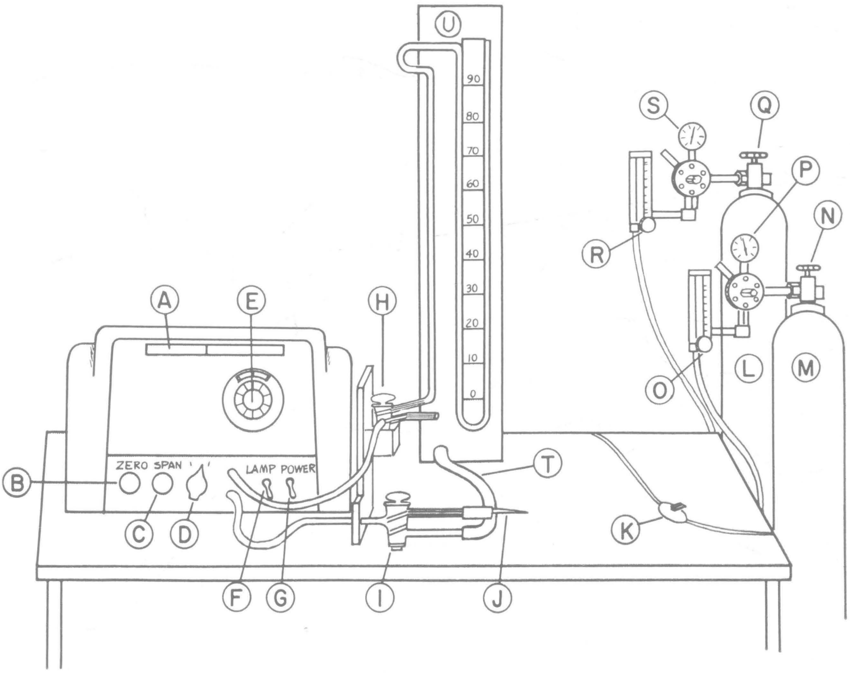

Fig. 4.—Line drawing showing parts of oxygen analyzer and gas cylinders. Key: a, translucent scale; b, zero dial; c, span adjustment knob; d, range knob; e, duodial; f, lamp switch; g, power switch; h, stopcock connecting analyzer to manometer; i, stopcock connecting vacuum pump to analyzer; j, inlet; k, power switch; l, nitrogen tank; m, compressed air tank; n, main valve of compressed air tank; o, knob on compressed air flow meter; p, pressure gauge for compressed air; q, main valve of nitrogen tank; r, knob on nitrogen flow meter; s, pressure gauge for nitrogen; t, hose to vacuum pump; and u, manometer.

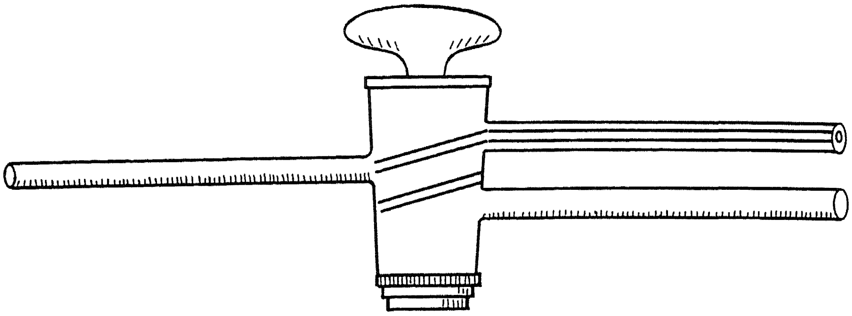

Fig. 5.—Three-way stopcock with arm of capillary tubing.

The other 3-way stopcock, leading from the analyzer to the pump and/or the outside air is equipped with capillary tubing in both outlets. These stopcocks need frequent inspection to make certain they are properly lubricated, clean and free of condensation.

In some localities tanks of compressed air and nitrogen may be obtained on a rental basis. The suppliers may furnish a report of the oxygen content of the air. Even if they do offer this service, it is suggested that analysis of samples of the compressed air be made by a reputable laboratory as a check.

Either an aneroid or mercurial type barometer may be used to determine barometric pressure during tests.

The analyses of samples of expired air should be checked routinely for oxygen content by another method such as the Peters and Van Slyke (9). Ideally equipment for such analysis should be available in the same laboratory but if it is not, the analysis can be made elsewhere.

Based on the general instructions set forth in the manufacturer's manual the following step-by-step procedure used in this laboratory for analysis of O_2 in expired air samples is presented.

Procedure for Oxygen Analysis of Expired Air Using Beckman Analyzer, Model E2

Warm-up Period

1. Turn on power switch G at least one hour previous to beginning of calibration and analysis. The power light which appears on the translucent scale A will go off in about 20 to 30 minutes.
2. At the same time turn on the main valves Q and N of the gas tanks.
3. Observe and record the level of mercury in the left hand column of the manometer U for future reference.

Evacuation

1. To evacuate system
   a. Open stopcock I to connect vacuum pump with analyzer.
   b. Open stopcock H to connect analyzer to manometer.
   c. Turn on power switch K which controls vacuum pump. Let pump run until height of mercury in the columns of the manometer are equal.
   d. Close stopcock I by turning it 90°.
   e. Turn off switch K.

Calibration with Nitrogen and Air

1. To flush system with nitrogen for zero adjustment
   a. Attach hose from tank L to outlet J.
   b. Open stopcock I with left hand and turn knob R with right so gas may flow into analyzer. Caution: adjust flow of nitrogen with knob R so the ball in the flow meter just floats to prevent damage to the analyzer.
   c. Close stopcock H by turning 180° clockwise as soon as level of mercury in left hand column of manometer has reached that observed at the beginning of the warm-up period. Stopcock H is now open to the outside air.
   d. Turn knob D to 0-25 percent range.
   e. Set duodial E so O on inner dial coincides with O (in small window) at the outer rim of the dial.
   f. Turn on lamp switch F. A light beam may be observed on the far right of the translucent scale and it will move to the left and then come to rest.
   g. Turn zero dial, B, until the light beam is centered on the vertical engraved line on the scale.
   h. Turn off lamp switch and disconnent hose at J.
   i. Turn knob R to close off the flow of nitrogen from the meter.
2. To evacuate system
   Proceed as in 1 under **Evacuation.**
3. To flush system with air for span adjustment
   a. Attach hose from tank M to outlet J.
   b. Open stopcock I with left hand and turn knob O with right so air may flow into analyzer.
   c. Close stopcock H as soon as level of mercury in left hand column of manometer has reached that observed at the beginning of the warm-up period.

d. Turn duodial E to calculated reading[2] for 0-25 range based on percentage of oxygen in the air in M.
e. Turn span adjustment knob C until light image is centered on the vertical engraved line on translucent scale.
f. Turn knob D to 16-21 percent (or 15-20 percent on some analyzers) range.
g. Turn knob on duodial E to adjust reading to that calculated in d above. Light image should remain stationary.
h. Turn off lamp switch F and disconnect hose at J.
i. Turn knob O to close off the flow of air from tank M.

The span adjustment should be checked as often as changes occur in barometric pressure.

Sample Analysis

1. Observe barometric pressure and record.
2. Evacuate as in 1 under **Evacuation.**
3. Attach clamped sample bag at J.
   a. Rotate stopcock I quickly until mercury levels remain stationary ending with stopcock closed.
   b. Turn off switch K.
   c. Open stopcock I to permit sample to flow into machine from J.
   d. Observe stability of mercury columns. If mercury does not remain stationary repeat steps a, b, and c, above. Observe levels again.
   e. Release clamp on sample bag.
   f. Open stopcock H to outside air when left hand mercury column reaches level observed at beginning of warm-up period.
   g. Turn on lamp switch F and center light image by turning knob on duodial E.

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[2]Calculated setting of duodial E is based on percentage of oxygen in air. Clean dry air contains on the average 20.93 percent oxygen. The company supplying the air may furnish an analysis, but if it does not, an analysis should be obtained.

The duodial is graduated so each range is divided into 1000 parts. The outer dial is numbered from 0 to 10 and for each rotation 100 points may be read on the inner dial. The following formulae are used in calculating readings:

On the 0-25 scale

$$\frac{X}{1000} \times 25 = 20.93$$ (or percentage determined for air used in calibration)

$$X = 837$$

On the 16-21 scale

$$\frac{X}{1000} \times 5 + 16 = 20.93$$

$$X = 986$$

If percentage of oxygen in sample is less than 16 (or 15 dependent on the range of the analyzer), it may be necessary at this point to switch to 0-25 percent range by turning knob D to this scale in order to get a reading.

h. Apply slight pressure with the hand to sample bag several times. Image will move slightly to left of vertical line when pressure is applied.

i. Record reading on duodial E when image comes to rest on vertical line upon release of hand pressure.

j. Turn off lamp switch F.

When all analyses have been completed turn off power switch G and close main valves Q and N.

Development of Forms

Each laboratory will need to develop a form for recording data best suited to their needs which is compact and easy to use. An example of one used in this laboratory and found adequate is presented.

To assist in reducing calculations to a minimum, a compendium of percentages of oxygen in expired air and the equivalent Calorie values has been compiled. The calculations are based on Weir's formula (12). The table contains the percentages of oxygen most commonly encountered in our observations. The general plan is as follows:

Percentage of O_2	Calories	Percentage of O_2	Calories
16.00	.2459	17.00	.1960
16.01	.2454	17.01	.1955
16.02	.2449	17.02	.1950
16.03	.2444	17.03	.1945
16.04	.2439	17.04	.1940
16.05	.2434	17.05	.1935
16.50	.2209	17.50	.1710
16.51	.2204	17.51	.1705
16.52	.2199	17.52	.1700

Correction factors for reducing volumes to 760 mm Hg and O°C. have been calculated for combinations of barometric pressures and temperatures most commonly encountered. The formula used for calculation was:

$$\text{Correction factor} = \frac{1}{1 + .00367(^\circ C)} \times \frac{\text{Bar. pressure} - \text{Vapor pressure}}{760}$$

SUBJ. ______ **ACT.** ______ **DATE** ______ **AGE** **HT.** **In.** **WT.** **Lb.** **SURFACE AREA** **M^2**

a.m. ______ p.m. ______ Meter # ______ % Sample ______ $C.F. = \frac{1}{1+.00367(°C)} \times \frac{Bar.\ P. - V.P.}{760}$

Activity	Bar. pressure	Temp.	Meter reading Start	End	Gross liters	Time in min.	L/min	Meter cor.	Corrected L/min	Liter/min 760 mm Hg and O°c.
E	744.5	27.0	171.0	245.1	74.1	4.33	17.11	0.95	16.25	13.96
C	744.0	26.0	763.9	912.9	149.0	8.97	16.61	0.95	15.78	13.63

Activity	Beckman reading 0-25 range	x.025	16-21 range	.005	+16	Factor for % O_2 (Weir)	Calories/min Liters/min at standard conditions X Weir factor
E	626	15.65				.2633	3.676
C			83	0.42	16.42	.2249	3.065

Fig. 6.—Form developed for recording data.

Calculation for barometric pressure of 743.5mm Hg, temperature of 26°C and vapor pressure of 25.209 mm Hg (for 26°C)

$$\frac{1}{1+.00367(26°C)} \times \frac{743.5-25.209}{760} = .863$$

Correction factors for various barometric pressures and/or temperatures may be compiled into a table. For example:

Barometric pressure	Temperature		
	26°	26.5°	27.0°
743.5	.863	.860	.858
744.0	.864	.861	.859
744.5	.864	.861	.859

The calculations of Calories expended given on sample record form are based on the above method.

Periodic Inspection of Respirometer

From time to time the top cover of the respirometer should be removed and the exposed parts inspected. Among the things to look for are: meshing of the gears, possible broken cogs, condition of tubing and diaphragms. Garry *et al.* (3) suggest that tobacco smoke be blown through the respirometer as a test for leaks in the diaphragms. Replacements for membrane rubber and small tubing may be purchased from a dental supply house. The respirometer should be calibrated following replacement of membrane rubber.

Testing the Equipment

In preliminary work comparisons were made of results obtained for basal metabolic rates determined by the use of the Kofranyi- Michaelis respirometer with those obtained by the use of the Benedict-Roth metabolism apparatus. Facility had been gained in the use of the latter over the years and comparisons of results on the two pieces of equipment should be a satisfactory method of testing results obtained with the K-M respirometer.

Examples such as the following, show the agreement that was obtained:

	Calories per Minute	
	Benedict-Roth	Kofranyi-Michaelis
Subject 1	0.910	0.894
Subject 2	0.843	0.868
Subject 3	0.831	0.878

Duplicate tests were made routinely on both pieces of equipment. The following examples demonstrate the agreement in rates that may be obtained within instruments as well as between the two:

	Calories per Minute			
	Benedict-Roth		Kofranyi-Michaelis	
	a	b	a	b
Subject 1	0.907	0.914	0.878	0.910
Subject 2	0.861	0.825	0.873	0.862
Subject 3	0.815	0.847	0.883	0.873

Triplicate tests were made using the K-M respirometer only when subjects performed certain standardized tests. The following are examples of values obtained for standing:

	Calories per Minute		
	a	b	c
Subject 1	1.106	1 065	1.093
Subject 2	1.185	1.225	1.202
Subject 3	1.379	1.312	1.348

Selection and Preparation of Subjects

It has been established that certain factors such as age of subject, food, and enviromental temperature may influence energy expenditures. In the studies being conducted in this laboratory certain criteria were established in the selection and preparation of subjects in order to reduce the influence of such factors. The younger women who served as subjects in the earlier studies (except bedmaking) ranged in age from 25 to 40 years, were 5′ 4″ to 5′ 6″ in height and within ± 10 percent of their suggested weight for height according to Hathaway and Foard (4) (Metropolitan Life Insurance Company standards). Another group of 10 women varied in age from 63 to 72 years; in weight, 5 of them were not more than + 17 percent of their suggested weight for height, and the remaining 5 were + 20 percent or more.

All subjects observed in the a. m. arrived at the laboratory in a postabsorptive state. Following the determination of the basal metabolic rate, if this test was scheduled, the subject ate a breakfast consisting of: 6 ounces orange juice, 1 poached egg, 2 slices whole wheat bread, 0.3 ounce margarine, and tea or coffee. Sugar and cream for the beverage were optional.

Subjects observed in the afternoon arrived at the laboratory shortly before noon and ate a lunch consisting of: 4/5 cup tomato soup, a peanut butter sandwich (2 slices whole wheat bread), 1 tsp. margarine, 1 tbsp. orange marmalade, 2 tbsp. peanut butter), 1/2 peach and 1/4 cup cottage cheese salad, tea or coffee, and 2 butter cookies.

The problem of measuring the effect of food on energy expenditure needs study but, in the opinion of the authors, the procedure followed in this laboratory tended to keep the effect similar among subjects.

Observations were made in an air-conditioned room varying in temperature between 72° and 79° F.

Basal metabolic rates were determined for all subjects preceding observations of energy expenditure in performing household tasks. They were used as criteria of general health status as well as making it possible to evaluate data on the basis of Calorie expenditures above basals as compared with total Calories. As a further precautionary measure the older women (63-72 years) were examined by a physician who evaluated their general health status as good.

Prior to each observation subjects were instructed as to their responsibilities as a subject, as to equipment to be used and its functions, and as to the routine to be followed during the tests. No coercion was used by the staff and participation as a subject was voluntary on the part of the women. Careful observation was made by the laboratory personnel of the comfort and welfare of the subjects. At least two staff members were present in the laboratory during tests to take care of any irregularities that might occur.

Standardization of Activities

Women accustomed to performing common household tasks in their homes will vary in the procedures they follow in the performance of these tasks. Procedures to be followed in the laboratory were standardized insofar as possible. In principle, the methods followed conformed to those recommended by specialists in the field of home management. For instance, in bedmaking activities the method of Mundel *et al.* (6) was followed. To control the rate of climbing stairs, the subjects walked to the timing of a metronome set for predetermined rates. Loads carried in stair climbing were all of the same weight but the position for carrying each was standardized, determined to some extent by the shape of the object carried. In caring for hard surface floors and in cleaning stairs covered with carpet and with vinyl treads, the same method was followed for each task by all subjects and the order of performance was rotated according to a statistical design.

For all activities performed except stair climbing, the individual's characteristic rate of work rather than a standardized rate was used. For instance one subject used 4.3 minutes for cleaning a carpeted stairs with a whisk broom and dust pan whereas another used 8.8. Energy expended was reduced to calories per minute for comparison.

The procedures followed in the performance of activities will be reported in greater detail in a subsequent report of energy requirement of the activities.

Reporting of Data

An annotated bibliography and a supplement of energy expenditure studies were prepared in the mid 50's in cooperation with workers at the Iowa station (10, 11). In compiling these references a problem became obvious. It is that of comparison of results reported by investigators because of the variety of ways used in presenting findings. Passmore and Durnin (7) presented results as gross calories per minute pointing out that calories per hour were liable to misinterpretation as few activities are performed continuously over this length of time. Durnin (2) gave arguments for expressing results as calories per minute of gross body weight. Others have reported results as gross calories, calories above standing, above sitting and above basal.

In reporting data, regardless of units used, authors could be helpful to others by reporting related data such as height, weight and age of subjects, basal rate and calorie expenditures for standing and sitting when obtained.

In this laboratory, in general, subjects have been selected on the basis of age, height and weight in order to reduce those variables in any one study. Selections on these bases limit the usefulness of data to the degree that the results may be applicable only for persons meeting these specifications. One study was designed to evaluate weight in relation to energy expenditure in stair climbing. In another, comparisons were made of expenditures on three bases, gross calories per minute, calories above basal and calories above standing to evaluate the use of basal and standing values as base lines. Another was directed toward studying recovery by making observations of energy expenditures following activities at 5-minute intervals.

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APPENDIX

Specifications for Equipment

Kofranyi-Michaelis respirometer (also called Müller-Franz Respiration Meter) complete consists of

Respirometer
1 pair carrying straps
2 corrugated tubes with joining pieces
1 plexiglass breathing valve
1 rubber mouth piece
1 nose clamp
1 inflatable rubber bag
Purchased from:
Zentral-Workstatt Gottingen
Busenstrasse 10, Germany
in June, 1960 at a cost of $135, import duty $18.22

Face Mask
#6418 Face mask, transparent plastic, clinical type A, complete
Purchased from:
Arthur H. Thomas Co.
Vine Street at Third
Philadelphia 5, Pa.
in November 1956 at a cost of $13.25

Accessories for face mask
#6418—B (cushion) $5.25 (in October, 1961)
#6418—C (head strap) $3.50 (in October, 1961)

Arnold O. Beckman Oxygen Analyzer
Model E2-1A1A, range 16-21%, 0-25% O_2
V+F; 115V, 60 cycles
Purchased from:
Beckman Instruments, Inc.
Fullerton, Califorinia
at a cost of $900, including installation and instructions, in May, 1955

Vacuum pump #91105 complete with motor on iron base with1/4 h.p. motor
Purchased from:
Central Scientific Co.
1700 W. Irving Park Road
Chicago 13, Illinois
at a cost of approximately $105 (in 1956)

Tanks

one 122 cu. ft. Nitrogen cylinder
one 122 cu. ft. compressed air cylinder

Purchased from:

National Cylinder Gas Co.
765 Woodrow Ave.
Columbus, Ohio
at a cost of $37.50 each in April, 1956
2 liter flow meters and adapters for above tanks at a cost of $40.00 each

Carrier for tanks

1 #24660 two-cylinder carrier

Purchased from:

National Cylinder Gas Co.
at a cost of $14.75 in April 1956

Syringes for holding samples

5031MS Syringes, Luer-Lok, B-D Multifit, 30cc
at a cost of approximately $4.00 each
Metal 3-way stopcocks for above, $3.50 each (in October, 1958)

Purchased from:

Wendt-Bristol Co.
1159 Dublin Rd.
Columbus, Ohio