INDIRECT CALORIMETRY AND ITS USE TO DETERMINE ENERGY EXPENDITURE BY WOMEN AT DIFFERENT AGES.

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		Page
Introduction		1
Part I.	<u>THE TECHNIQUE OF INDIRECT CALORIMETRY</u>	
1.	The Development of Calorimetry	
	Introduction: direct and indirect calorimetry	4
	The birth of calorimetry	6
	The classical period	8
	The calorific value of oxygen	10
	Protein correction	11
	The identification of direct and indirect calorimetry	11
2.	The Max-Planck Respirometer	
	Introduction	13
	Structure and functioning	15
	Maintenance	22
	Calibration of the respirometer:	
	i. Introduction	24
	ii. History	25
	iii. The method of calibration	27
	The use of the respirometer	31
	Effect of temperature	35
	Modifications to the respirometer	
	i. General	36
	ii. The electrically operated sampling pump	38
	iii. Performance of the modified respirometer	39

3. The Standard Dry-flow Air Meter 41

4. Resistance to Air Flow 45

5. Masks:

Requirements of a mask 57

Masks designed for aircrew 58

A "home-made" mask 60

The reflected edge seal mask 61

6. Gas Analysis:

General 64

Chemical methods 64

Physical methods 66

The Beckman Paramagnetic Oxygen Analyser 67

The Pulmo-Analyser 70

7. The Measurement of Total Daily Energy Expenditure 78

8. Dietary Survey 82

9. Selection of Subjects 85

Part II. THE ENERGY EXPENDITURE BY WOMEN OF DIFFERENT AGES.

1. A Review of the Literature on the Energy Requirements of Women 90

2. Introduction to Experimental studies 96

RESULTS AND DISCUSSION

3. Comparison of the Groups

Analysis of 'diary cards' 101

Estimate of energy expenditure

Bed 104

Sitting and standing 105

Housework and working 105

Walking 116

Personal necessitites 116

Shopping 116

Other activities 116

Measurement of food intake 127

Discussion 132

4. Statistical assessment of Technique

Introduction 137

Results 138

Discussion 143

5. The Decrement in Energy Expenditure with age

Introduction 147

Results 147

Discussion 148

6. The Decrement in Energy Intake

Results 159

Discussion 159

Summary 163

Acknowledgements 166

References 167

Appendices

A. Record sheet used with the Max-Planck Respirometer 178

B. Solutions used for absorbing oxygen in Haldane's apparatus 179

C. Letters used when contacting subjects 181

D. Reprints of relevant publications 184.

INTRODUCTION.

The work described in this thesis is a study of exercise and ageing in human beings. "Exercise" is used here in its broadest sense, in that overall physical activity for periods of one week is the topic of the experimental investigation, rather than specifically defined muscular operations of relatively short duration. This overall physical activity is studied from the point of view of the determination of the total expenditure of energy required for its performance.

The subjects who took part in the investigation were all women; ranging from early adulthood to early senescence. Women form an obviously important, and yet often physiologically neglected, part of the community. In our modern society much interest is focussed upon the elderly members of the population. They represent an economically important fraction of the total population, and every advance in preventive and curative medicine brings with it a possibility of a relative and absolute increase in the numbers of elderly people. The interest in the problems of ageing is reflected in the ever-growing bulk of literature on geriatrics and gerontology. The majority of this literature deals with the clinical and sociological aspects of the problems; there have been relatively few studies made of the changes which occur in the normal, as distinct from the pathological human body as it grows old. Another problem, although perhaps one of global rather than of national importance, is that of food supplies. Before the extent of this problem can be fully appreciated it is necessary to know the food requirements of the various groups of the total population. The first stage in formulating the food requirements of any particular group is an estimate of the <u>energy</u> requirement of that group. Thus work of the type described in this thesis is of real importance from the physiological, economic and social standpoints.

The work described in this thesis falls into two major sections. The first section is a description of the development and technique of indirect calorimetry as applied to studies of the expenditure of energy by human beings, especially in field studies. The second section of the thesis is devoted to a brief review of the literature on the energy requirements of women and to the presentation and discussion of the results of some experimental studies on the energy expenditure and food intake of women of different ages.

A considerable proportion of the first section of the thesis is devoted to original and unaided work of the writer (e.g. the calibration and maintenance of, and the modifications to, the Max-Planck respirometer; the measurement of resistance to air flow of various components of respiratory equipment). On the other hand some of the material in the first section is not claimed to be original work: such material is given when it has not appeared in full in the literature, or when it has not been collected together in one place (e.g. a complete description of the Max-Planck respirometer has never been published, only a brief account appeared in the original German paper).

The experimental work described in the second section of the thesis is, of course, entirely original, although it cannot be claimed as the outcome of unassisted effort. Experiments of this type require a relatively large number of scientific and technical staff to obtain results on what frequently appears to be a disconcertingly small number of subjects. Inevitably studies of this nature are the result of the co-operation of several members of a research team. Our results in fact refer to 34 x 7 = 238 "woman-days" studied in all, although only 32 x 7 = 224 "woman-days" information was obtained on energy expenditure as two of the subjects could only be studied from the point of view of food intake.

PART I

THE TECHNIQUE OF INDIRECT CALORIMETRY.

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1. THE DEVELOPMENT OF CALORIMETRY.

Introduction: direct and indirect calorimetry.

The metabolic rate of an organism, i.e. the rate at which it is using energy is measured in terms of heat output per unit time. In the case of human beings the conventional form of expression of metabolic rate is "kilogram-calories per hour" or more sensibly, "per minute". This is an expression of gross metabolic rate; for comparative purposes it is usual to quote metabolic rate per unit of body size, e.g. "kilogram-calories per square metre per hour" or "kilogram-calories per kilogram per minute". The kilogram-calorie (kilo-calorie, large calorie, Kcal. or Cal.,) is a physical unit for the measurement of amount of heat; it is equivalent to 1000 gram-calories (or calorie, cal.) The calorie is usually defined as "the amount of heat required to raise the temperature of 1 gram water from 14.5°C to 15.5°C.

There are two distinct general types of method of measuring the metabolic rate of an organism: direct or indirect. The former implies the measurement of heat output directly, i.e. in physical terms by physical means (although the technique may be so laborious and involved as to appear anything but direct.) The instruments required for direct calorimetry, particularly for an organism of the weight of a human being, are of necessity large, complicated and expensive, especially in terms of the capital outlay. Direct calorimeters range from the classical models, for example that of Atwater & Rosa (1897, 1899); (this was in fact a combined direct and indirect calorimeter) to the more recent "gradient layer" instruments, an example of which was described by Benzinger & Kitzinger (1949).

Indirect calorimetry measures heat production by the application of chemical analysis to the substances consumed and eliminated by the body, e.g. metabolic rate can be estimated from the respiratory exchange of the organism. The indirect calorimeter has appeared in a variety of forms, including the large gas meter of Geppert & Zuntz (1888), the instruments of Atwater & Rosa (1897, 1899) mentioned above, those described by Tigerstedt (1911) and the modern respiration chambers large enough to contain a cow, described by Wainman & Blaxter (1958). Indirect calorimeters may operate on either open or closed circuit principles. In the latter the air expired by the subject or animal passes through an absorber which removes carbon dioxide before being rebreathed. Oxygen may be added to maintain a constant volume of gas in the system, or the reduction of gas volume may simply be noted. A simple example of this type of apparatus is the Benedict-Roth spirometer (Roth 1922). In open circuit indirect calorimetry it is necessary to ascertain the composition of the inspired gases and the composition and volume of those expired.

In the experiments described in this thesis the expenditure of energy of the subject has been measured by indirect calorimetry, using an open circuit method. The results have been calculated using the equations derived by Weir (1949).

The birth of calorimetry.

The earliest attempts to measure the amount of heat produced by an animal were made by Crawford (1779) working in Glasgow with a water calorimeter, and by Lavoisier & de la Place (1780) in Paris, with an ice calorimeter. The two experiments were remarkably similar: in each case the animal studied was a guinea pig, estimates were made of the amount of carbon dioxide produced by the animal, the calorimeters were "calibrated" by burning wax or carbon in them and calculations were made of the amount of heat liberated in the combustion of sufficient organic material to produce the same amount of carbon dioxide as that eliminated by the guinea pigs. Both Crawford and Lavoisier & de la Place concluded that the processes of respiration and combustion were essentially similar, although the deductions of the latter authors appear more acceptable in that they explained their findings in terms of the oxidation of carbon, whereas Crawford attempted to explain respiration in the light of the "phlogiston" concept. Lavoisier & Seguin (1789) carried out an experimental study of respiration in which they attempted to measure carbon dioxide production and oxygen consumption in man. These authors studied the respiratory exchange during work and at rest, both with and without the influence of a previously ingested meal. Dulong (1823) and Despretz (1824) made further contributions to the study of calorimetry and respiration. Working independently these authors used water calorimeters to estimate the heat production of small mammals. Despretz concluded that about eighty per cent. of the heat production of the animal was due to the combustion of carbon and hydrogen in the body, while the comparable figure of Dulong was a little lower (Lusk (1928) pointed out that if Despretz had used a more accurate figure for the calorific value of hydrogen the heat production which he calculated as being due to combustion would have been closer to that observed as being due to the animal.) Despretz suggested that the difference between the observed and calculated values for heat production was due to secondary physical causes (e.g. internal friction of the body.) While this suggestion is unacceptable it is of considerable interest that it shows that Despretz was groping towards the concept of the conservation of energy. The first formal enunciation of the principle of conservation of energy was due to Mayer in 1842, and its applicability to animals was confirmed experimentally by Rubner (1894).

The classical period.

Leibig (1846) showed that the materials undergoing combustion in the body were protein, fat and carbohydrate, and not carbon and hydrogen as had previously been assumed. The work of Voit (1866) established the concept of nitrogen equilibrium, and demonstrated that the quantity of nitrogen eliminated from the body in the faeces and urine could be used as a measure of the extent of the metabolism of protein. In the same year Pettenkofer & Voit (1866) published details of a study of the metabolism of a fasting man. During the experimental period these authors measured the water consumption of the subject, the change in his body weight, and the amount of faeces, urine and carbon dioxide eliminated. The oxygen consumption of the man was calculated from his change of weight (after correcting this for the water consumed and the substances eliminated), and the protein metabolism estimated from the nitrogen excretion. The weight of carbon which was originally combined in the metabolised protein (the "protein carbon") was subtracted from the total carbon production of the subject. The remaining carbon production was then assumed to be due to the breakdown of body fat (the amount of carbohydrate, i.e. glycogen, available for metabolism was taken to be negligible under the experimental conditions). From their experiment Pettenkofer & Voit deduced that the carbon dioxide production (and hence the respiratory quotient) was dependent on the material undergoing metabolism.

Voit (1901) summarised the subsequent developments of this technique for the study of metabolism. The total amount of carbon eliminated from the body could be partitioned in the following way. After subtraction of the protein carbon from the total carbon, that which remained was due to the metabolism of carbohydrate and fat. Carbohydrate is fully metabolised regardless of how much is ingested, so that, if the amount of carbon consumed in the form of carbohydrate is known this can be subtracted from the carbon due to carbohydrate and fat to find the amount of carbon produced in the metabolism of fat.

Rubner (1895) published results of his determinations of the calorific values of protein, fat and carbohydrate and of the urinary constituents. The latter he subtracted from the value for protein in order to give the "physiological fuel value" of protein to the body. (i.e. Rubner realised that while the energy of fat and carbohydrate was fully available to the body, some of the energy of protein was not as it was lost in the nitrogenous compounds excreted in the urine). For mixed diets Rubner suggested that the physiological fuel value of both protein and carbohydrates was 4.1 kilocalories per gram, and that of fat was 9.3 kilocalories per gram. The scope and precision of studies of this type were extended by Atwater and his associates. The physiological fuel value of the proximate constituents of a mixed diet proposed by

Atwater & Bryant (1900) were 4.0 kilocalories per gram for protein and carbohydrate and 8.9 kilocalories per gram for fat. The figures given by Rubner on one hand and Atwater & Bryant on the other are not strictly comparable: Rubner did not include an allowance for faecal energy losses in his factors (although he did quote figures for such losses) whereas Atwater and Bryant included an allowance in their factors. One other point of difference between these two standards for the physiological fuel values of foodstuffs was pointed out by Tigerstedt (1909): Rubner dealt with a calorie defined at a temperature of $0^{o}C$ to $1^{o}C$, whereas Atwater's calorie was defined at $20^{o}C$ to $21^{o}C$. The work of Atwater and his colleagues in relation to the energy value of foodstuffs has recently been reviewed by Merrill and Watt (1955).

The calorific value of oxygen.

Zuntz (1897) and Zuntz & Schunburg (1901) made further contributions to the theory of indirect calorimetry. The workers reported on the respiratory quotients which resulted from the separate metabolism of protein, fat and carbohydrate, and on the number of calories which arose therefrom for each litre of oxygen consumed. They also published tables showing the calorie value of each litre of oxygen consumed at different respiratory quotients when mixtures of fat and carbohydrate are being metabolised. Other workers following this particular line of investigation have been Loewy (whose work was cited and revised by Lusk (1928), with particular reference to protein metabolism, and Cathcart & Cuthbertson (1931) with particular reference to fat metabolism.

Protein correction.

Magnus-Levy (1901) suggested that a fixed adjustment be made to Zuntz's values for the calorific value of oxygen consumed, on the basis that 15% of the total meat production of man was due to the metabolism of protein. This concept was extended, and the relevant calculations of metabolic rate simplified by Weir (1949). Weir showed that the influence of the respiratory quotient was so small as to be negligible in the final calculation of metabolic rate, and that if it was assumed that 12½% of the total heat production was due to the metabolism of protein the calorific value of each litre of expired air was one-twentieth of the difference between the percentage oxygen concentrations of the inspired and expired air (the "oxygen extraction"). These findings allowed a simplification in the technique of indirect calorimetry. All that is necessary is to measure the volume of air expired by the subject in a known time and to collect a sample of this expired air for analysis for oxygen concentration.

The identification of direct and indirect calorimetry.

The final criterion which must be satisfied before indirect calorimetry can be accepted as an experimental technique is that the metabolic rate indirectly determined is identical with that measured by direct calorimetry. (It is, of course, essential that the direct calorimeter is technically satisfactory if this criterion is to be valid). The comparison between the direct and indirect techniques has been made with favourable results, on numerous occasions: with human beings by Atwater and his associates (Atwater & Rosa 1897, 1899; Atwater & Benedict, 1899, 1902 a, 1902 b), with dogs by Lusk (1915) and Murlin & Lusk (1915) and again with human beings by Du Bois and his colleagues (Coleman & Du Bois, 1914; Soderstrom, Meyer & Du Bois 1916; Du Bois 1916 a, 1916 b; Meyer & Du Bois, 1916; Peabody, Meyer & Du Bois, 1916; and Allen & Du Bois, 1916).

2. THE MAX-PLANCK RESPIROMETER.

Introduction.

The simplest form of apparatus which can be used for indirect calorimetry is that required for the classical Douglas bag technique (1911). The apparatus consists of a mouthpiece and noseclip, inspiratory and expiratory valves, connecting tubing and the bag itself. This apparatus can be carried on the subject's back, allowing determinations of metabolic rate to be carried out during exercise. The air expired by the subject in measured time is collected in the bag. At the end of the period of collection, a sample of the contents of the bag is withdrawn for analysis and the volume of expired air in the bag is measured by expelling it through a gas meter (usually of the "wet-flow" type.) The disadvantages of this technique lie in the bulk of a filled Douglas bag (which reduces its portability by the subject) and the relatively small capacity of the bag, which limits the time over which expired air can be collected.

The most obvious way of overcoming these disadvantages is to replace the bag by the gas meter (that is, to measure the volume of air expired continuously) and to introduce some device which can extract a proportionate sample of the expired air passing through the gas meter. The wet flow meter is quite unsuitable if the apparatus has to be carried by the subject during exercise, so it is necessary to use a "dry-flow" or bellows type of gas meter. First attempts to do this were made by Geppert & Zuntz (1888) and later by Simonson (1929) but these met with little success. The first successful instrument was that of Kofranyi & Michaelis (1940) of the Max-Planck Institut fur Arbeitsphysiologie in Dortmund. Indeed, the respirometer is frequently referred to as the Kofranyi-Michaelis respirometer, or, more briefly, as the "K.M." In its early form the instrument consisted of a small, light-weight gas-meter, with a piston-pump sampling mechanism which was driven from the bellows of the gas meter. Thus, the device measured the total volume of expired air passing through it, and withdrew a small aliquot sample of this air. This sample was collected in a rubber (football) bladder for subsequent analysis. The respirometer was fitted with shoulder straps so that it could be easily carried on the experimental subject's back, in the manner of a ruc-sac. Later models of the meter were fitted with a modified sample pump. This modified version consisted of two separate membrane pumps.

Müller & Franz (1952), also of the Max-Planck Institut, described further modifications to the respirometer, and it is in this form that it is in current production.[1] The instrument, in its present form,

[1] The Max-Planck Respirometer is manufactured commercially by Zentralwerkstatt, Göttingen, Germany.

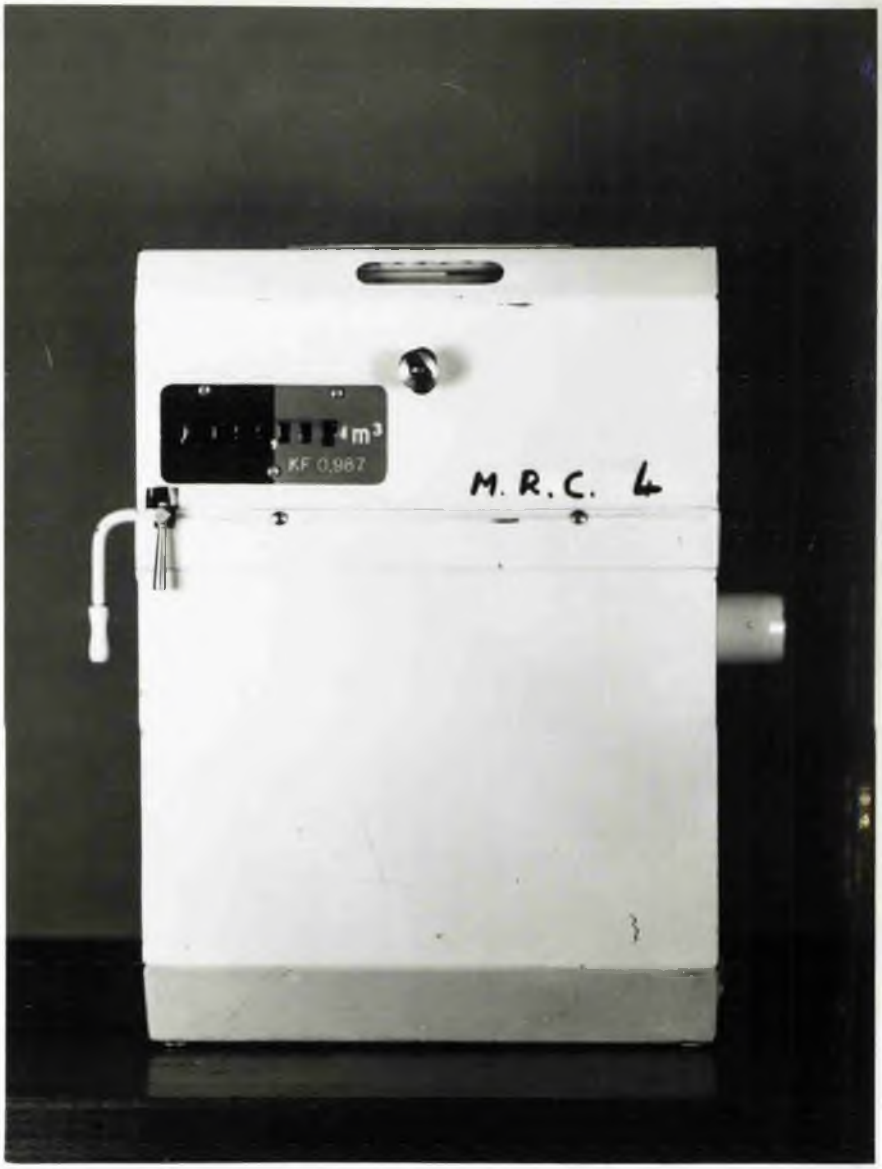


Fig. 1. The Max Planck Respirometer.

is sometimes referred to as the "Müller-Franz respirometer", particularly in literature published in the United States. It has also been described as a calorimeter, but this it most certainly is not. The shape of the present version differs somewhat from that of the original, and its weight is reduced a little from the earlier figure of 4.3 kg ($9\frac{1}{2}$ lb). The two separate membrane pumps are now combined into one double-acting unit. The respirometer, which is shown in Fig. 1, has an overall size of approximately $10\frac{1}{2}$ in. x 8 in. x $4\frac{1}{2}$ in., and weighs about 7 lb. The mechanism of the gas metering device is contained in the lower half of the respirometer casing. The upper part of the respirometer casing, which can be easily removed, houses the sampling mechanism and the counter which records the volume of expired air which has passed through the meter. A "mercury-in-glass" thermometer is mounted in the upper part of the respirometer casing. This thermometer records the temperature of the air being exhausted from the meter.

Structure and functioning.

A gas or air meter of this type measures the volume of gas passing through it by the alternate filling and emptying of compartments which are separated by flexible bellows; the movements of these bellows drive the recording counter and actuate the valves directing the flow of gas into and out of the compartments. Diagrams showing the operation of this mechanism are given in Fig. 2, 1-6. In

Fig. 2. MAX PLANCK RESPIROMETER. BELLOWS AND VALVES.

1. Side view, bellows compartments.

2. Front view, bellows compartments.

3. Top view, cover removed, showing valve boxes

4. Top view, cover removed, showing valve plate in position.

5. Section of valve, position 1.

6. Section of valve, position 2.

In 3 and 4 the stippled areas show the openings to the transfer ports and bellows compartments. The arrows in 1-4 show the direction of mechanical movement; in 5 and 6 they show the direction of air movement.

Legend

A_1A_2, B_1B_2: Bellows compartments.

C. transfer port.

D. valve box

E. valve plate crank lever

F. vertical shaft

G. bellows crank lever.

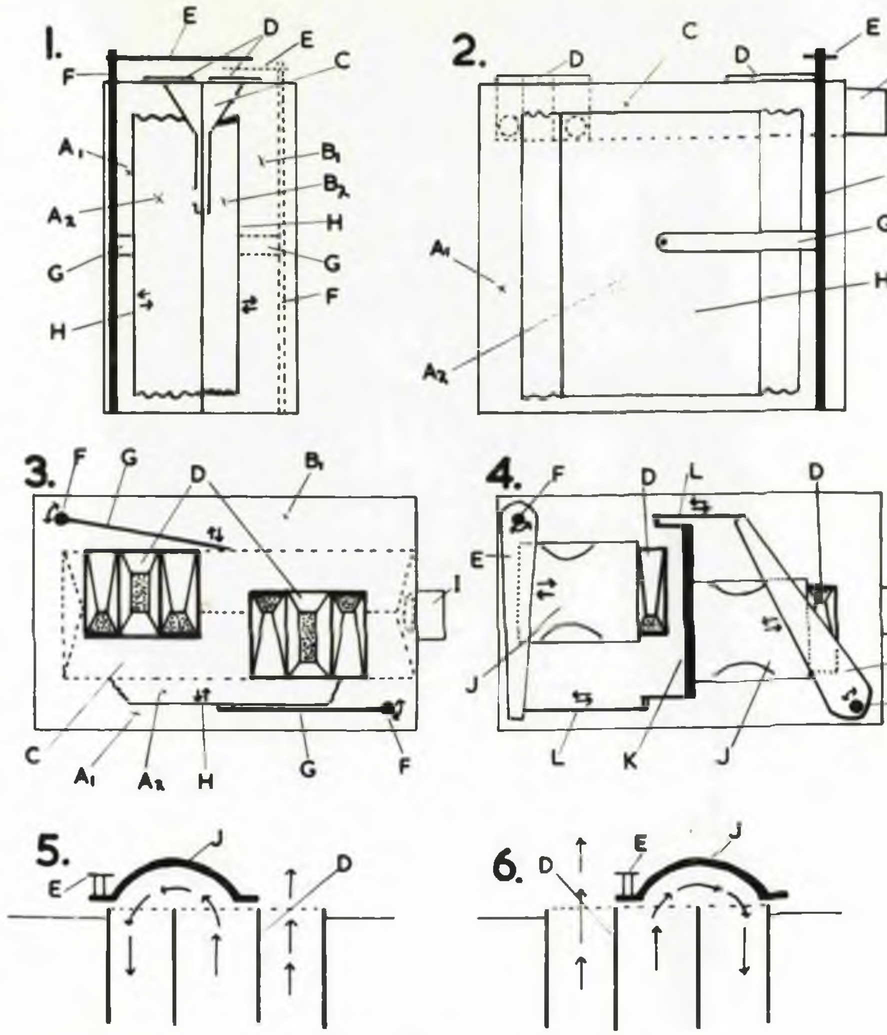
H. bellows plate

I. inlet tube

J. valve plate

K. main crank shaft

L. connecting rods



MAX-PLANCK RESPIROMETER: METER BELLOWS & VALVES.

Fig. 2.

practice, the meter consists of two primary compartments, of rigid shape and fixed volume; each of these primary compartments is subdivided, by leather bellows, into two secondary compartments. (Fig. 2, 1. A_1A_2 and B_1B_2). The air stream to be measured is directed simultaneously into, say, compartments A_2 and B_1. The bellows consist of a leather membrane (specially treated to be unaffected by moisture) with a metal plate, H (Fig. 2, 1, 2 and 3) fixed in its centre. This plate is connected, through a crank lever, G, to a vertical shaft F. This shaft passes an air-tight gland to top of the meter. As compartments A_2 and B_1 fill with air, the bellows plates, H, are moved, along with their crank levers. These movements impart a rotary motion to the vertical shafts. Above the meter casing two further cranks, the valve plate crank levers (E, Fig. 2, 1, 2 and 4) are attached to the upper ends of the vertical shafts; these cranks follow the movements of the bellows crank levers, but are set at approximately right angles to the latter. (Fig. 2, 2 and 4). The valve-plate crank levers, E, are linked to the main crank shaft, K, (Fig. 2, 4) by the connecting rods, L. The main crank shaft drives the counter (see below). The valve-plate crank levers also operate the valve plates, J, (Fig. 2,4), which direct the air-flow through the meter. When compartments A_2 and B_1 are full the valve plates re-direct the air-flow into compartments A_1 and B_2. As the latter compartments fill, the air in

A_2 and B_1 is pushed out through the valves and exhausted to the atmosphere. The action of the valves is shown in Fig. 1, 5 and 6. There are two valves, one to each of the primary compartments. Each valve consists of two parts: the plate, J, and the box, D, these parts are moulded from low friction plastic. The valve box is divided into three sections. The centre section is connected to the transfer port, C, (Fig. 2, 1, 2, 3 and 4). The transfer port is an extension of the inlet tube, I, to the meter. The two outer sections of the valve box are connected one to each of the secondary compartments of the meter. The valve plate has a concavity in its under surface. This concavity is always connected to the centre section of the valve box, and so, through the transfer port to the inlet tube of the meter. The concavity is also alternately connected to one or other of the outer sections of the valve box. The section of the valve box which is not, at any time, under the plate is open to the atmosphere. Thus, air entering the meter via the inlet tube and transfer port is directed into one secondary compartment on each side of the meter, while the other two secondary compartments empty the air in them to the atmosphere. Once compartments A_1 and B_2 are full the valve plates are repositioned so that A_2 and B_1 start filling, repeating the cycle as described. During each complete cycle 2 litres of air pass through the meter. The sequence of events is kept in phase by the interconnected cranks, levers and shafts.

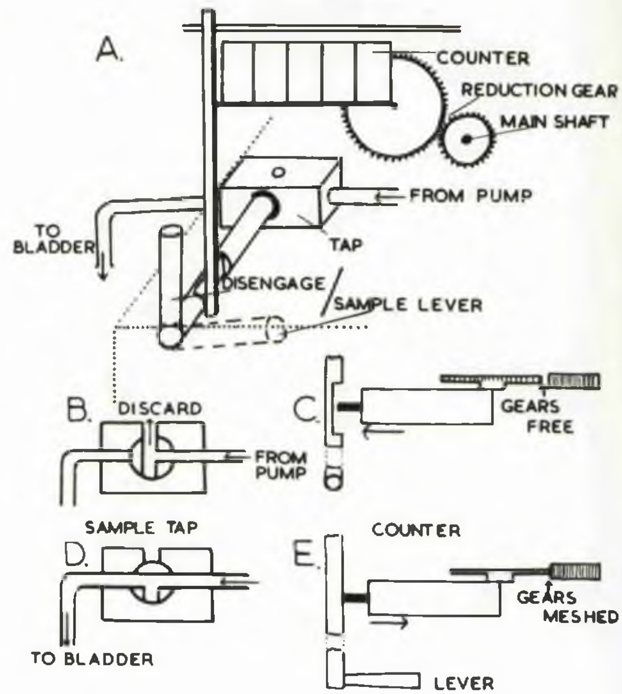
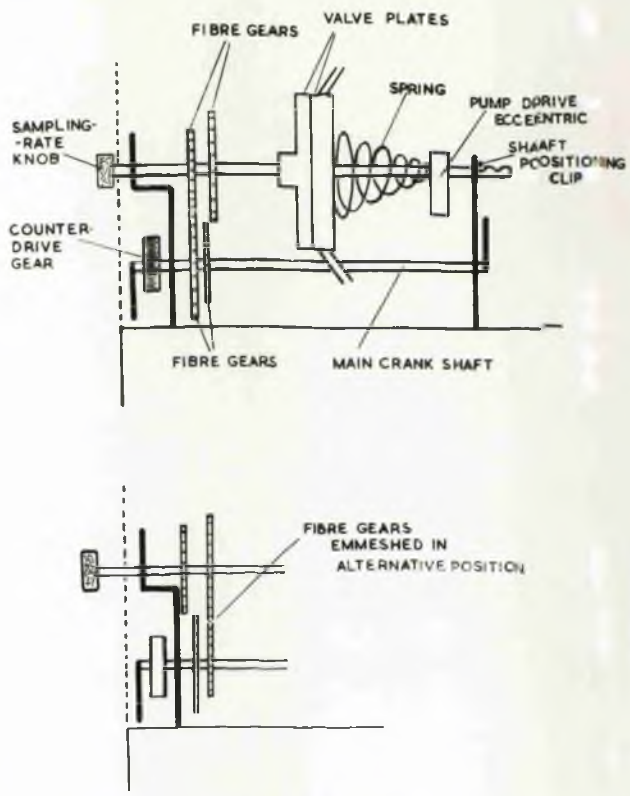


Fig. 3. Max Planck respirometer, counter and sample tap.

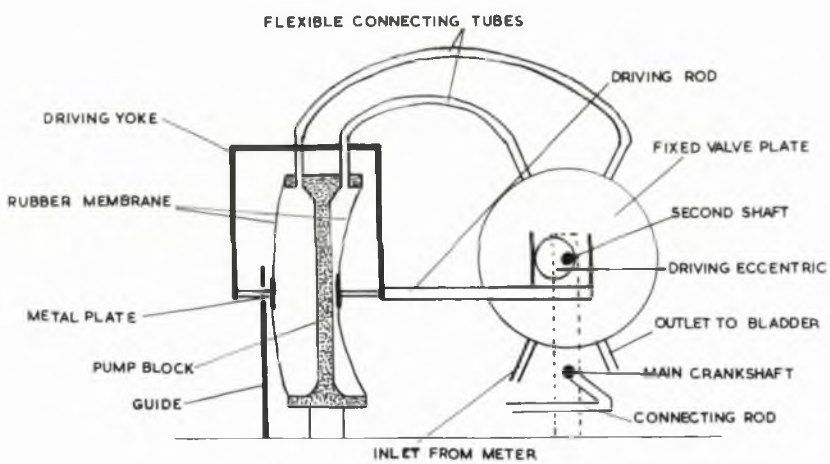


MAX-PLANCK RESPIROMETER:
SAMPLING RATE GEARS.

Fig. 4.

The counter is of the "Veeder" or cyclometer type, not the rotating pointer on a fixed scale normally fitted to gas meters. (c.f. the dry flow air meter). The counter can be read to 0.2 litre, and has a capacity of 9,999 litres. It cannot be re-set to zero each time it is used. The counter is driven through a reduction gearing from the main crank shaft, (Figs. 3, A, C and E and 4); the drive can be engaged or disengaged by the action of a small handle projecting from the front of the respirometer casing (Fig. 3, A). This handle also controls the tap on the outlet side of the sampling pump (see below).

In addition to the drive to the counter, the main crank shaft of the meter carries two fibre gear wheels. These mesh with two further fibre gears on a second shaft mounted vertically above the main crank shaft. (Fig. 4). This second shaft can be positioned so that one or other gear wheel from each of the pairs can engage, providing two alternative speeds of rotation of the second shaft for any one speed of rotation of the main crank shaft. This second shaft is fitted with an eccentric cam, which operates the membranes of the sampling pump (Figs. 4 and 5). This shaft also carries the two valve plates of the sampling pump. One of these plates is attached to the shaft and rotates with it, while the other, which is merely

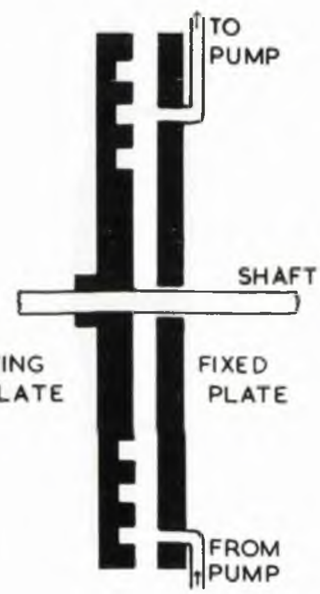


MAX-PLANCK RESPIROMETER: ACTION OF SAMPLING PUMP.

Fig. 5.

supported by the shaft, remains stationary (Figs. 5 and 6). The two plates are held closely together by a spring. The change of position of the second shaft, and hence the speed of its rotation and the rate of sampling, is controlled by a knob projecting from the front of the respirometer (the sampling rate knob, Fig. 4). This knob is pulled out to engage the gears for the low rate of sampling, and pushed in for the high rate. The two rates of sampling are 0.3% and 0.6% (nominally - though in fact rarely as much) of the volume of air passing through the meter.

The pump itself consists of a circular aluminium block of biconcave section (Fig. 5 and 7). Each concavity is enclosed by a thin rubber membrane. A small metal disc is attached to the centre of each membrane, and these discs are linked together by a yoke. The yoke is moved "to-and-fro" by a rod, which is in its turn driven by the eccentric cam mounted on the second shaft, as described above (Fig. 5). The yoke connects the membranes of the pump so that as one membrane is pushed into the concavity on its side of the block, the other membrane is pulled out from its concavity, and vice versa. The reciprocating movements imparted to the yoke by the eccentric cam thus create alternating positive and negative pressures in the chambers of the pump blocks. These pressure changes are out-of-phase on each side of the pump, i.e. when the pressure is positive in one chamber it is negative in the other. Each chamber



MAX-PLANCK RESPIROMETER
SECTION OF VALVE PLATES.

Fig. 6.

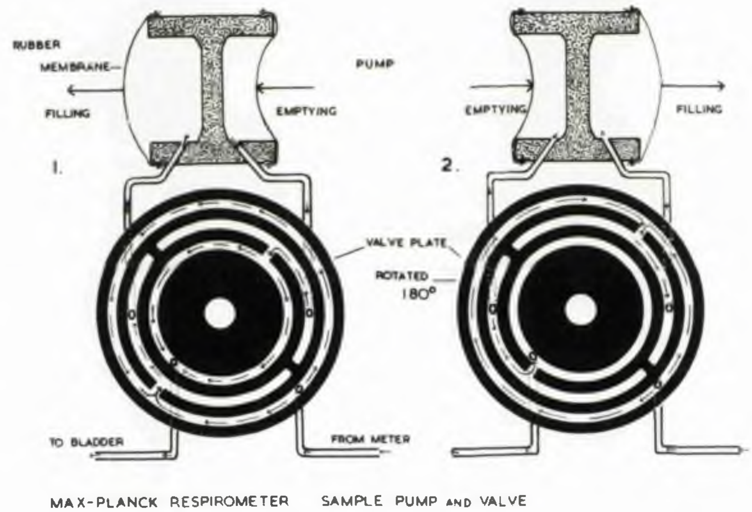


Fig. 7.

The arrows on the valve plate show direction of air flow; those on the pump, the direction of mechanical movement.

is connected, by a flexible (polythene or rubber) tube, to the stationary valve plate (Figs. 5 and 7). This stationary valve plate also has connections to the inlet tube of the meter and, through the sampling tap, to the storage bladder (Fig. 5 and 7). The connections are brought to the inner face of the stationary plate (Fig. 6) where they are arranged in the following way:

1. from the meter: outer radius

2.3. to and from pump: middle radius.

4. to bladder: inner radius.

(The endings of these connections are shown by the dotted lines in Fig. 7). The radii to which these connections are made correspond to three annular grooves milled in the inner face of the rotating valve plate (Fig. 6 and 7). (The diagram in Fig. 7 is drawn at the level of the inner faces of the two valve plates and shows features of each plate.) Air in the outer groove is able to pass into half of the middle groove; similarly air in the other half of the middle groove can pass into the inner groove. The two sections of the middle groove are pneumatically separated. This plate, rotating with the shaft, alternately connects the inlet from the meter (outer groove) to one or other of the tubes (middle groove) leading to the pump block. When the inlet from the meter is connected to one side of the pump, the other side is connected to the bladder. The passage of air through the pump and valve to the bladder may be summarised as follows:

1. Inlet of meter to stationary valve plate.
2. Stationary plate to outer groove of rotating plate.
3. Outer groove to one half of centre groove of rotating plate.
4. Centre groove of rotating plate to fixed plate.
5. Fixed plate to pump chamber.

Stages 1-5 occur under the influence of negative pressure in the chamber of the pump.

6. Pump chamber to fixed plate.
7. Fixed plate to second half of centre groove of rotating plate.
8. Centre groove to inner groove of rotating plate.
9. Inner groove of rotating plate to fixed plate.
10. Fixed plate to sampling tap and storage bladder.

Stages 6-10 occur under the influence of positive pressure in the chamber of the pump, In practice stages 1-5 are occurring simultaneously, on one side of the pump, with stages 6-10 on the other side.

A three-way sample tap is fitted to the respirometer (Figs. 3 & 9). This tap directs the expired air sample from the pump either to the bladder (Fig. 3D) or to the atmosphere (Fig. 3B). The third connection is from the bladder to the atmosphere. As mentioned above, the handle of this tap also engages the reduction gear drive to the recording counter. When sample of expired air is directed from the pump to the atmosphere ("discard") the mechanism of the counter is disengaged from the main crank shaft of the respirometer. When the sample from the pump is directed to the bladder the counter drive is engaged. The counter drive is also engaged in the third position of the tap.

Maintenance.

All metal-to-metal bearing surfaces should be regularly lubricated with light mineral oil. The plastic valve plates and boxes need no lubrication. Particular attention should be paid to the inner faces of the two valve plates of the sampling pump. These plates should be cleaned and lightly oiled. It is essential that the plates seat evenly, or leaks will occur, resulting either in a reduced volume of sample or, more seriously, in contamination of the sample with atmospheric air. The tension of the spring (Fig. 4) which holds the plates together should be such that the plates bear evenly on one another and yet without great pressure. If the pressure is unnecessarily high, large frictional forces must be overcome to drive the pump. The rubber membranes of the pump should be inspected from time to time, and replaced if they show any signs of perishing. In order to replace the membranes of the pump it is necessary to dismantle the pump driving mechanism, and to remove the pump block from the respirometer. Latex rubber dental dam of medium grade thickness is a

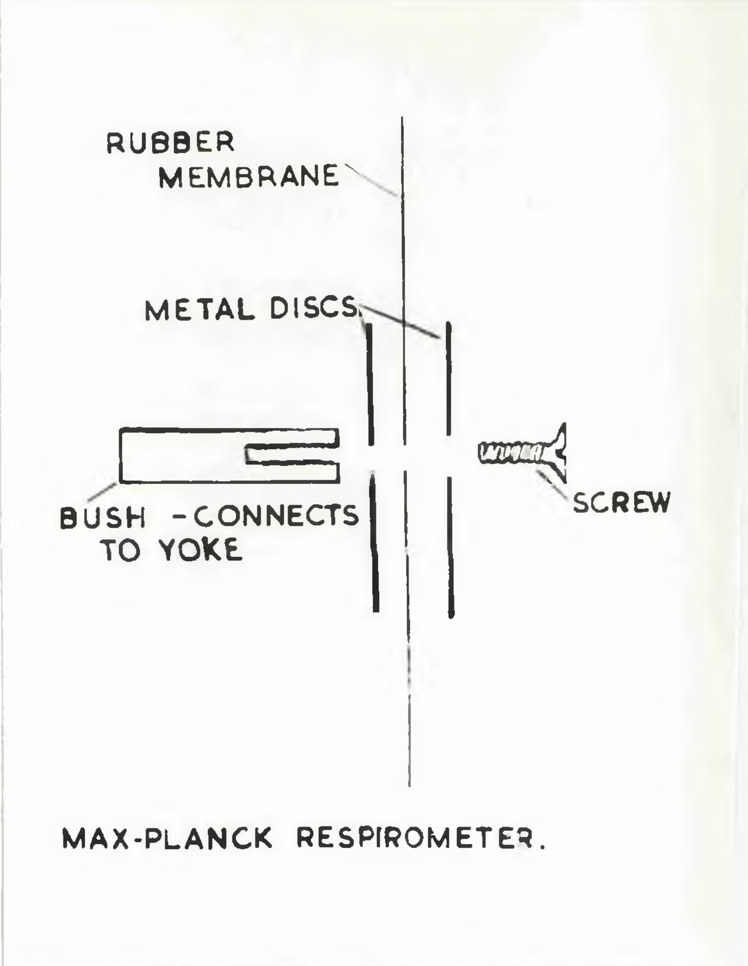


Fig. 8. Replacing the rubber membranes of the sampling pump.

suitable material to use when replacing the membranes. It should be cut, roughly circular, about one inch diameter larger than the old membrane. A small hole is cut in the centre of the sheet of latex and the metal discs fixed with rubber solution and then screwed together (Fig. 8). The membrane is secured to the pump block by either an elastic band or a piece of thread or fine cord. A shallow groove is milled around the outside of the pump block at each side (Fig. 7); this groove accomodates the elastic or thread securing the membranes. When fixing the membranes to the pump block care should be taken that the metal disc is positioned accurately in the centre line of the block. Once the membranes have been secured to the block the excess rubber can be trimmed off. Careful servicing of the pump is essential as a large part of the respirometer's resistance to air flow is due to the operation of the pump (see below: 'Resistance'). The resistance due to the pump varies from meter to meter, from about one quarter to one half of the total resistance. The flexible tubes connecting the pump block to the valve plates should also be inspected and replaced when necessary.

The sample-tap/counter unit requires little attention apart from an occasional drop of oil on the key of the tap. However, in some meters the tap block has become unsoldered from the upper part of the meter casing. Trouble has also been experienced with the soldered joint between the valve-plate crank levers (E) and the vertical shaft (F, Fig. 2). If the meter has to stand up to rough treatment,

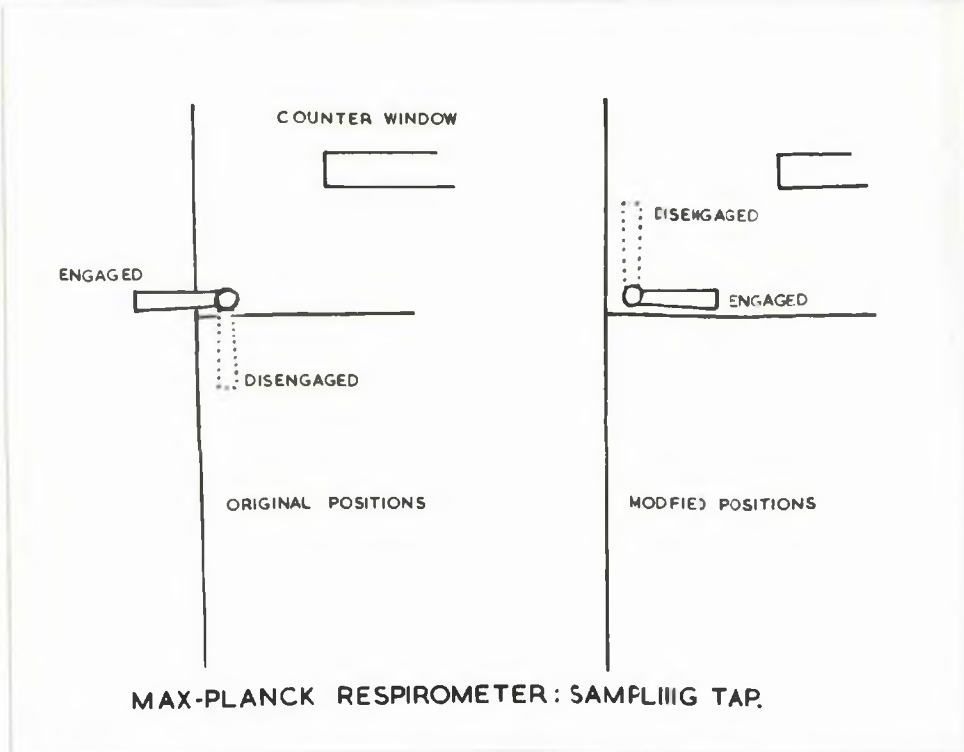

COUNTER WINDOW
ENGAGED
DISENGAGED
ORIGINAL POSITIONS
DISENGAGED
ENGAGED
MODIFIED POSITIONS
MAX-PLANCK RESPIROMETER: SAMPLING TAP.

Fig. 9.

it is worthwhile to change the position of the handle of sample tap, as described by Garry et al. (1955) and to replace the handle with a knob (Insull 1954). (On the respirometers as supplied by the makers this handle projects sideways geyond the meter casing. Garry et al. recommend that the handle be reversed on its shaft so that it is protected by the meter casing (Fig. 9)).

The bellows are sealed in the lower part of the respirometer casing, and it is inadvisable to disturb them unless some gross upset has occurred which can be definitely attributed to their malfunction. After prolonged use (a year or more) the bottom part of the meter casing may become corroded and perforated. This is particularly the case with some of the older respirometers whose cases were made of tinplate; the newer models have brass cases. If the meter casing does become perforated a serious error in measurement is likely to be introduced. Small holes may be soldered individually, but if the area of corrosion is large it is better to solder a thin sheet of brass over the entire area. After each period of use it is advisable to drain off any moisture which may have condensed inside the bellows compartments.

Calibration of the respirometer: i introduction.

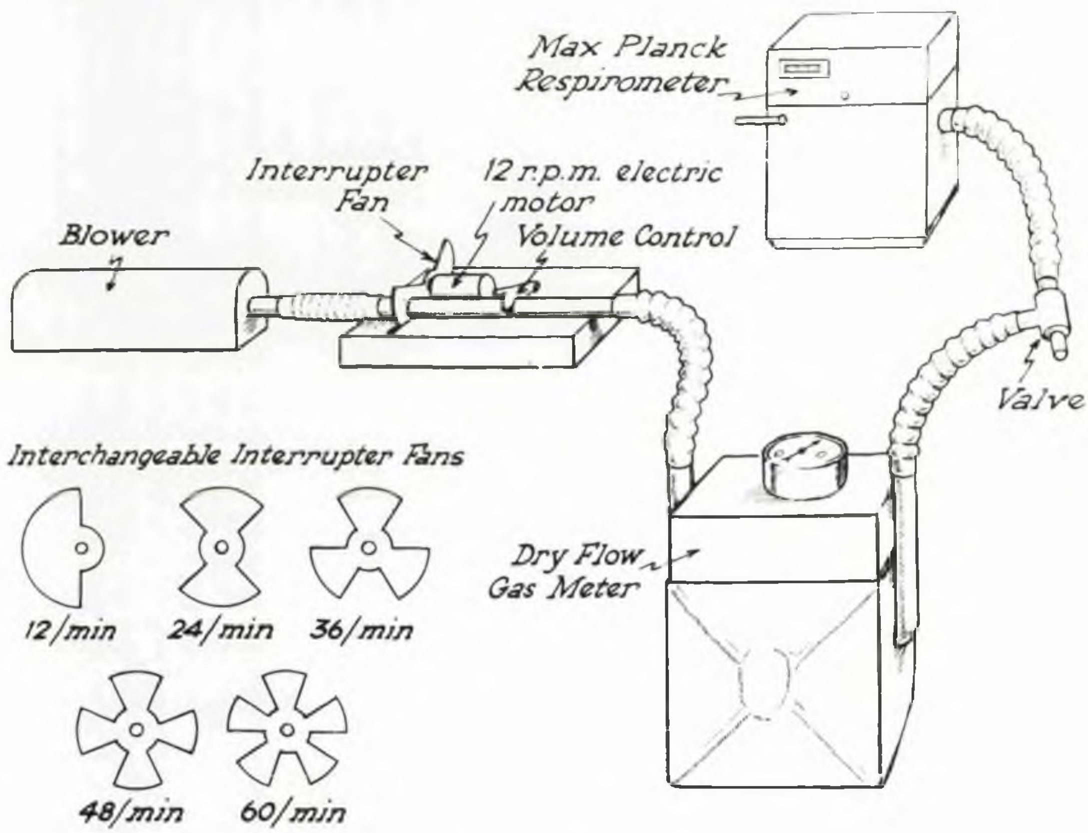
The Max Planck respirometers are calibrated by the manufacturers before they are despatched from the factory. The correction factor ('K.F.') obtained from this calibration is engraved on or near the window of the recording counter. Unfortunately the system of calibration employed by the manufacturers is open to question (see below), and we have never found their factor to be accurate. Users of the respirometer are advised to ignore this factor and re-calibrate the instrument for themselves. It is essential that the respirometers be calibrated with air-flows of the same pattern as those which they will be required to measure when in use. This means that the calibrating air-flows should be pulsatile at physiological respiration frequencies (12-60 per minute), and should also cover the range of flow rates encountered in normal human pulmonary ventilation (5-100 l./min, interrupted flow.)

ii History.

In their original description of the Max Planck respirometer Kofranyi & Michaelis (1940) give a table of correction factors for the respirometer at flow rates ranging from 5.5 l./min to 96.5 l./min. No description of the method of obtaining these correction factors is given beyond stating that an exact dry gas meter was used for comparison. In the first scientific paper dealing with the respirometer and written in English, Orsini & Passmore (1951) calibrated the Max Planck respirometer with air flows from a Douglas bag or Benedict spirometer filled with a known volume of air. Steady non-pulsatile flows, at various rates, were used. As a further means of calibration these authors also compared the pulmonary ventilation of subjects performing standardised activities as measured by the respirometer and by the standard Douglas bag technique. Müller & Franz (1952) dealt briefly with the calibration of the respirometer. They state that the respirometers are calibrated against an accurate gas meter, and that for any one respirometer the correction factor is constant at steady flows from 10 l./min to 60 l./min. This is contrary to our experience. It is understood that the manufacturers calibrate the respirometer against a wet-flow meter, using only steady flows of fairly low rate. Insull (1954) calibrated the respirometer by measuring the pulmonary ventilation of subjects performing standard activities, and comparing it with that recorded by the Douglas bag technique.

Durnin (1955) described a method of calibration of the Max Planck respirometer using a wet-flow gas meter and Douglas bag. The bag is filled with an accurately known volume of air, measured by the flow meter. The bag is then disconnected from the flow meter and connected to the respirometer. The contents of the bag are next pushed out, through the respirometer, in a pulsatile manner, to produce an air-flow pattern similar to that occurring in normal respiration. This procedure is repeated at all "ventilation" and "respiration" rates likely to be encountered. This method, while fulfilling all the desirable criteria outlined above, is difficult and tedious to perform.

In 1958 four independent descriptions of different methods of calibration appeared in the literature. Wolff (1958) described the system used to calibrate the integrating pneumotachograph. Montoye,



Apparatus for Calibration of Respirometer

Fig. 10.

Huss, Reinke & Cockerell (1958), in what appeared to be a rather unsatisfactory paper, described a method similar to that of Durnin (1955) except that only steady air-flows were used. Brown & Croton (1958) used a mechanically driven interrupter fan to produce a pulsatile flow in the air stream from a centrifugal blower. This pulsatile flow of air was directed through the respirometer, collected in a Douglas bag and subsequently measured by a standard gas meter. Correction factors at various flow rates were derived from the differences between the respirometer and standard meter readings. Riendeau & Consolazio (1958, 1959) use a Tissot spirometer as a standard. Air is pumped from the spirometer through the respirometer by means of a manually operated double acting pump. This procedure is carried out at various flow and "respiration" rates and correction factors calibrated.

iii. The method of calibration.

The method of calibration of the Max Planck respirometers used in this laboratory is based on that of Durnin (1955) and on that of Wolff (1958). The apparatus is shown diagrammatically in Fig. 10. It consists of (1) a blower capable of delivering a steady flow of up to about 500 l./min: (a cylinder vacuum cleaner used "in reverse" is ideal; one was kindly donated by Messrs. Hoover Ltd.); (2) a motor-driver interrupter fan. This consists of a low-geared constant speed (12 rev./min.) electric motor and a set of five interchangeable interrupter fans. These fans allow the air-flow in the system to be interrupted

12, 24, 36, 48 or 60 times per minute. Alternatively, a variable speed motor and a single fan could be used. The fans have alternate segments cut out (see inset, Fig. 10). Used in conjunction with 1 inch bore tubing, these fans produce an air-flow pattern roughly similar to that of normal human respiration. By changing the shape of the cut-outs on the fans and the section of the tube it is possible to produce practically any shape of air-flow pattern desired. A volume-control shutter is mounted on the same unit as the interrupter fan. This operates, guillotine-wise, in a slot across the air-supply tubing, and it is used to regulate the volume of air passing through the system. (3) a large "standard" gas meter: this is a refined version of the commercially produced bellows gas meter (see below). It has been found to be consistently accurate in its measurements at the required low rates, and because of its large size, and the type of mechanism used in bellows' meters, it is as accurate in its measurements of pulsatile flow as of steady flow (see below). This "standard" meter is periodically re-calibrated, and if necessary re-set, by the makers.

The calibration apparatus is connected in series with the respirometer under test, through a valve and length of tubing as in actual use. Using the volume control shutter in conjunction with the appropriate fan (see Table 1) the rate of air-flow through the system is adjusted to approximately 5 l./min, as measured by the respirometer under test.

Table 1.

Rate of Flow Litres/min.	Interruptions per minute.
→ 20	12
20 - 50	24
50 - 70	36
70 - 100	48
100 →	60

With the blower running, the interrupter fan is stopped so as to completely cut off the air-flow to the meters. Readings are taken on the standard meter and respirometer. The interrupter fan is re-started and a volume of 20-30 litres of air is allowed to pass through the system. The interrupter fan is then stopped (again so as to completely cut off the air-flow) and the meter and respirometer re-read. The correction factor is calculated as shown:

Vol. of air passed through standard meter: 20 l.

Vol. of air recorded by respirometer: 18.5 l.

Correction factor (at 5 l./min) $= \frac{20}{18.5} = 1.08$

The process is then repeated, and the mean factor obtained from the calibrations taken as the correction factor of the respirometer at the flow rate used.

The flow rate of air in the system is then re-adjusted to approximately 10 l./min, and the calibration and calculation of the correction factor repeated. The respirometer is calibrated at flow rates of 5, 10, 20, 30... l./min up to the highest rate likely to be met with, this will probably not exceed 50 l./min for normal activities. Should any large changes occur in the correction factors when calibrating at 10 l./min intervals, factors should be determined for intermediate rates of flow. A calibration chart is thus prepared for each respirometer in use. (Table 2).

Table 2.

Respirometer No.......

Rate of Flow Litres/min	Correction Factor
5	1.08
10	1.07
20	1.05
30	1.06
40	1.06
50	1.07
60	1.08

To find the corrected pulmonary ventilation the volume recorded by the respirometer is multiplied by the correction factor appropriate to the recorded flow rate. For example, if the respirometer had recorded a volume of 200 litres during 10 minutes, and, if the correction factor at a flow of 20 l./min was 1.05, the true pulmonary ventilation during that period would be:

$$\frac{200}{10} \times 1.05 = 21.\ \mathrm{l./min}$$

This figure would then normally be adjusted to N.T.P. or to B.T.P.S.

The calibration of the respirometer should be checked prior to use each day. The correction factor has been found frequently to change by 0.01 from day to day (1% change of accuracy of the total volume recorded), even when apparently working quite satisfactorily. Due to various causes, (frictional or corrosive) much larger changes may occur unnoticed if such frequent calibration is not carried out.

The use of the respirometer.

The Max-Planck respirometer is normally carried on the experimental subject's back, except when recording during such activities as sitting or lying. (In these cases the respirometer is conveniently placed on a chair beside the subject.) The length of the shoulder straps of the respirometer should be adjusted so that it is carried high on the subject's back, fitting closely yet without restricting his movements. For recording during violentactivity, it is advisable to secure the lower corners of the respirometer with a strap around the subject's body; this prevents the respirometer from swinging about. A rubber football bladder (size No.5 is suitable) is tightly rolled up to expel its contents and attached to the outlet pipe of the sampling tap. The tap lever should be in the disengaged position, i.e. the driving gears of the recording counter are not meshed and the tap directs the sample expired air from the pump to the atmosphere. The reading of the counter is noted on specially prepared record sheet of the type shown in Appendix A. The sample rate selection knob is positioned suitably for the activity to be recorded. That is, if the exercise is strenuous, e.g. running, the 0.3% rate of sampling is selected, while for more moderate forms of activity, e.g. sitting, the rate of sampling should be 0.6% of the total volume of expired air passing through the meter.

A 24 in. length of 1 in. bore flexible hose is attached to the inlet tube of the meter. The manufacturers supply black corrugated rubber tubing with the respirometer. The sole virtue of this tubing is its light weight. It has been found to "kink" very readily and is easily collapsed by quite moderate external pressure, such as it might encounter if jammed between the subject's arm and body. In this laboratory 1 in. bore "low pressure oxygen breathing tubes*" are used. These tubes are made of rubber moulded over a helictical wire spring. The inside of the tube is of fairly smooth bore (to reduce the resistance to air-flow) and the outer surface is covered with green rot-proof fabric. These tubes are completely free from "kinking" and they cannot be collapsed

*Manufactured by Dunlop Rubber Co. Ltd., Hose Division, Manchester.

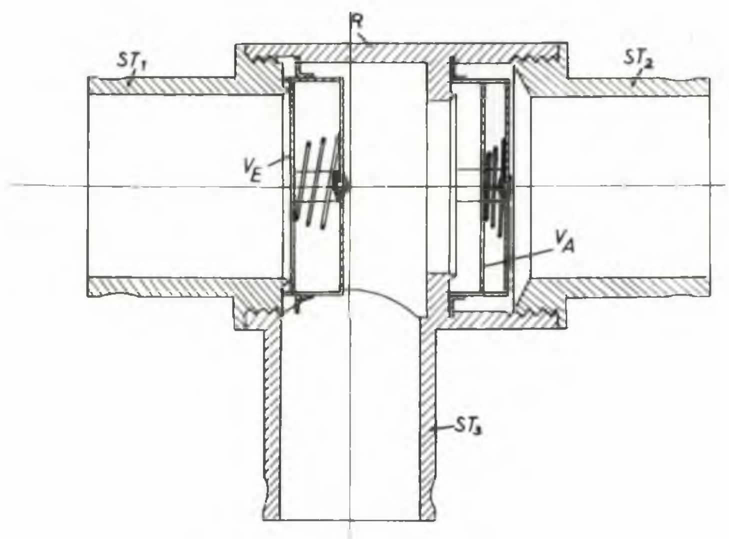


Fig. 11. Section of two-way respiratory valve used with Max Planck respirometer.

Fig. 12. Tubing, valve, mouthpiece, bladder and harness used with Max Planck respirometer.

by any external pressure they are ever likely to encounter in this type of use. These tubes suffer from the disadvantage of being rather heavy. The other end of the hose is connected to the expiratory side of an inspiratory/expiratory valve. This valve (Fig.11) is made of "Perspex" with mica discs and phosphor bronze or stainless steel springs and guides. It is T-shaped; the inspiratory and expiratory valve discs and their springs and guides are housed in the cross piece of the 'T' while the "down-stroke" makes common connection to the subject. The valves themselves consist of a circular mica disc held on to an annular perspex knife-edge by a spring. These valves are supplied by the manufacturers of the respirometer. A rubber mouthpiece is attached to the valve. The mouthpiece, which has a short ($\frac{1}{2}$ in.) tube on one side to connect it to the valve, consists of an oval flange with two lugs which are gripped between the subject's teeth, while the flange lies between the lips and gums. It is advisable to have available several sizes of mouthpieces to fit the different sized mouths of various subjects. The subjects' nostrils are closed with a nose clip, to ensure that all his expired air is directed through the respirometer. Fig. 12 shows the ancillary equipment used with the respirometer. Once this equipment is fitted to the subject the determination of energy expenditure has begun. In an initial period of five minutes the subject becomes accustomed to carrying and breathing through the respirometer. This initial period also serves to allow the subject to attain the physiological "steady-state". In none of the experiments described in this thesis were we measuring the energy expenditure of activities in which the steady state was not attained. In the initial period the pulmonary ventilation is not recorded (the counter being disengaged) and no sample of expired air is collected in the bladder; although the pump is operating the sample is discarded to the atmosphere after flushing out the pump and its connections. At the end of the initial period the sampling tap lever is moved to the "engaged" position, i.e. the counter drive is engaged and the sample of expired air directed from the pump into the rubber bladder. This recording period usually lasts ten minutes. Should the rubber bladder become filled before the conclusion of this period the sampling tap lever should be moved to its third position, i.e. connecting the bladder to the atmosphere, and some of the expired air in the bladder squeezed out to the atmosphere. In this position the counter drive is still engaged. Once the bladder has been partially emptied the sampling tap lever is returned to the engaged position. At the end of the ten-minute recording period the tap lever is returned to the "disengaged" position; the subject discontinues his activity and sits down. The temperature of the expired air is read from the thermometer in the top casing of the respirometer, and noted, along with the final reading of the counter, on the record sheet. The bladder containing the sample of expired air is removed from the respirometer and its tube is clipped shut with a pair of artery forceps, and its contents subsequently transferred to a glass sample tube. The respirometer is removed from the subject's back and any moisture drained from its inside. The hose and valve are removed and rinsed with cold water. The rubber mouthpiece is sterilized in 1% Milton solution for 1-2 hours (1% Milton is 10^{-4} sodium hypochlorite solution).

Effect of temperature.

The temperature of the expired air passing through the respirometer is registered on the thermometer in the upper cover of the meter. It is from this temperature that the volume of air passed through the respirometer is corrected to S.T.P. or to B.T.P.S. This temperature is in fact that of the outlet side of the meter, which may, in certain circumstances, be considerably lower than that of the inlet side of the meter. The error thus introduced into the pulmonary ventilation when adjusted to standard temperature and pressure is normally quite small. A 4°C drop causes an error of about 4% in the calculation of the pulmonary ventilation. When used indoors the temperature drop across the respirometer will rarely be as large as 4°C, though out-of-doors in cold weather, the drop may well exceed 10°C. If the meter is to be used in conditions of low ambient temperature it is worthwhile to fit an additional thermometer to the inlet tube of the meter and to adjust the pulmonary ventilation to S.T.P. using the mean temperature of the two thermometers.

Modifactions to the respirometer: i general.

The Max-Planck respirometer is an extremely useful piece of apparatus, indeed, there is only one other instrument (The integrating motor pneumotachograph Wolff, 1958.) at present available which is suitable for studies on indirect calorimetry outside the laboratory. (The Douglas bag is not considered suitable because of its limited capacity and large bulk. The former limited the duration of the measurements and the latter impedes the subject's movements; the objections become more serious as the activity increases in intensity.) Nevertheless ther is considerable room for improvements in the design and general contruction of the respirometer. The general standard of workmanship is poor, the design of the sample pump, though ingenious, is not fully satisfactory both from the point of view of resistance and sample size, and the measurement of the temperature of the expired air passing through the respirometer could be made more accurate. The general arrangement of components is good and the actual gas-metering part of the respirometer is quite satisfactory. It was hoped to interest a British firm in a project to produce a respirometer suitable for field studies. Two companies were approached with this project in view but neither was able to co-operate. These two companies were members of the two major groups concerened with the manufacture of domestic and industrial gas metering equipment. Several other companies with interest in the field of respiratory physiology were approached, but again without success.

As mentioned above, a considerable part of the total resistance of the respirometer is due to the operation of the sampling pump. Some subjects find the resistance of the respirometer objectionable, but there appears to be no way of sensibly reducing the resistance as long as the power required to drive the sampling pump is derived from the bellows mechanism of the meter. Further, the maximum size of sample which can be obtained from the pump normally fitted to the respirometer is rarely as large as the 0.6% sample claimed by the manufacturers. When using the Pulmo-analysor (see below: "gas analysis") it is desirable to have a somewhat larger volume of air for analysis than is needed for the Haldane apparatus. The collection of a larger sample of expired air with a pump of the type normally fitted to the respirometer would result in a further increase in its resistance. The conventional form of pump is probably the most efficient way of utilising the movements of the bellows for sampling purposes, so it appeared that an alternative form of power supply was desirable. Apart from its resistance, the pump currently fitted to the respirometer is ideal from the physiological point of view: sampling is continuous throughout the whole expiration, and takes place at a rate proportional to the rate of air-flow through the respirometer. That is, the sample withdrawn by the pump is truly representative of the expired air by the subject. It would not be possible to build an electrically operated pump which could sample in this fasion, and yet be easily portable. A relatively complex electrical circuit would be necessary, and its power requirements would be large.

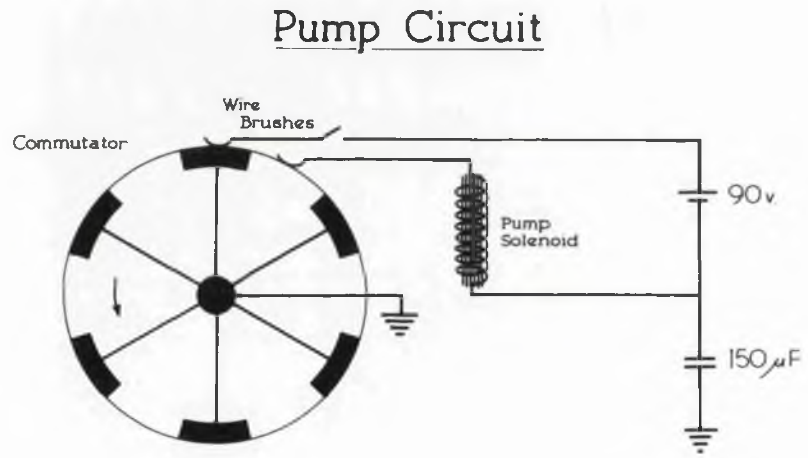


Fig. 13. Circuit diagram of pump of modified respirometer.

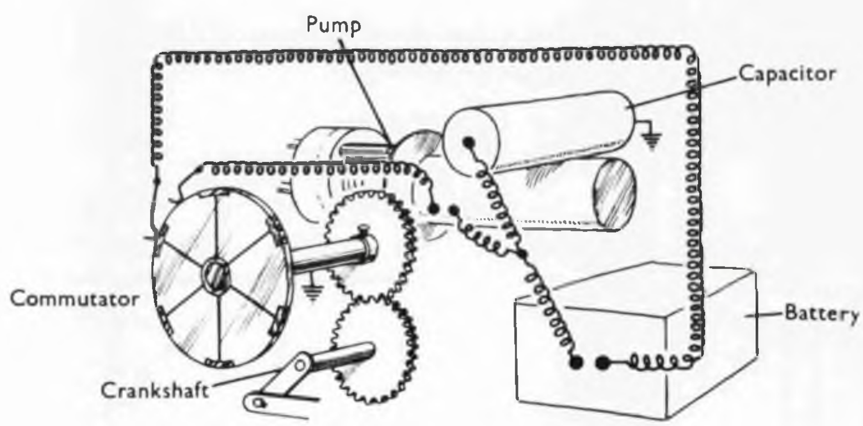
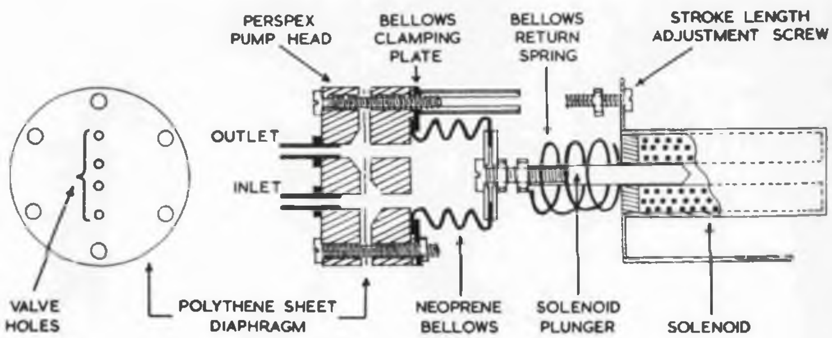


Fig. 14. Arrangement of components of modified respirometer.

However, a fairly close approximation to the ideal can be obtained using a pump driven by a solenoid, andoperating fairly frequently and at random times during expiration.

ii The electrically operated sampling pump.

The conventional sampling pump and its driving mechanism has been removed from the respirometer and replaced by a battery powered electro-magnetic pump. The solenoid of this pump is energised by the discharge of a 150 μF electrolytic capacitor; the capacitor is charged from a 90 V layer type high tension battery (Ever Ready Batrymax No. B 126) The alternative charging and discharging of the capacitor is effected by means of a rotating cummutator. The body of the commutator is moulded from the cold setting dental acrylic resin. It has six peripheral brass insets connected by copper wire to a central brass boss. The length of each brass inset is slightly less than the circumferential distance between insets. The commutator is 5 cm. diameter and about 1.5 mm in thickness. Two spring wire brushes bear on the periphery of the commutator and are so positioned that when one of them makes contact with a brass inset the other rests on the non-conducting acrylic material. Fig. 13 is the diagram of the eltrical circuit. The commutator is attached to a short shaft mounted vertically above the main crank shaft of the respirometer and driven from it by fibre gear wheels of a ratio of one to one. Fig. 14. shows the arrangement of the various components of the modified sampling device. The main crank shaft of the respirometer makes one revolution for each two litres of air passing through the respirometer.



Diagrammatic cross-section of the sample pump.

Fig. 15. The "Wolff" sampling pump.

Fig. 16. The modified Max Planck respirometer, with top cover removed.

It has been shown (Wolff, 1958) that this type of operation provides a truly representative sample of expired air over a period of ten minutes. The actual pump is of the type used in the integrating motor pneumotachograph (Wolff, 1958); this is shown in Fig. 14 and 15. The stroke-volume of this pump can be adjusted from 0.3 ml to 2.5 ml, and at a frequency of operation of three per litre this provides a range of sampling of from 0.1% to 0.8% of the volume of air passing through the respirometer. The range could be extended at either end by modifying the pump and /or the commutator.

The respirometer is fitted with two bi-metallic strip thermometers to record the temperature of the expired air passing through it. One of these thermometers is mounted near the inlet tube of the meter and records the temperature of the air entering the respirometer, The second thermometer is mounted in the upper cover of the meter just above on of the valve plates and records the temperature of the air leaving the meter. When reducing the recorded volume of expired air to standard conditions (either S.T.P. or B.T.P.S.) the mean of the tepperatures recorded by these thermometers is used.

Performanee of the modified respirometer.

The modified respirometer (shown with top cover removed in Fig. 16) is of the same physical dimensions as the convential model although its weight is increased by 0.5 lb. The working life of the battery is equivalent to the passage of upwards of 7000 litres of air through the respirometer. Table 3 shows the changes in the size of the sample delivered by the pump which can be expected during the sampling of 9,000 litres of expired air.

TABLE 3

Volume of air passed through respirometer litres	Size of sample %
1000	0.86
3000	0.87
5000	0.85
7000	0.85
9000	0.73

The resistance of standard Max Planck respirometers varies somewhat, but is in the order of 1.5 cm water at a pulmonary ventilation of 10 litres per minute and 3 cm water at 70 l/min of this, one half to one third is contributed by the operation of the pump. The resistance due to the electrically operated pump is approximately 0.2 cm at all rates of pulmonary ventilation. Thus the modified respriometer offers about 40% less resistance to air-flow through it than does the conventional model. These figures are presented in greater detail in the section dealing with the measurement of resistance to air-flow (p.52).

The modified respirometer has withstood use in strenuous excercises such as step testing and uphill running and has been used by independent workers in situations ranging from the melting shop of a steelworks to a clinical research unit.

Fig. 17. The Standard Dry-flow Air Meter.

Parkinson and Cowan, type C.D4.

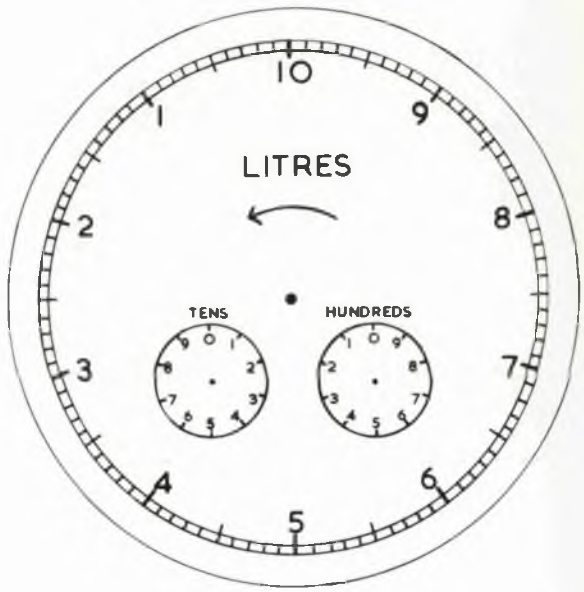


Fig. 18. Index of Dry-Flow Air Meter (diagramatic)

3. THE STANDARD DRY-FLOW AIR METER.

This instrument is a large industrial "bellows" gas meter which has been modified for physiological applications by the manufacturers (Parkinson & Cowan, Ltd., Cottage Lane, London, E.C.1). The meter is known as a type C.D4; it can record rates of steady air flow of over 700 litres per minute, although in fact the makers rate its maximum capacity as 250 litres per minute. This meter can be used in the laboratory for the direct measurement of pulmonary ventilation, although its use in the work described in this thesis was confined to that of a standard meter against which the Max Planck respirometers were calibrated.

The meter is shown in Fig. 17. The recording index, which is mounted horizontally on the top of the meter, is in the form of a 4½ inch diameter dial with a centrally positioned rotating pointer. This dial is graduated from zero to ten litres, in divisions of one-tenth of a litre. Two smaller circular dials, within the circumference of the large one, register tens of litres (0-90 litres) and hundreds of litres (0-900 litres). The arrangement of these scales is shown in Fig. 18, where, for the sake of clarity, the pointers have been omitted. The interior of the meter is specially treated to prevent corrosion by moisture, and a drain tap is fitted to the bottom of the inlet pipe permitting the removal from the instrument of condensed water vapour. Some modifications to the meter were made in this laboratory; including the fitting of thermometers (British Rototherm Co. Ltd., Merton Abbey, London, S.W.19) to the inlet and outlet pipes and of a sampling tap to the inlet. These fittings are of a benefit when the meter is used for physiological rather than physical purposes.

The dry-flow meter is normally re-calibrated every three or four months. This is done by the manufacturers who have a branch workshop in Glasgow. The meter is generally calibrated at two rates of steady flow, namely 400 cubic feet per hour and 25 cubic feet per hour (190 and 12 litres per minute). The calibration is made with the use of a large "spirometer"-like gas holder. The reason for the use of "cubic feet per hour" rather than "litres per minute" is simply that the gas holder is itself calibrated in cubic feet and the technicians in the manufacturers' workshop "think" in British rather than metric units. The correction factor of the meter which is determined from the calibration (and which must subsequently be applied to readings of the meter) has never been found to differ by more than 0.005 (½%) at the two widely differing rates of flow used in the calibration. If the correction factor exceeds a value of 1.015, or is less than 0.985 (i.e. the error in the meter reading is greater than 1½%) the meter can be quite easily adjusted by the makers, although in fact in four years' experience with two of these meters this adjustment has only been necessary on one occasion.

If it was every necessary it would not be difficult to calibrate this type of meter at a higher rate of air flow. For the purpose of a standard against which the Max Planck respirometer can be calibrated a steady flow-rate of 190 litres per minute is adequate in nearly all cases. In the work of this thesis 190 litres per minute was invariably more than adequate. The assumption underlying this statement is that the peak flow-rate during expiration is in the order of 2½ to 3 times the pulmonary ventilation (Silverman, Lee, Yancey, Amory and Lee, 1945); 190 litres per minute peak flow-rate would thus be equivalent to a pulmonary ventilation of over 60 litres per minute. At the other end of the scale a peak flow-rate of 12 litres per minute represents a pulmonary ventilation of 4-6 litres per minute.

A possible objection which might be raised to the use of the dry-flow meter as a standard for the calibration of the respirometers is a question of the ability of the meter to accurately measure pulsatile, as opposed to steady, air flows. This matter has been investigated using the apparatus described for use in the calibration of the Max-Planck respirometer (see above) except that a large Douglas bag was used instead of the respirometer. Using the combinations of "respiration" and "ventilation" rates shown in Table 1 (above) to produce a pulsatile air flow the Douglas bag was filled, clamped off, disconnected from the outlet pipe of the meter and reconnected to the inlet and its contents re-passed through the meter at a steady flow rate of about 25 litres per minute. The volumes of air recorded by the meter during the intermittent filling and the continuous emptying of the Douglas bag bag were compared. The differences between these pairs of recorded volumes were never more than 1-2%, and more importantly, the "steady flow" volume was neither consistently above nor consistently below the "pulsatile" volume. At first sight these findings may appear a little surprising, but on consideration there is little reason to expect that a meter of this type would be less accurate when dealing with pulsatile than with steady flows.

When a steadily flowing stream of air enters a "bellows" meter the very nature of the metering device converts the steady flow into a very disturbed one as the air stream is partitioned into the various compartments of the meter. Any recording instrument is likely to measure a pulsatile phenomenon inaccurately if the inertia of moving parts has to be overcome during the acceleration of these parts and the energy of their momentum dissipated during their deceleration, as opposed to a steady state of motion of the components of the instrument when it is recording a continuous phenomenon. Rotary instruments are particularly liable to inaccuracy arising from this source, but it is difficult to imagine an instrument such as a "bellows" gas meter being upset by a pulsatile flow when even during steady flow conditions its moving parts are undergoing continual acceleration and deceleration.

4. RESISTANCE TO AIR FLOW.

A gas, such as air, will only flow through a conducting system (valves, tubing, meters, etc.) if the inlet and outlet sides of the system are at differing pressures. The region of high pressure represents a source of potential energy; this energy is utilised to drive the gas through the conducting system, flow continuing until the pressures at each end of the system are equal. If a constriction or partial blockage is introduced into the system the rate of gas flow through it will be reduced, unless the pressure differential through the system is increased. To maintain a constant rate of gas flow in the system the pressure must be proportional to the extent of the blockage: the more complete the blockage the higher the pressure differential necessary. To some extent each component of a conducting system presents a partial blockage or resistance to the air flowing through it. The amount of work done in moving air through the resist nce of a conducting system is represented by the loss of energy of the gas during its passage, i.e. by the drop in the pressure of the gas.

The resistance of equipment to air flow is normally measured in terms of the decrease in pressure (ΔP) of air between the inlet and outlet sides of the apparatus. "...In the general case, one can only measure resistance by determining the loss of mean total head;.." (Ower, 1949). The mean total head of pressure at any point in the airflow through a conducting system is made up of two components: 1. the velocity head, and 2. the static head. The velocity head is

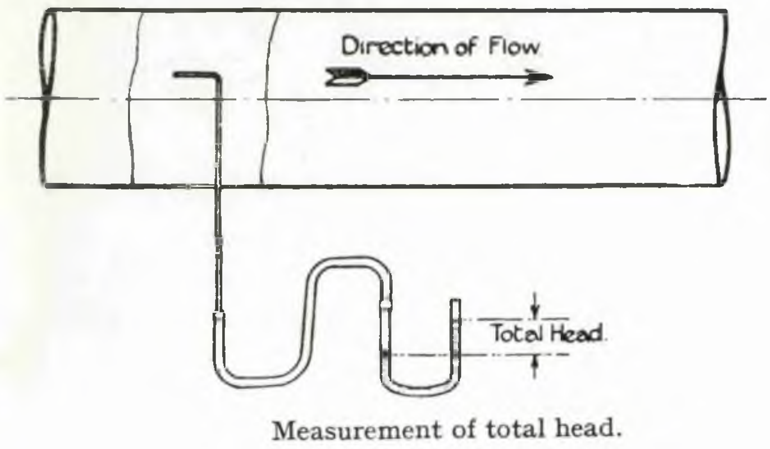


Fig. 19. The principle of the Pitot tube (after Ower)

the pressure exerted by the air by virtue of its directional movement (i.e. flow), while the static head is the pressure which the air exerts independently of its flow. Fortunately the mean total head is readily determined by a single measurement. This is made by inserting a small L-shaped tube into the air stream as shown in Fig. 19. This tube is known as the pitot tube or total head tube. One end of the pitot tube is open and faces into the air stream and the other end is connected to a suitable pressure measuring device (a water or mercury manometer is the most straightforward). Pitot tubes of similar dimensions are inserted into the inlet and outlet ends of the equipment under test (it is essential to ensure that the inlet pipes are of the same bore). The resistance of the equipment is found by subtracting the mean total pressure head recorded in the outlet pipe (P2) from that recorded in the inlet pipe (P1).

$$P_1 - P_2 = \Delta P \propto \text{Resistance}$$

The apparatus used to measure human pulmonary ventilation usually consists of inspiratory and expiratory valves, a length of flexible tubing and gas metering device. Hence the resistance offered to the subject's expiration is considerably greater than that to inspiration. As mentioned above, some resistance is inherent in all air conducting systems, and this certainly holds for respiratory equipment. However, provided that the resistance is kept as low as possible its effects on the subject's respiration are small. The effect of high resistance to to respiratory air flow manifests itself in three ways: 1. subjective sensation, 2. alteration of respiratory pattern, and 3. increase in the work of breathing.

The subjective sensations produced by increased respiratory resistance are variable: some subjects rarely complain, or even notice quite high resistance, i.e. of the order of 6-10 cm water, while others find resistances of 2-3 cm water objectionable. Most subjects can tolerate a considerably greater resistance to inspiration than to expiration (Silverman et al 1945) but some find that inspiratory resistance is more unpleasant than expiratory (Wolff - personal communication). Due to the arrangement of the apparatus used in these studies, we have rarely, if ever, had complaints about inspiratory resistance; this is always small. For example, even if the pulmonary ventilation was as high as 70 l./min the resistance of the inspiratory side of the valve used would only be 2 cm water compared with a total expiratory resistance of nearly 7 cm water at the same ventilation rate (see Fig. 23). Even when the resistance is small and causes no physiologically detectable effect, it is none the less desirable to keep it as low as possible to ensure maximal co-operation from the subject.

The alterations to the respiratory pattern caused by inspiratory and expiratory resistances, separately and together, have been studied by Silverman _et al_. Those phases of the respiratory cycle affected by resistance show changes in the shape of the pneumotachogram. Both the height and the slope of the curve of the pneumotachogram are reduced, and the duration of the affected part of the respiratory cycle is increased. Changes may occur in the respiratory rate (which may be reduced), the tidal volume and the oxygen extraction (both of which may be increased). The extent of these changes is dependent on the size of the resistance encountered, but with moderate resistances (up to about 7 cm water) they produce little or no change in the total oxygen consumption of the subject. Hence, from the standpoint of indirect calorimetry, such changes are of no great significance, but of course in experiments of a purely respiratory nature they may be important. Silverman et al. state that high resistance to respiratory air flow causes a reduction in the total oxygen consumption of the subject, and a consequent increase in the oxygen debt.

Except where the resistance to air flow is very high (above 10-12 cm water) the increase in the expenditure of energy by the respiratory musculature is small when compared with the expenditure of energy by the remainder of the body. Unless the apparatus used to measure the pulmonary ventilation is of completely unsuitable design, and the rate of pulmonary ventilation very high the resistance is unlikely to be large enough to cause a measurable increase in the energy expenditure; this is particularly so in experiments involving indirect

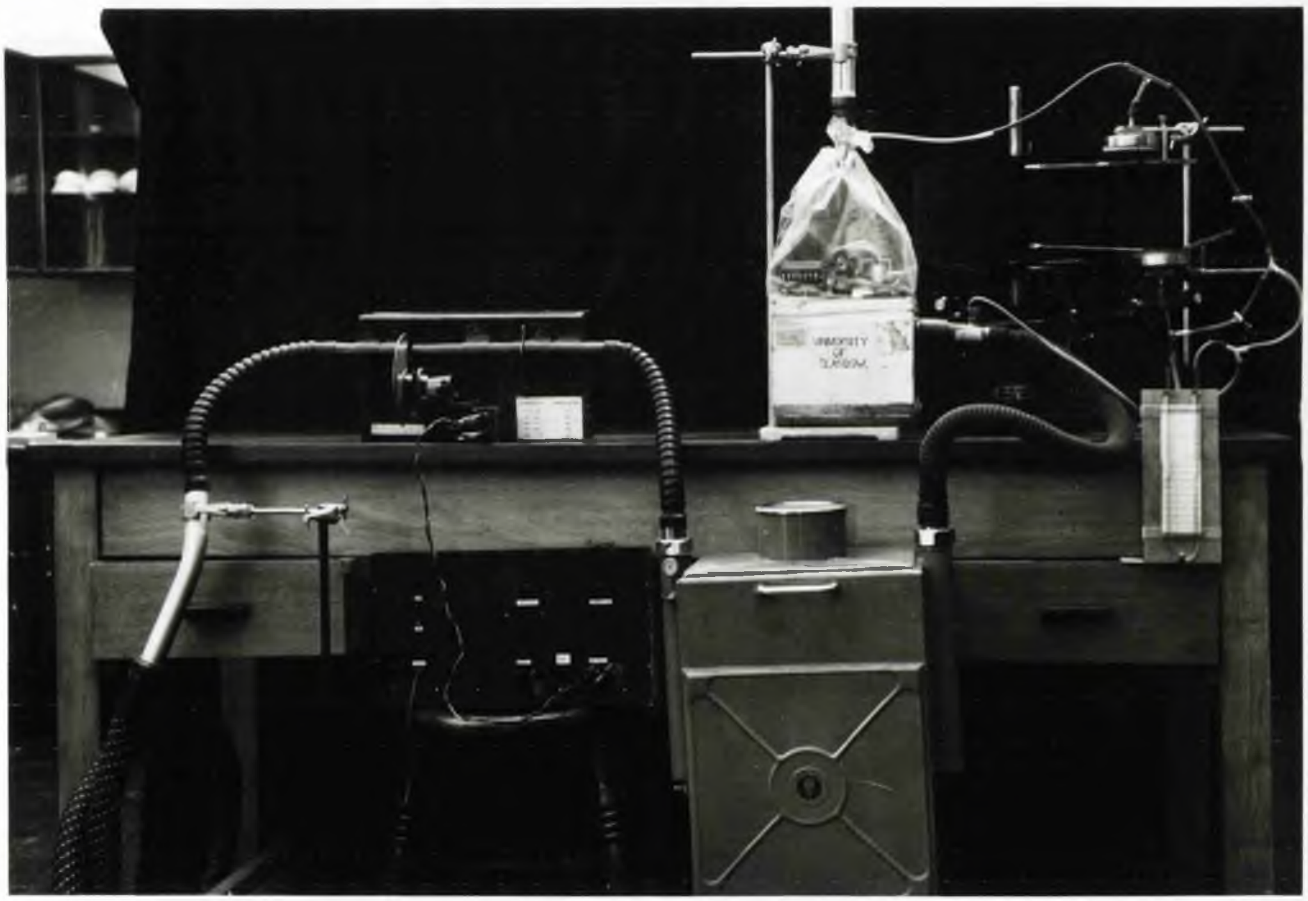


Fig. 20. Apparatus used to measure resistance to air flow.

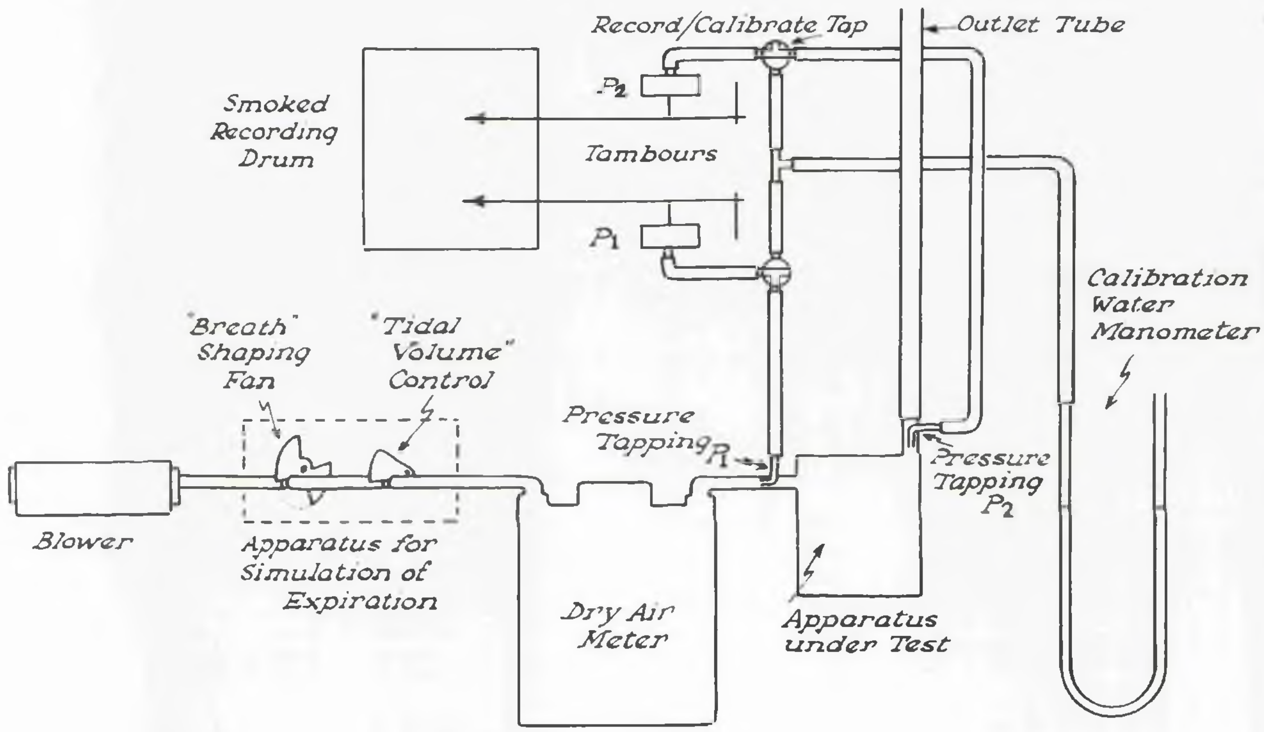


Fig. 21. Apparatus used to measure resistance to air flow - diagramatic.

calorimetry where very high rates of pulmonary ventilation (80-100 l./min) will only be encountered at correspondingly high expenditures of energy (15-20 kcal/min).

As a guide to the acceptable upper working limit of respiratory resistance we have taken the figures of Silverman et al. "Physiological and subjective reactions indicate that for heavy work... resistance exceeding 82 mm (water) inspiratory and 53 mm expiratory are not well tolerated. "These resistances are measured at a steady flow rate of 85 l. per minute, which is equivalent to a pulmonary ventilation of approximately 30 l. per minute.

The actual measurements of the resistance of the various pieces of respiratory equipment were made with the apparatus photographed in Fig.20 and shown diagrammatically in Fig.21. The air flow pattern in breathing is of pulsatile nature, and the peak rate of flow is some two-and-a-half to three times the recorded pulmonary ventilation. In order that the measurements of resistance be made under conditions closely resembling those in actual use, a pulsatile air flow, simulating human breathing, is produced in the fasion described above inthe section on the calibration of the Max-Planck respirometer. Such a system creates cyclical changes in the total head pressure as measures by the pitot tube, and this oscillation of pressure precludes the use of a water manometer as a pressure recording device. Instead, the pitot tube is connected to a rubber

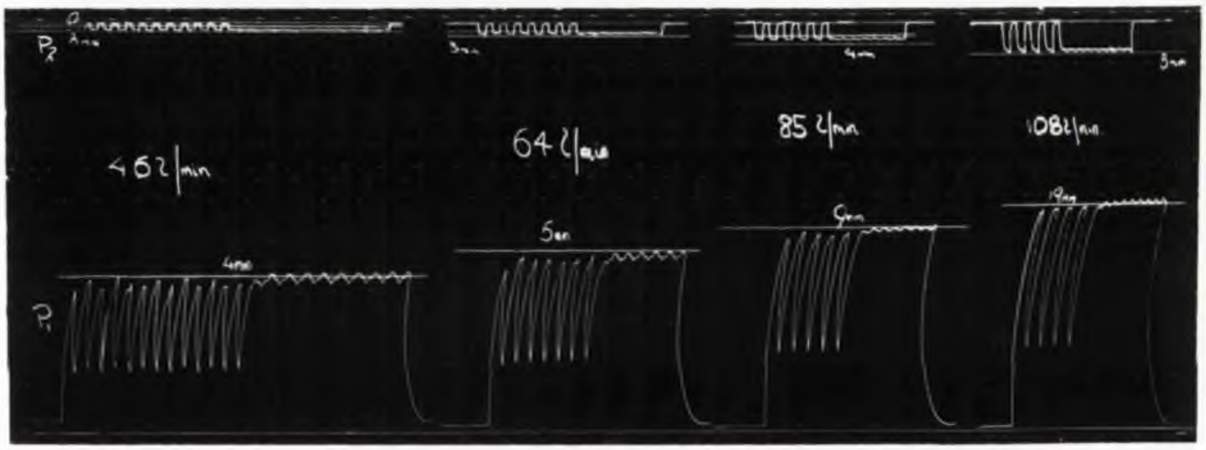


Fig. 22. Part of graphic record of an actual measurement of resistance to air flow. Upper trace, P_2, total head at outlet; lower trace, P_1, total head at inlet of component under test. Resistance is proportional to ΔP. $\Delta P = P_1 - P_2$. Note the calibration lines on the record.

covered tambour. The excursions of the diaphragm of the tambour are recorded on a smoked drum on an electrically driven kymograph. The use of this routine physiological pressure recording technique for purely physical determinations simplifies what might otherwise be a problem of some technical difficulty. In practice two pitot tubes are used; these are of identical construction and are mounted in 3 in. lengths of 1 in. bore copper pipe. These pipes are attached to the air inlet and outlet of the component under test. One tambour is connected to each pitot tube, and the writing levers arranged to write vertically above one another on the surface of the drum. Recordings are made simultaneously of the total head of pressure at the inlet and outlet sides of the component under test, at various rates of simulated pulmonary ventilation. As there is not an outlet pipe on the Max-Planck respirometer the upper part of the meter was sealed into a sleeve of polythene film; the other end of this sleeve (see Fig.20) was sealed on to the pipe containing the pitot tube used to measure the pressure at the outlet side of the meter. Before the drum is removed from the kymograph the graphic record is calibrated. This is done by disconnecting the tambours from the pitot tubes and connecting them to a water manometer. Air at various pressures is injected into the tambours and calibration lines drawn on the drum. Part of graphic record is shown in Fig.22.

The results of the measurements of the resistance to air flow of some of the various pieces of equipment tested are shown in

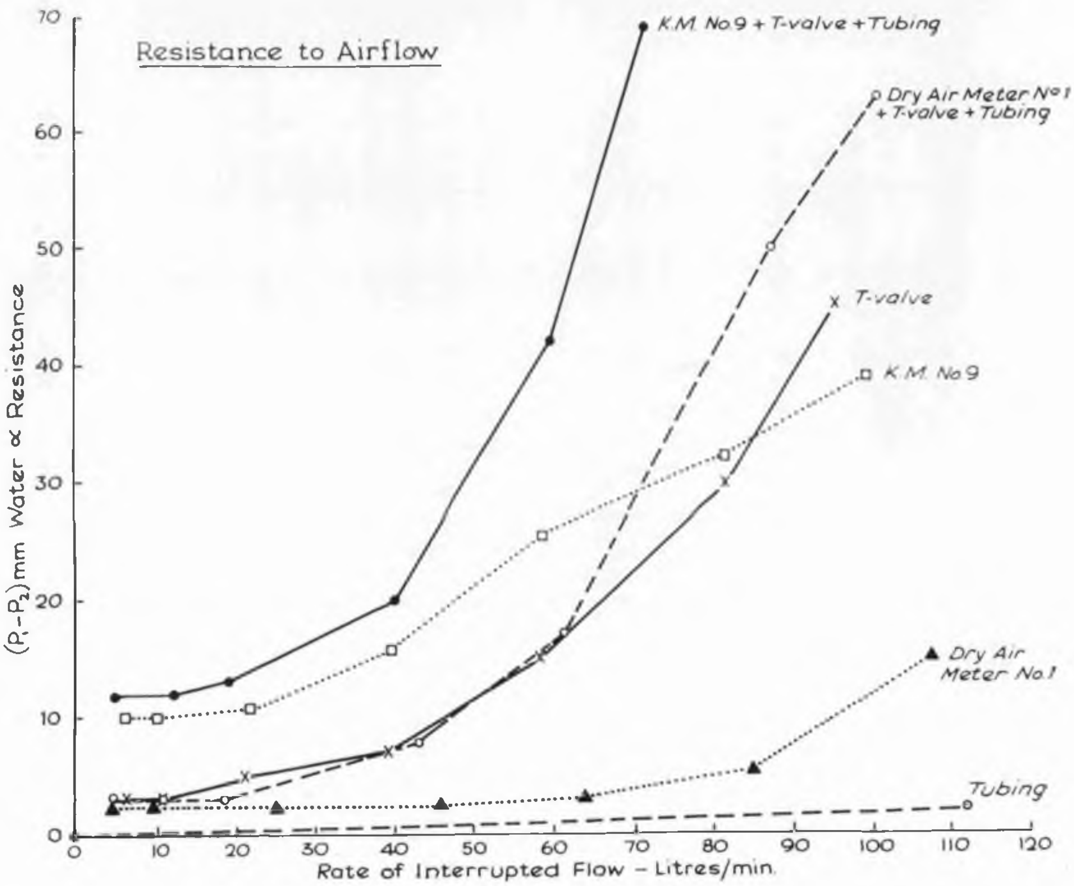


Fig. 23. The resistance to air flow of some of the apparatus described.

Fig.23. In this graph resistance (Δ P) is plotted against rate of simulated pulmonary ventilation. Curves are drawn for a 24 in. length of 1 in. bore flexible breathing hose (Dunlop pattern, see above; this curve is labelled "Tubing" in the Fig.23), for a dry flow air meter (that manufactured by Parkinson and Cowan), for a Max-Planck respirometer (the curve labelled "K.M. No.9") and for the expiratory side of the two-way T-shaped valve supplied with the Max-Planck respirometer. Curves are also drawn showing the total resistance which would be offered to expiration by a subject breathing out through a valve, length of tubing and Max-Planck respirometer, or through valve, tubing and dry air flow meter. The curves shown in Fig.23 are typical of those obtained for the various types of apparatus. There are variations between, say, one valve and another, but for all components except the Max-Planck respirometers these are small, although the differences between one respirometer and another may be as large as 1 cm water at all rates of air flow. The values of the resistances shown in Fig.23 are all within the limits stated by Silverman <u>et al</u>., even if the pulmonary ventilation equivalent to a peak flow rate of 85 l./min were high as 40 l./min, the resistance of the Max Planck-respirometer, valve and tubing would be only approximately 20 mm water, compared with the figure of 53 mm quoted as being the maximum expiratory resistance which is well tolerated. At a pulmonary ventiltaion of 70 l./min the total resistance to expiration of the respirometer, valve and tubing is approximately 70 mm water. The equivalent peak flow rate

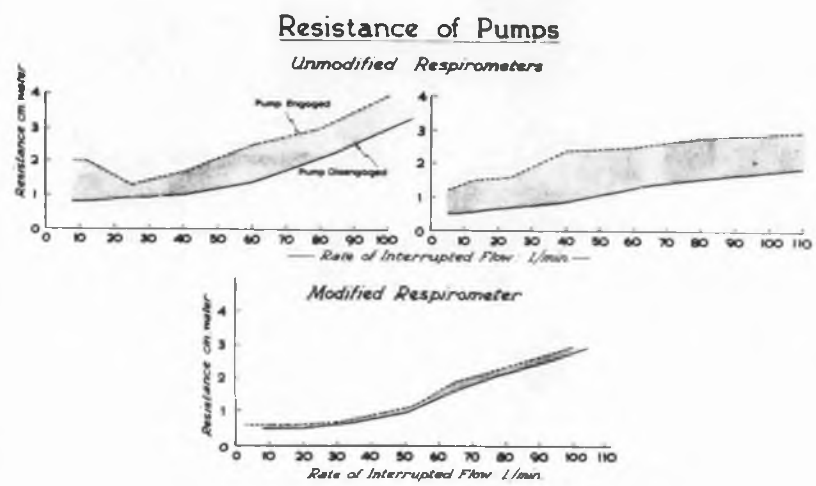


Fig. 24. The resistance of modified or unmodified Max Planck respirometers. The shaded portion on each graph represents the resistance offered to air flow by the sampling pump. Note the considerable reduction in the resistance of the modified pump, and the variability of the resistance of the "bellows mechanism" of the different meters (i.e. areas under lower curves.)

is probably in the order of 150-200 l./min, and at this rate of flow the maximum well tolerated resistance would be approximately 100-120 mm water. Despite these apparently satisfactory values for the resistance of our equipment, it was felt that there was little ground for complacency: some subjects did find the resistance unpleasant. It seemed desirable to try to reduce the resistance to air flow of the Max-Planck respirometer and of the two-way respiatory valve.

Details of the modifications made to the Max-Planck respirometer are given in the sedtion dealing with that instrument (above pp.36-40). The reduction in resistance effected by these modifications is quite considerable. This is shown in Fig.24. Three graphs are shown in this figure: the first two refer to two unmodified respirometers with mechanically operated sampling pumps driven from the bellows mechanism of the meter, while the third graph refers to a modified respirometer with an electrically powered sampling pump. In each graph two lines are drawn. In each case the lower line is the cruve of the resistance of the bellows mechanism plotted against rate of interrupted air flow. (The equivalent steady flow rate is more than double this "ventilation rate".). The upper lines of these graphs are the curves of the overall resistance of the respirometer when the pump is operating (i.e., the resistance of both bellows mechanism and sampling pump.) The shaded areas between the lines represent the resistances due to the operation of the pump alone. It is obvious that the resistances of the bellows mechanisms of these three respirometers differ considerably from one to another. Hence, to make a fair assesment of the reduction of resistance brought about by the modification to the respirometer one should regard the lower curves bounding the shaded areas of these graphs as being the base lines. The resistance of the pumps on the unmodified respirometers is between half and one centimeter of water at all rates of flow; that of the pump on the modified respirometer is in the order of one to two millimeters. If this latter resistance were to be substituted for the resistances due to the pumps on the unmodified respirometers it would have the effect of lowering the total resistance by one third to one half.

The major factors contributing to the resistance of the respiratory valves are the tension of the valve closing springs, the sticking of the mica discs onto their seatings when wet, and the tortuosity of the path which the air passing through the valve must follow (see Fig.11). The spring tension is at, or very near to, the minimum which can be relied upon to provide rapid closing and effective sealing of the mica discs in the valve; it thus appeared that little or no reduction of resistance could be obtained by modification of these springs. As previously mentioned (see page 33) the mica discs in this type of valve seat onto an annular knife-edge. In some of the valves supplied with the respirometers this knife-edge is blunt: this means that the area

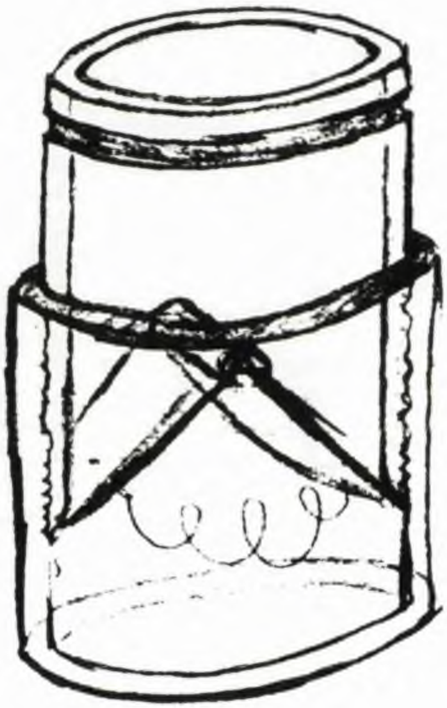


Fig. 25. The "butterfly" valve - an elegant design, but one which could not be made to operate successfully.

of contact between the disc and its seating is larger than need be. In use, the valve becomes moist, and the film of water on the blunt seating adheres, with considerable power, to the mica disc. This results in the necessity of a high pressure gradient across the disc before it is lifted off its seating, i.e. the resistance of the valve is high. This defect is easily remedied by "sharpening" the annular knife-edge seating; this operation is best performed on a lathe. No modification of the T-shaped valve could reduce the number of bends around which air has to flow on its passage through the valve; so it appeared that a completely new design was necessary if the resistance of this component was to be further reduced. Starting from the basis of the Y-shaped two-way valve described by Durnin (Durnin 1954), it seemed that it might be possible to design and build a valve through which the flow of air could be in a nearly straight line. The valve flaps in the valve described by Durnin were of unsatisfactory design, in that, at high rates of flow it was mechanically impossible for them to open far enough to provide an air-way the full diameter of the tube. A model was made of a single one-way valve; which would later be used as one of the arms of a two-way Y-shaped valve. The valve flap in this model was similar to the throttle butterfly-valve of a motor car carburettor; but differed from the latter valve in that the flap was made in two parts, hinged together across the diameter of the valve pipe (Fig.25). These two half-flaps were held apart, by a light spring, against a "kettle-spout" shaped seating screwed into the valve pipe. This model was only partly successful. Its resistance was lower than that of the conventional valve at peak flow rates of between 50 and 100 l./min, but below this its resistance was rather highter than that of the conventional valve, and at flow rates above 100 l./min the valve flaps developed a violent fluttering, which made the valve virtually unusable. Alternative types of spring were tried, mainly of the "hairpin" variety, but without significant improvement; the flaps were also moulded out of rubber latex, as a single piece, but this was not at all succesful. None the less it was believed that this was a basically sound principle upon which to build a valve, if a suitable type of spring could be found. Several firms interested in respiratory equipment were approached, among them Messrs. Garthur, Air-Med and Mines Safety Appliances. (It was later learned that Messrs. Normalair Ltd. had previously experimented with a valve of this type, but had no great success, and had abandoned the project.). At that time Messrs. Mines Safety Appliances Ltd. were interested in the development of low-resistance respiratory valves and agreed to try to manufacture a valve along the lines suggested. Unfortunately, once again, this design, elegant on paper though it may appear, proved to be too difficult to translate into a working model. Messrs. Mines Safety Appliances then started on the development of a new design of "Straight-through"

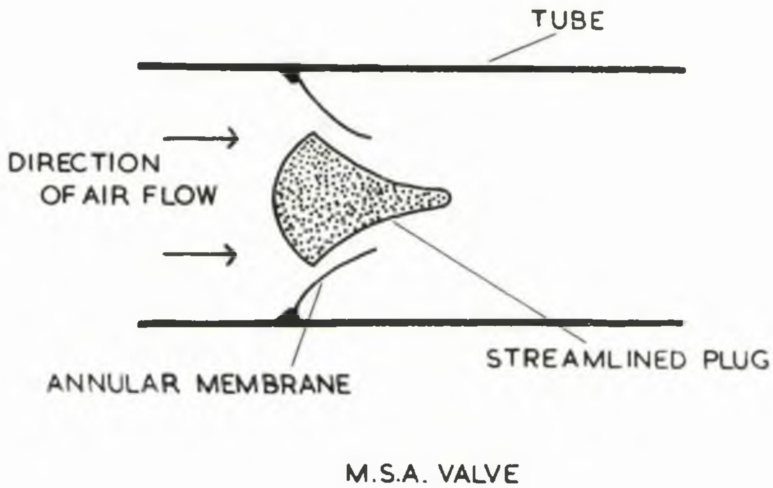


Fig. 26. Diagramatic cross section of a prototype low-resistance valve being developed by Mines Safety Appliances.

valve. A prototype has been manufactured which appears to offer hopeful possibilities for the future, though in its present form it is rather heavy. It consists of a small streamlined plug mounted in the centre of a length of 1 in. bore tubing (Fig.26). An annular funnel-shaped membrane, moulded of rubber or polythene, is attached circumferentially inside the tube; the free inner edge of this membrane is supported by the streamlined plug. When air pressure is higher at the broad end of the plug than at the narrow end, the free edge of the membrane is lifted off its seating on the plug, and air can pass along the tube. When air pressure is low at the broad end of the plug the membrane is forced down onto its seating, preventing the flow of air. Whether, in fact, this pattern of valve will ever reach the level of commercial production remains to be seen. Even if it does, there is no guarantee that it will be suitable for field studies involving indirect calorimetry, but it does appear to offer at least some hope for the future.

5. MASKS

Requirements of a mask

It is possible to use a mask in place of the nose clip and rubber mouthpiece normally used with the Max-Planck respirometer. Provided it complies with the requirements detailed below, a mask would appear to offer certain advantages over the mouthpiece and nose clip. It is probably easier for an untrained subject to accustom himself to a mask, as he is able to breathe normally through his nose; such actions as coughing or swallowing are rather difficult to perform when using a mouthpiece, but present no difficulty when the subject wears a mask. Subjects who wear dentures, or who have tender mouths, are often inconvenienced by the drag of the hose to the respirometer on their mouths and teeth. Occasionally, too, a subject may find the nose clip painful or that it disturbs his vision. Sometimes it is difficult to ensure that the nose clip does not slip off the subject's nose. Against all this a mask becomes unpleasantly warm to wear, particularly during strenuous exercise; indeed, most experienced subjects prefer the use of the mouthpiece to that of the mask. If a mask is used it should have the following properties.

1. It must be completely free from leakage during expiration, that is, all the expired air must pass through the expiratory valve and so through the respirometer. This is, of course, the reverse requirements of protective (gas) masks, in which an expiratory leak is of no importance, in fact many rely on

Fig. 27. The "H-type" oronasal mask, inner and outer sides (manufactured for the Royal Air Force by Airmed Ltd.)

an expiratory leak as their only outlet.

2. The 'dead-space' of the mask should be minimal to avoid any changes in the respiratory pattern, particularly carbon dioxide retention. Forthis reason a small close-fitting oro-nasal mask is preferred to one which encloses the whole face.
3. The harness by which the mask is fitted to the subject should be easily adjustable to suit various head sizes and shapes. The harness should also hold the mask firmly in place, regardless of movements of the head and drag of the hose to the respirometer.
4. The mask should be of such a design that it can fit all shapes and sizes of faces. Alternatively it should be available in several sizes and fittings.
5. The mask should be made of a material that can be easily cleaned and sterilised.

Masks designed for aircrew

A mask which has been found moderately suitable for use is the "H-type" mask manufactured (by Airmed Ltd., Harlow, Essex.) for the Royal Air Force. This mask (Fig.27) complies with the requirements detailed above, but a great deal of trouble must be taken in fitting the mask if it is to be leak-proof during expiration. This mask has three inspiratory valves (one over each cheek and a third over the nose) which go part of the way towards reducing the problem of overheating of the subject's face.

A perspex valve, of the type described for use with the Max-Planck respirometer, is fitted into a short ($\frac{1}{2}$ in.) tube in the facepiece. The expiratory side of this valve is joined to the hose to the respirometer as described above. This type of mask can be used for laboratory studies, but it is felt that the care needed to ensure the absence of expiratory leak obviates its use in field studies, such as energy expenditure surveys. These masks are available in three sizes, but even the smallest size is too large for most female subjects.

A modified version of the "H-type" mask has been developed by the manufacturers for semi-pressurised breathing systems. This is known as the "J-type" mask and incorporates a moulded foam rubber pad on the inside of the facepiece. This pad is intended to give a better seal on to the subject's face. However, this mask has to be unpleasantly tight to avoid leakage, and it, too, is unsuited to women's faces. We attempted to improve upon the H-and J- type masks by fitting an inflatable rubber tube around the inside edge of the facepiece, in the hope that a good seal would be obtained. In this we were unsuccesful . When the tube was inflated, it was found that the moulded rubber facepiece was so flexible that it lifted off the subject's face, particularly in the concavities between nose and cheeks.

To counteract this it seemed desirable to fit a rigid cover or shield over the outer surface of the rubber facepiece. The

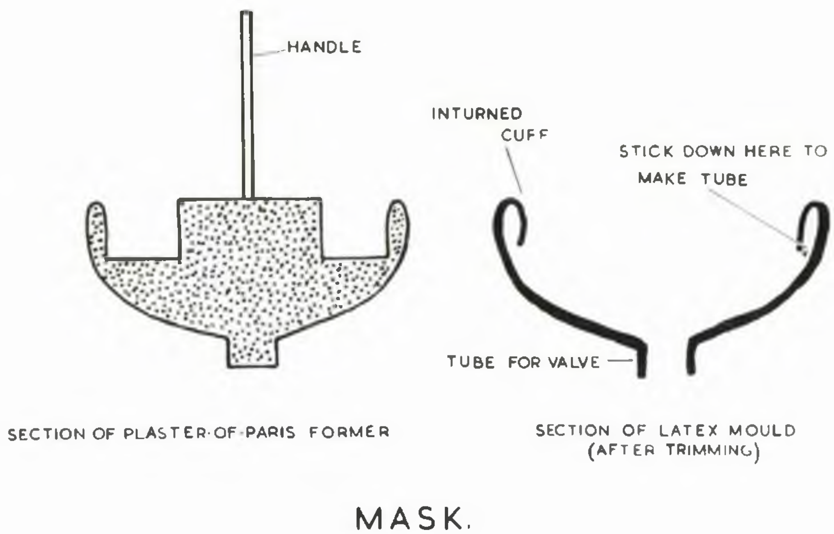


Fig. 28. Cross sectional diagram of plaster former used in dipping latex mask.

complex shape of the H-type facepiece made this very difficult, and in consequence it was decided to try to make a completely new facepiece.

<u>A "home-made" mask</u>

A plaster cast of the writer's face was made with the assistance of the Dental Prosthetics Department of the Glasgow Dental Hospital. On this case a facepiece was made from dental modelling wax. Next, a plaster mould was used to case a shield made of acrylic moulding compound, using the standard technique employed in the fasioning of acrylic plates for dentures. The plaster mould was also used as a former for the latex dipping of the facepiece. The latex dipping was done using a material known as "GR-Revultex 10/2" (Manufactured by Revertex Ltd., 51-55 Strand, London, W.C.2.). This is a useful material for the manufacture of small items, of simple shape, from rubber latex. This type of latex dipping compound requires no coagulant other than the plaster-of-paris former. The former is simply dipped into the latex, carefully withdrawn, and the resulting film of latex allowed to dry. The process of dipping and drying is repeated until sufficient thickness of latex has been built up on the plaster former. Once the latex is completely dry it is stripped off the former and, after any necessary trimming, is ready for use (see Fig.28). The facepiece which was made was designed to have an inflatable tube around its edge. It had been dipped so as to produce an inturned cuff, which merely required to be stuck

Fig. 29. The oronasal mask made in this laboratory. Inner and outer sides. The inturned cuff can be seen around the edge of the inner side.

down along its border to make the inflatable tube around the facepiece (Figs.28,29). Before the inturned cuff was stuck down to form an inflatable tube, however, tests were made on the facepiece and its acrylic shield. It was found that the inturned cuff of the facepiece produced an excellent seal on the subject's face. Unfortunately the mask proved to be a little too large for the majority of faces, and before a new plaster former could be made we received a sample mask from Messrs. Mines Safety Appliances Ltd. (M.S.A.).

The reflected edge seal mask

This mask (Figs.30,31) was very similar to the one made in our laboratory. It consisted of a plastic shield and a moulded rubber facepiece, with an inturned cuff. This cuff is known as a "reflected edge seal". A small rubber strip is moulded across the inside of the facepiece, joining the reflected edge seal at each side. This strip of rubber lies between the subject's upper lip and nose when the mask is fitted, and ensures that the reflected edge seal is closely applied to the face. When correctly fitted this mask will withstand a maximal expiratory effort without permitting any leakage. This type of mask proved to be so satisfactory that it was decided to discontinue our own efforts to produce one. The M.S.A. reflected edge seal mask is commercially available in the United States, where it is manufactures by parent company of the group. It is difficult to obtain these masks in the United Kingdom, but we are informed by the British subsidiary

Fig. 30. The M.S.A. oronasal face piece with reflected edge seal, and plastic shield.

Fig. 31. The M.S.A. mask complete.

company* that they hope to st rt production of the mask in this country in the near future.

Recently two other "reflected edge seal" masks have come into production. The first of these is the "Clora" mask and is manufactured by Auer, a German subsidiary company of Mine Safety Appliances. The second of these masks is the "Duoseal" which is made by Airmed Ltd.. The "Clora" mask is designed for use in emergency oxygen rescue sets. It is a technically beautiful moulding in green rubber. The "Duoseal", which is an anaesthetic mask and not such a good example of craftmanship, is made of black "anti-static" rubber. Both of these masks are interesting in that they are attempts to combine the properties of the soft, flexible reflected edge seal with rigidity of the plastic shield.

This combination is achieved in the "Clora" and "Duoseal" masks by an increase in the thickness and stiffness of the rubber of the central part of the facepiece while preserving the flexible inturned cuff around the edge. Neither of these masks is as satisfactory as the M.S.A. mask and shield described above. The "Clora" is not sufficiently stiff although it provides an excellent fit and is comfortable to wear. The "Duoseal" is a little too inflexible and does not make a completely leak-free seal at the sides of the nose of all subjects.

*Mine Safety Appliances Co. Ltd., Queenslie Industrial Estate, Glasgow, E.2.

Before a mask can be used in field experiments of the type described in this work we feel that it is essential to have available either the M.S.A. mask and shield or another mask at least as satisfactory. To date we have been unable to obtain further masks of this type from the manufacturers, but we are still trying to do so.

6. GAS ANALYSIS

General

In the experiments described in this thesis it is frequently necessary to analyse quantitatively samples of expired air for oxygen, carbon dioxide and nitrogen. (From a physiological point of view "nitrogen" is taken to include th inert gases argon, neon, etc.). The concentration of oxygen present in the gas mixture is usually of primary importance. Normally the concentrations of oxygen and carbon dioxide are determined analytically while that of nitrogen is found by subtraction.

There are two possible basic approaches to the problem of quantitive gas analysis: chemical and physical. At present the volumetric chemical method is the one of preference when a high degree of accuracy is desired; physical methods are, as yet, not sufficiently developed to be usable without frequent cross-checking against chemical ones. Physical methods do offer, however, the possibility of speedy analysis and freedom from the tedium normally associated with quantative chemical analysis. This is an important point when large numbers of samples have to be analysed; in the past many investigations have been limited by the bottleneck of chemical methods of gas analysis.

Chemical Methods

Two main methods of chemical gas analysis are available to the physiologist dealing with expired air from human beings: that of Haldane (Haldane 1898, Haldane & Graham 1935) and that of Scholander (1947). Both these methods are volumetric in nature; a measured volume of the gas sample is exposed to an absorbent of carbon dioxide, and the reduction in volume noted; the remainder of the sample is then exposed to a strong reducing agent which removes the oxygen and the further reduction in volume is noted. Both methods provide means of ensuring that the volumes of gas are recorded at the same pressure each time, and provide automatic compensation for changes in ambient temperature and pressure during analysis. The procedures for the actual analysis are routine, and it is not proposed to describe them here. However, mention is made in appendix "B", of the various solutions which have been used for the absorption of oxygen in the Haldane apparatus in this laboratory over the past few years.

Chromous chloride is the solution of preference in this laboratory, but none is unsatisfactory, and the choice of oxygen absorbent probably remains a matter of individual preference amongst various workers. Personal preference, rather than intrinsic superiority is also the most probable criterion in choosing between the Haldane and the Scholander apparatus for the routine analysis of samples of expired air. None the less where extreme precision is required the Haldane apparatus with a carefully calibrated 20 ml burette, in the hands of a skilled operator, is probably the most accurate means of analysis available. The Scholander micrometer analyser deals with very small (0.5 ml) samples of expired air; this may, or may not, be a desirable feature, depending on circumstances. Sometimes only very small volumes of sample are available, but very small samples may lead to errors in sampling. It is claimed by some laboratories that the Scholander apparatus can be used to make more, accurate analyses in a given time than can the Haldane. Despite this, it is our experience that a highly trained technician using the 10 ml Haldane apparatus can analyse as many samples in the course of a working day as can his or her counterpart using the Scholander micrometer apparatus.

Physical Methods

Physical methods of quantitative gas analysis are usually based on one or other of the following systems: mass spectrometry, infra-red spectrometry, paramagnetometry or thermal conductivity. These systems will be considered only with respect to the gases present in the expired air.

1. Mass spectrometry. This method is suitable for any gas, and has in its favour its rapidity of response to change in gas concentration, i.e. it can be used to follow the changes in gas concentration during a single exhalation. The disadvantages of this method are its very high initial cost and the lack of accuracy obtainable in apparatus available to date.

2. Infra-red spectrometry. Both nitrogen and carbon dioxide show characteristic absorption spectra in the infra-red wave lengths, and analysers are available for the quantitative detection of these gases by means of their spectra. In general, though, the same instrument cannot be used for the analysis of both gases. The time of response of these instruments is short, and, at least for carbon dioxide, a high degree of accuracy is obtainable with careful calibration of the analyser. The carbon dioxide analyser is commercially easily available and allegedly reliable, though

Fig. 32. The Beckman model D2 paramagnetic oxygen analyser.

the fast response instrument is expensive. Instruments of this type are in use in clinical and research units specialising in respiratory studies. Oxygen has no infra-red absorption spectrum, but it should, at least theoretically, be possible to build an oxygen analyser making use of an absorption band in the ultra-violet wave lengths, though no such instrument has yet been made.

3. Paramagnetometry. This method is suitable only for the analysis of oxygen. There are several models of paramagnetic oxygen analysers commercially available, and one of these is claimed to be capable of following rapid changes in oxygen concentration, though its response rate is not sufficiently rapid to enable it to follow changes in oxygen concentration during a single exhalation.

4. Thermal conductivity. This method can be used for the analysis of oxygen and carbon dioxide. The same instrument can be used to measure both gases, though it is not possible to follow instantaneous changes in gas composition.

We have had experience with two types of instruments which analyse gas mixtures on the basis of their physical properties, viz, a Beckman paramagnetic analyser and the Pulmo-analysor which is a thermal conductivity analyser.

<u>The Beckman Paramagnetic Oxygen Analyser</u>

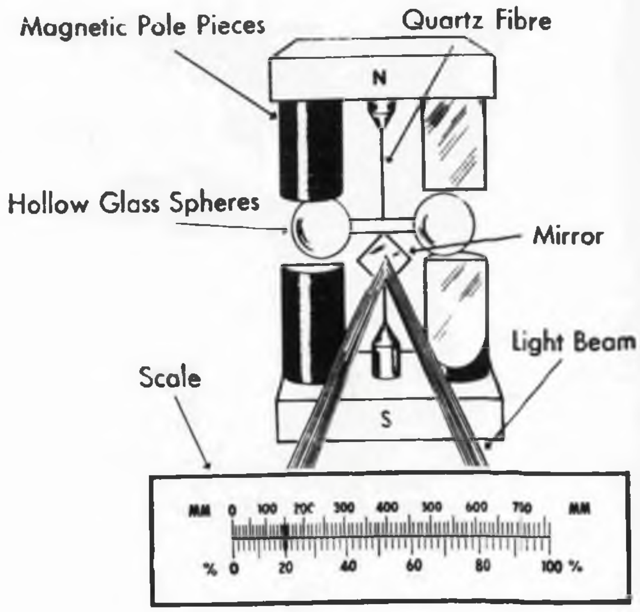
Trials of a portable and relatively inexpensive (about £70) paramagnetic oxygen analyser have been made in this laboratory. The instrument was the Beckman model D 2 oxygen analyser* (see Fig.32). The scale on the instrument is directly graduated in

*Manufactured by Beckman Instruments Ltd., Glenrothes, Fife. Scotland.

percentage and partial pressure of oxygen. Two ranges of scales are available 0-100% oxygen and 0-25% oxygen. The latter scale, which was on the analyser we tested, is graduated in 0.5% divisions and can be read to within 0.1% oxygen.

By means of a hand operated aspirator bulb a sample of the gas mixture to be analysed is drawn through a silica gel drying tube into the analysis cell of the instrument. When a button on top of the analyser is depressed the oxygen concentration can be read directly from the scale illuminated in the manner of a spot galvanometer. The analyser was calibrated against a Haldane apparatus in the following way. A rubber bladder was filled with expired air. After pummelling the bladder to ensure thorough mixing of the contents some of the air was transferred to a glass sample tube and then analysed in duplicate by Haldane's method. The bladder was then connected to the inlet connection of the Beckman analyser and again duplicate analyses were made. Samples of expired air were used ranging from alveolar air to air from the anatomical respiratory "dead space" after a period of hyperventilation. Within the limitations of "readability" of the scale the analyser was found to be completely accurate over this entire range (roughly 14%-20% oxygen) i.e. the differences between the analyses on the Haldane apparatus and the analyser never exceeded 0.05% oxygen.

The essential features of the instrument are shown



D2 Oxygen Analyser Schematic View

Fig.33.

diagrammatically in Fig.33. A hollow glass "dumbell" with magnetic susceptibility is mounted horizontally on a taut vertical quartz fibre. This dumbell can rotate between two permanent magnetic poles, twisting the quartz fibre as it does so. Also mounted on the quartz fibre is a small mirror which reflects a beam of light from a small electric (flashlight) bulb onto the scale of the instrument. The electric bulb is illuminated only when the button on top of the analyser is pressed. When there is no oxygen present in the analysis cell the magnetic forces of the dumbell and the torque of the quartz fibre are so balanced that the beam of light is focused on the left hand (zero) end of the scale. When oxygen is present in the cell its paramagnetic properties (i.e. oxygen is attracted into a magnetic field) cause a disturbance in the net magnetic forces in the cell, resulting in a new equilibrium position of the dumbell. In reaching its new equilibrium position the degree of rotation of the dumbell (and consequently alteration in the scale reading of the beam of light) is proportional to the change in magnetic force acting upon it. The change in magnetic force is a function of the concentration of oxygen in the analysis cell.

The instrument is battery powered, but due to its very low power requirements this is no drawback, indeed, combined with its portability (it only weighs four pounds) the use of batteries may be a distinct advantage in some situations. The analyser appeared to be quite robust and the suspension of the dumbell

Fig. 34. The pulmo analyser, type 44A2.

is much improved from this point of view compared with some of the more expensive analysers manufactured by the same company. Apart from the inherent lack of sensitivity of the analyser (i.e. the oxygen can only be measured to the first decimal place of percentage concentration) the major disadvantage lay in the large volume of gas required to flush-out the analysis cell before successive readings of the oxygen concentration of a sample of expired air became constant. The maker's instructions suggested that three or four "squeezes" of the aspirator bulb were sufficient, but we found that about twenty five "squeezes" were necessary. This is a considerable disadvantage as it frequently represents a larger volume of sample than is collected by even the modified Max-Planck respirometer during a period of sampling lasting ten or fifteen minutes. This matter has been raised with the manufacturers who, it is understood, are taking steps to rectify it. Once this has been done this Beckman oxygen analyser will be a useful tool in surveys of the type described in this thesis. In the calculation of metabolic rate there is only a small possible error due to the insensitivity of the analyser.

The Pulmo-Analysor

This instrument is one of a series manufactured by a Dutch company, Messrs. Godart-Mijnhardt Ltd., of Utrecht (Visser 1957). The model used in this laboratory (Fig.34) is known as type 44A2. It can analyse all concentrations of oxygen, carbon dioxide and helium, though up to the present date we have used it only for the analysis of oxygen and carbon dioxide in expired air. The procedure is fairly simple and a complete analysis, in duplicate, of both oxygen and carbon dioxide can be performed in less than four minutes.

The essential feature of the Pulmo-analysor consists of four electrically heated filaments of platinum wire connected in the form of a wheatstone bridge circuit. The bridge circuit is "balanced" when the gas mixtures surrounding the filaments on each side of the bridge have the same thermal conductivity. During an analysis the unknown gas mixture is drawn over one side of the bridge while a reference gas is drawn over the other side. If the thermal conductivities of these two gases are dissimilar the balance of the bridge circuit will be disturbed due to the differential cooling powers of the two gases causing unequal changes in the electrical resistance of the platinum filaments. The extent of the "imbalance" of the bridge is a function of the difference in thermal conductivity. The degree of imbalance is registered on the bridge circuit galvanometer. This galvanometer is graduated in one hundred divisions, and the concentration of the gas under test in the unknown mixture is found from a calibration curve showing the relationship between galvanometer reading and gas concentration. When analysing for oxygen in the unknown mixture carbon dioxide-free atmospheric air is used as the reference gas; when analysing for carbon dioxide, a carbon dioxide-free sample of the unknown gas is used for the reference gas. This system of comparison of thermal conductivities is only justified if the analyser is calibrated with gas mixtures of the same type as those encountered in actual analysis.

Calibration and Accuracy

The manufacturers of the Pulmo-Analysor claim that a carefully calibrated and correctly used instrument is as accurate as the Haldane apparatus. A calibration graph and certificate is supplied with the Pulmo-Analysor but these only refer to concentrations of oxygen above that occuring in atmospheric air; the apparatus is primarily designed for use in closed circuit oxygen systems, although it is said to be equally suitable for the analysis of oxygen at concentrations below 20.93%. As a general rule it is inadvisable to accept uncritically manufacturers' calibrations, and in this particular case it was essential to calibrate the Pulmo-Analysor over the range of gas concentrations occuring in expired air of human beings inspiring atmospheric air.

The calibration was carried out in the same way as that described above for the Beckman paramagnetic oxygen analyser, i.e. expired air from a rubber bladder was analysed in duplicate on both the Haldane apparatus and on the Pulmo-Analysor. Our initial calibration was very disappointing. This we felt was partly due to the absence of an intelligible set of instructions for the use of the instrument. The only instructions which were originally available in English had been translated from a French translation of the original Dutch version. Numerous errors had been introduced in these translations, to such an extent that the

English version was frequently completely "Gibberish". Eventually a more satisfactory English form was obtained, and from these it was apparent that the Pulmo-Analysor was temperature sensitive. In our original calibration we had made no attempt to control, or to compensate for changes in ambient temperature, and in our laboratory, which has an extensive glass roof, the changes in temperature throughout the day can be both large and rapid.

The next series of calibrations were made under conditions in which attempts were made to control temperature. Initially electric heaters and draught screens were used. Next the analyser was enclosed in a "perspex" cabinet which was heated by a hot air circulating system controlled by a "Simmerstat" energy regulator. After this a heat exchanger was arranged so that the gas entering the analyser was brought to constant temperature. The heat exchanger consisted of copper tubing immersed in a constant temperature water bath. The sample of air being analysed was drawn through the copper tubing before entering the Pulmo-Analysor. Finally the actual analysis "Cell" was itself immersed in a bath of water maintained in constant temperature. It became obvious that none of these solutions would be wholly satisfactory unless we were prepared to spend a large amount of time and money in the construction of a sophisticated control system, and were prepared to accept a marked increase in the "dead space" of the analyser. This latter point is of importance in that it would necessitate an increased volume of sample of gas being available for analysis, which may not always be possible to obtain and would also increase the time required to perform each analysis. These attempts had revealed two other important points. Firstly, that the Pulmo-Analysor was considerably more accurate when analysing carbon dioxide than oxygen, and secondly, that when analysing for oxygen it was essential to equate the pressure at which the atmospheric reference gas was supplied, with that of the unknown gas mixture.

The test gas mixture is supplied to the Pulmo-Analysor from a rubber bladder and it was found necessary to use a second bladder to supply the atmospheric reference gas. This bladder which is of similar physical properties to that containing the sample of unknown expired air, is inflated with atmospheric air by an aspirator bulb until it contains a similar volume of gas (and hence is at a similar pressure) to that in the bladder of test gas.

In view of the comparative failure of our attempts to control temperature it was decided to try to compensate for it when constructing the calibration graphs of the Pulmo-Analysor. The manufacturers' instructions state "_ _ one has to understand that the sensitivity of the Pulmo-Analysor for oxygen is increasing with 1% per grade, whilst the sensitivity for carbon dioxide 0.5% per grade decreases", (sic.). Examples are then given which show that if a concentration of oxygen of 10.0% gives rise to a full scale deflection of the pointer of the galvanometer at a temperature of 20°C, a similar deflection would be obtained from

10.1% oxygen at 19°C and from 9.9% oxygen at 21°C. In the case of carbon dioxide, if a concentration of 2.00% carbon dioxide gives rise to a full scale deflection on the galvanometer at 20°C, 1.99% carbon dioxide at 19°C, and 2.01% carbon dioxide at 21°C, will produce similar deflections on the galvanometer scale. These quoted values for the temperature related changes in sensitivity, are apparently only approximate (Visser, 1957) and should only be applied to analyses made within 5°C of the temperature at which the Pulmo-Analysor was calibrated. The changes in sensitivity can be summarised in the form of two generalised equations.

For oxygen:

$$O_{t.an} = O_{t.cal} - (t.an - t.cal)\ 0.01 \times O_{t.cal} \quad \ldots\ldots\ldots\ldots (1)$$

and, for carbon dioxide:

$$C_{t.an} = C_{t.cal} + (t.an - t.cal)\ 0.005 \times C_{t.cal} \quad \ldots\ldots\ldots\ldots (2)$$

- O : percentage oxygen concentration.
- C : percentage carbon dioxide concentration.
- t.an : temperature (°C) at which analysis is made.
- t.cal : temperature (°C) at which calibration was made.

To construct the calibration graphs (one each for oxygen and carbon dioxide) galvanometer deflections were plotted against gas concentration. The lines representing the functional relationships of the points of each graph were then drawn.

Unfortunately the plotted points did not all fall exactly on the line of the functional relationship. The departure of these points from the line is a measure of the accuracy (or, more strictly, the inaccuracy) of the Pulmo-Analyser. In the case of carbon dioxide it was found that all the plotted points lay within ± 0.05% concentration from the calibration line. The overall mean departure of the points was ± 0.03% carbon dioxide; the standard deviation of this mean was 0.02% carbon dioxide. There was no apparent relationship between the degree of inaccuracy and the carbon dioxide concentration. Over a range of carbon dioxide concentrations from 2.0% to 5.5% the Pulmo-Analysor was accurate to within ± 0.05% concentration. When analysing for oxygen, however, the instrument was not so accurate. The overall mean departure of the plotted points from the oxygen calibration line was ± 0.13% oxygen, the standard deviation being 0.11%; as in the case of carbon dioxide there appeared to be no relationship between the degree of accuracy of the Pulmo-Analysor and the concentration of gas being analysed. Over the calibration range of from 13.5% to 19.5% oxygen the accuracy of the analyser was better than ± 0.24% concentration in two thirds of all the individual analyses.

This represents an undesirably large possible error and in no way supports the manufacturer's claims for the accuracy of the instrument. Over a period of about one year the calibration was repeated on several occasions, each time with similar results. The accuracy when analysing carbon dioxide continued to be quite good and the slope of the calibration line remained constant. In the case of oxygen the accuracy fluctuated a little, with the mean departure of the individual points from the line varying from ± 0.08% to ± 0.16% concentration of oxygen. When their standard deviations are added to these mean values the accuracy (in two-thirds of individual analysis) varied from not worse than ± 0.14% to not worse than ± 0.30% oxygen. The slope of the calibration line for oxygen tended to "wander" somehwat in the subsequent calibrations. More recently two further calibrations have been made and the accuracy of the analysis of oxygen appears to have deteriorated, being now in the order of up to ± 0.50% concentration of oxygen in two-thirds of individual analyses.

This obviously is completely unsatisfactory, the more so when the Pulmo-Analysor, which cost over £400, is compared with the Beckman paramagnetic analyser which costs only £70. We are at present trying to persuade the manufacturers either to replace our instrument with one which is more reliable or to refund the cost of the analyser.

7. THE MEASUREMENT OF TOTAL DIALY ENERGY EXPENDITURE

It is not normally practicable to employ the technique of indirect calorimetry to measure the expenditure of energy of human beings throughout the entire 24 hours of the day. Such a procedure would call for more co-operation than the subject usually is prepared to give and would undoubtedly cause digressions from the normal pattern of daily activities. Furthermore, it would impose a considerable strain on the resources of both the experimenter and his laboratory, thus reducing the number of subjects that could be dealt with. In our experiments the estimates of total energy expenditure throughout each day over a period of seven days were made using a combination of actual measurement of energy expenditure and a record of the time spent on each form of activity. The separate activities of each subject can be ascribed a "calorie-cost per minute", from the measurements made with the Max-Planck respirometer, and, knowing the number of minutes per day spent on each activity, the deriviation of the total daily expenditure of energy is made by the addition of a series of simple multiplications.

The record of the time spent of each activity is kept in a minute-by-minute "diary ". The use of this method of recording was first described by Garry et al. (1955), and the accuracy of this method of estimating energy expenditure has been evaluated by Rankin, Koniski, Insull & Marcinek (1956). These authors compared estimates of the expenditure energy obtained simultaneously by (a) continuous indirect calorimetry (using the same apparatus as

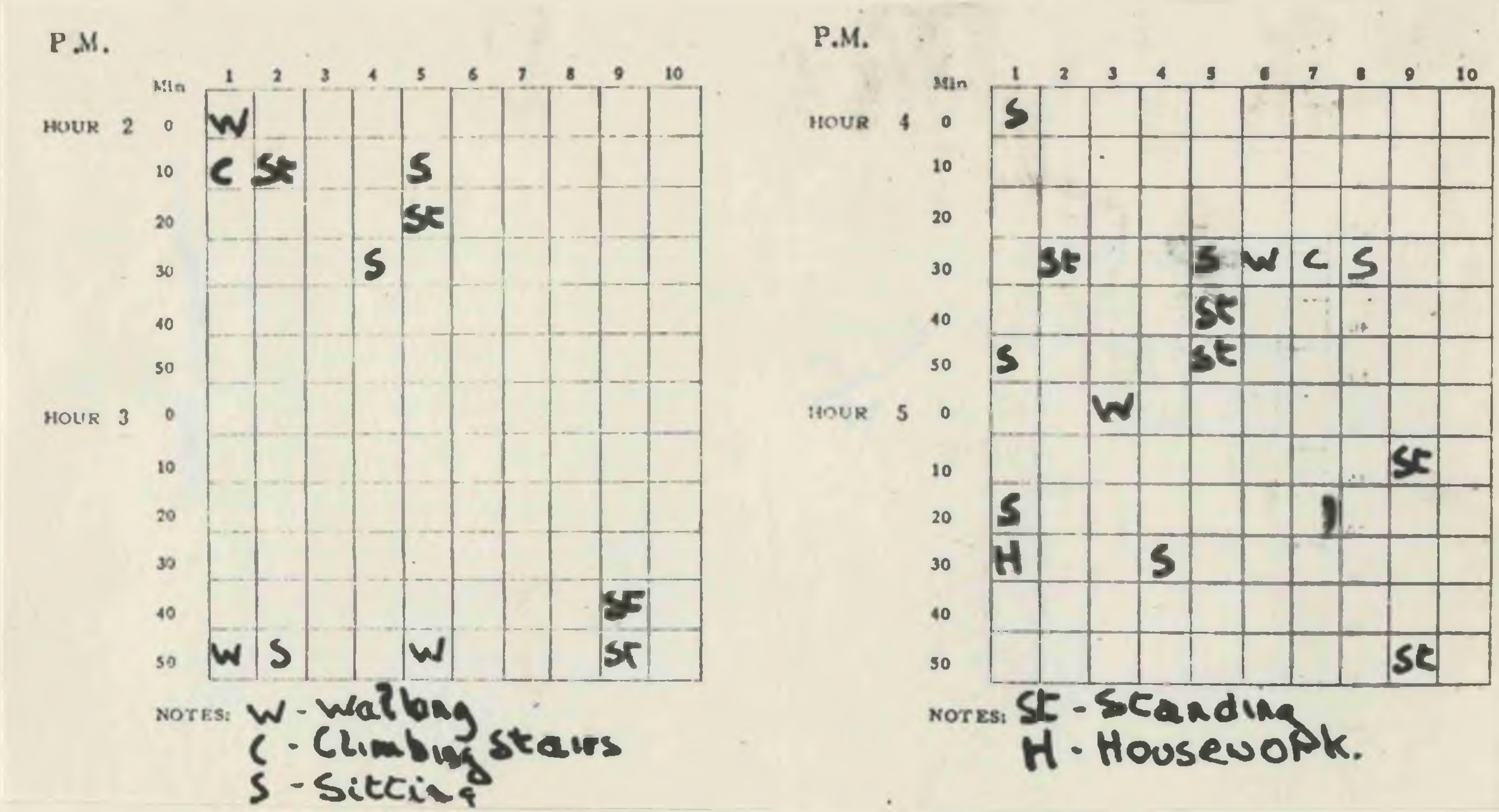


Fig. 35. Part of completed "diary."

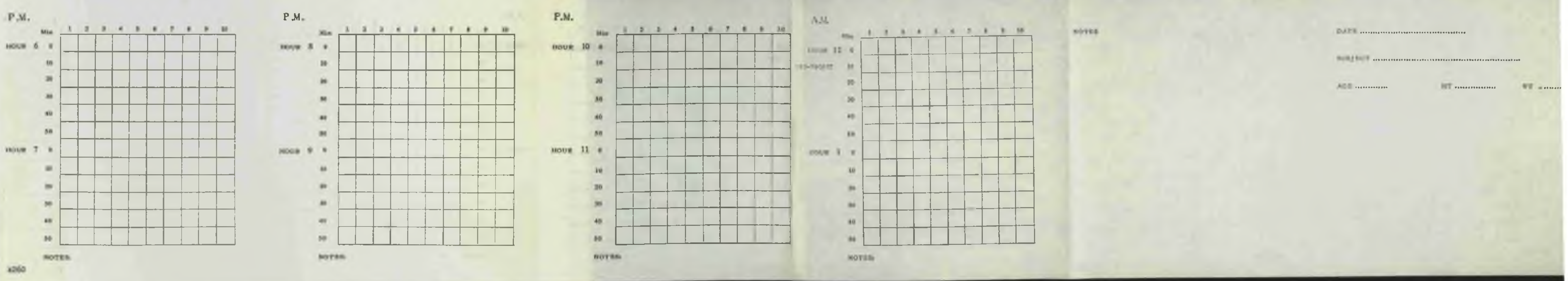


Fig. 36. Unused "diary".

M.

Min.	1	2	3	4	5	6	7	8	9	10
6 0										
10										
20										
30										
40										
50										
7 0										
10										
20										
30										
40										
50										

NOTES:

A.M.

Min.	1	2	3	4	5	6	7	8	9	10
HOUR 8 0										
10										
20										
30										
40										
50										
HOUR 9 0										
10										
20										
30										
40										
50										

NOTES:

A.M.

Min.	1	2	3	4	5	6	7	8	9	10
HOUR 10 0										
10										
20										
30										
40										
50										
HOUR 11 0										
10										
20										
30										
40										
50										

NOTES:

P.M.

Min.	1	2	3	4	5	6	7	8	9	10
Noon HOUR 12 0										
10										
20										
30										
40										
50										
HOUR 1 0										
10										
20										
30										
40										
50										

NOTES:

P.M.

Min.	1	2	3	4	5	6	7	8	9	10
HOUR 2 0										
10										
20										
30										
40										
50										
HOUR 3 0										
10										
20										
30										
40										
50										

NOTES:

P.M.

Min.	1	2	3	4	5	6	7
HOUR 4 0							
10							
20							
30							
40							
50							
HOUR 5 0							
10							
20							
30							
40							
50							

NOTES:

that described in this thesis), and (b) a combination of indirect calorimetry and time and motion study as described above. This method is described by Rankin et al. as the "factorial" or "time-motion, work element energy cost" technique.

The "diaries" used in our experiments consist of strips of paper, about twenty-six inches long by four and one half inches wide, folded concertina-wise. Five blocks, each composed of one hundred and twenty small squares, are printed on each side of this strip of paper. Each block occupies one "page" of the concertina, and represents two hours activity (one minute per square of the block). Space is provided at the foot of each page for notes, and one complete page is available for further notes on the back page of the diary. The main purpose of these blank spaces is for an indication of the meaning of the code letter used in compiling the diary e.g. "S": sitting "St.": standing "W": walking, etc. The front page of the diary is used to record the subject's name, height and weight and the date.

It has been found that the period 6 a.m. to 2 a.m. covers the requirements of the great majority of subjects. When dealing with subjects who habitually go to bed after midnight it is convenient to consider their "days" as lasting from 2 a.m. until 2 a.m., rather than from midnight until midnight. Part of a completed diary is shown in Fig.35, and an entire unused diary in Fig.36

The entries in the diaries were generally made by the subjects themselves, and these were carefully scrutinised by the experimenters, at least once, and frequently twice daily. In the cases of some of the young women it was found better that the compilation of the diaries was made by an observer during the subject's working hours. This was particularly so for the women working in the busier departments of the store. On one occasion it was necessary for the writer to spend a somewhat embarassing evening at a well-known Glasgow dance hall, watching one of the youngest of the young women and recording her every activity in her diary!

The number of the various categories of activity recorded in the diary are, of necessity, limited if the keeping of the diary is not to become too great a burden on the subject. For example, time spent in bed is simply recorded as "bed" with no attempt to assess separately that part of it spent sleeping; such items as washing, dressing, etc. are grouped together under the heading of "personal necessities". We do not normally expect the subjects to describe their time spent sitting as anything more than just "sitting", as opposed to "sitting reading" or "sitting sewing". Standing is usually subdivided into "standing" and "standing working" (or possibly simply "working" if all the work is of a similar nature). Walking is differentiated from "fast walking". To a large extent we encourage the subjects to devise their own classification of activities rather than attempting to impose a rigid system upon them.

One possible source of error in records of this type could lie in activities whose duration is less than one minute: the resolution of the recording system is insufficiently fine to "detect" such activities. For instance, a woman may be spending an evening sitting reading, and may leave her chair for a few seconds to switch on the light or to collect another book. If these actions do not last at least one minute on any one occasion the subject has no means of recording them. The error from this source is, however, unlikely to be of appreciable magnitude unless activities such as these are of frequent occurance.

The keeping of a simple diary of this type is usually a fairly straightforward matter for the subject: after the first day or two the making of entries in the diary becomes automatic, and, at least in the majority of cases we have every reason to believe that the diary represents a faithful record of time spent in the various activities.

8. DIETARY SURVEY

In these experiments the total food intake of the subjects was also measured over the period of seven days. The actual measurements were carried out with the assistance of trained and student dieticians from the Glasgow and West of Scotland College of Domestic Science.

The surveys were made by the "Individual Inventory" method (Widdowson 1936; Widdowson & McCance 1936). This involves the weighing and recording of each item of food eaten, <u>at the time of eating</u>. After each meal any uneaten portions of food (i.e. "plate wastage") are similarly noted. The weighing was normally done by the subjects themselves. The subjects were visited in their homes, at least once each day, by the dieticians who scrutinised the records, clarified any points of doubt and obtained the recipes of dishes such as soups, stews and puddings not listed in the food tables. The subject also weighed and recorded any food eaten away from home. As far as possible, without disturbing their normal pattern of eating, the subjects were encouraged to restrict any such additional items of food (e.g. confectionary) to standard, packaged forms, so that duplicate samples could be purchased and weighed by the dieticians. Participation in a dietery survey of this type imposes no great burden on subjects of reasonable intelligence; indeed, a large proportion of the subjects were very interested in their records of food consumption. All were co-operative and, as far as could be judged, all were conscientious in the accurate weighing and recording of the food they ate. We have every reason to believe that the records were of a high order of accuracy, and that, in general, they presented a true picture of the eating pattern of the subject. It is difficult to be dogmatic about this last point in that there is a possibility that some of the subjects may have altered their eating habits because of the survey. It was however continually emphasised to all subjects that it was of the utmost importance that they did not change their normal pattern of eating, either to simplify the recording or in an attempt to impress the dieticians with "sensible" or lavish feeding. While considerable reliance may be placed upon the accuracy of the records of the weights of the various items of food eaten by the subjects, it is not possible to be so confident about the food tables from which the caloric and nutrient intakes are computed. It is extremely difficult, if not impossible, to evaluate the accuracy of food tables with respect to the diet of any particular individual without actual chemical analysis. In the majority of cases it is impossible to carry out such analysis: the labour involved would be immense. At the best, food tables can only provide an average figure for the composition of each foodstuff. Even with the most careful recording of the various items eaten during the course of one week, there are frequently items which cannot be fitted with any certainty to the list of foods found in the tables. The tables take but little account of possible seasonal and regional variations in the composition of the foods. Further, because of the amount of work necessary for the production of a set of food tables, these are frequently out of date, particularly where processed or manufactured foodstuffs such as bread, cakes, etc., are concerned. The actual tables used for the calculation of caloric and nutrient intakes were those supplied the Ministry of Food (1951); certain amendments have been incorporated into these tables to allow for the changes that have taken place in the composition of wheat flour since the tables were published. These tables are based mainly on those of McCance & Widdowson (1946).

Apart from drawing attention to the potential inaccuracies inherent in the use of food tables, it is felt that this is not the place for a detailed discussion of these inaccuracies.

9. SELECTION OF SUBJECTS

The subjects were all volunteers, although the initial approaches to them, with a view to securing their co-operation, varied. In the case of young women the initial contact was through their place of work. The middle-aged women were contacted indirectly through their daughters, and the elderly women through their physicians.

With the approval of the management of the departmental store (Pettigrew & Stephens, Ltd.) in which all the young women were employed a copy of the notice given in appendix C-1 was shown to each employee in the selected age group (below 30 years).

Those women who expressed interest in the project were then individually interviewed and details were given of the exact nature of the investigation, and of what it involved from the subject's point of view, were given. Those young women who thought that their mothers might be willing to co-operate arranged a convenient time for a member of the research team to visit their homes. Eventually 12 mothers and their daughters agreed to take part in the survey. The range of ages of mothers was from 45 to 60 years. In all cases, except that of Mrs. Stevenson, there were no young children in the family. Socially all the subjects would probably be considered to belong to the upper working and lower middle classes. In the way of labour-saving devices all families except one had vacuum cleaners, three had washing machines (though only one of these had a power wringer) and in one case the mother

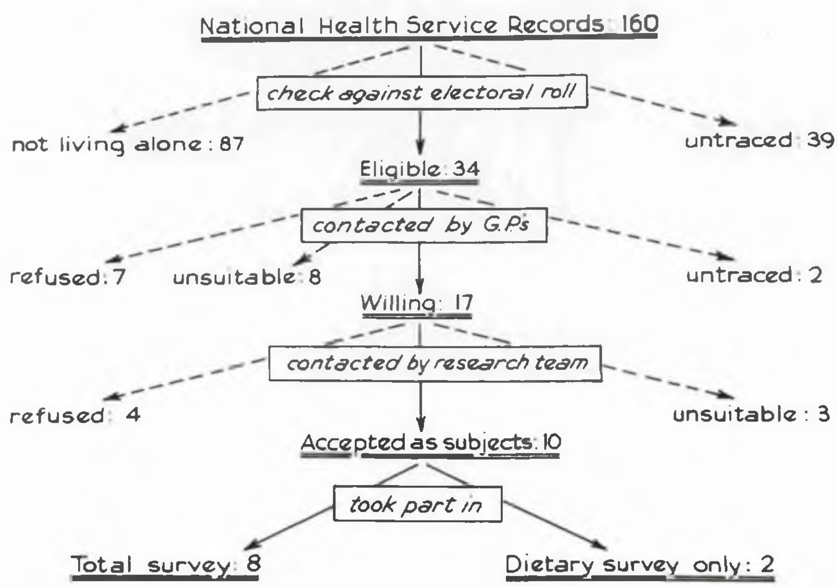


Fig. 37. Selection of elderly subjects.

had the assistance of a charwoman for a few hours per week.

The elderly subjects studied were a random sample of women in the age range 60-69 years, who were living alone, in the town of Paisley. Initially, a random sample of the names of women aged 60-69 years were taken from the records of the National Health Service Local Executive Council of Paisley. These names were then referred to the town's electoral register to allow selection of those women who appeared to be living alone. These procedures were made possible through the co-operation of the local government officials concerned. A letter was then sent to the local general medical practitioners whose patients included the women selected, suggesting that they should ask the elderly women to participate in the survey. A note was then given to each woman by her general practitioner. Copies of our letter to the practitioners and of the note to the women are given in appendix C-2 & 3.

At all stages of the selection care was taken to explain that the women were under no form of duress and that their participation in the survey was on a purely voluntary basis. 160 names were originally obtained from the National Health Service records; this number was eventually reduced to 10 subjects who took part in the survey, although measurements of energy expenditure could only be obtained from 8 of these women (the remaining two subjects completed only the food intake part of the investigation.). Figure 37 shows how the 160 original names were reduced to 10 subjects. Like the young women and their mothers, the elderly subject would all be considered to belong to the working and lower middle classes.

The individual and mean ages, heights and weights of the three groups of subjects are given in tables 4,a,b, & c. The standard deviations of these parameters are also shown in these tables.

TABLE 4a

YOUNG WOMEN

	Age : yrs.	Height : cm	Weight : kg
Jean Barrie	20	163	52.0
Margaret Christie	25	154	53.0
Elma Drummond	16	164	63.5
Margaret Duff	20	168	51.5
Muriel Duncan	26	168	56.5
Sheila Galston	17	169	55.5
Nada Hamilton	23	175	73.0
Evelyn Jack	18	159	53.5
Nan McQuarter	20	168	70.0
Neta Simpson	27	165	54.5
Rita Stevenson	17	152	46.0
Janette Whiteside	17	154	52.0
Mean	20.4	163	56.7
Standard Deviation	3.7	6.6	7.7

TABLE 4b

MIDDLE-AGED WOMEN

	Age: yrs.	Height : cm	Weight : kg
Mrs. Barrie	58	160	67.0
" Christie	52	159	65.0
" Drummond	61	167	65.5
" Duff	51	160	69.5
" Duncan	51	161	60.0
" Galston	46	161	58.5
" Hamilton	53	161	60.0
" Jack	45	160	65.5
" McQuarter	53	152	73.0
" Simpson	51	162	64.5
" Stevenson	50	151	73.5
" Whiteside	45	156	49.0
Mean	51.3	159	64.3
Standard Deviation	4.6	4.2	6.5

TABLE 4c

ELDERLY WOMEN

	Age : yrs.	Height : cm	Weight : kg
Mrs. Brown (1)	68	148.5	66.25
" Burt	65	151.0	71.5
" Frame	66	151.0	50.75
Miss Hampsey (2)	60	161.5	53.5
" Muir	64	161.5	70.75
" Muir	66	159.0	50.75
Mrs. Skinner (3)	66	159.0	75.25
" Smith	68	151.0	41.75
Miss Spiers (1)	64	151.0	66.75
" Wilson	63	161.5	60.25
Mean	65.0	155.3	60.4
Standard Deviation	2.3	5.2	10.1

(1) Only food intake measured

(2) Asthmatic

(3) Arthritic

(4) Heart Trouble

N.B. Miss A. Muir and Miss J. Muir were unrelated.

PART II

THE ENERGY EXPENDITURE BY WOMEN AT DIFFERENT AGES

PART II - THE ENERGY EXPENDITURE BY WOMEN AT DIFFERENT AGES

1. A REVIEW OF THE LITERATURE ON THE ENERGY REQUIREMENTS OF WOMEN

The report of the Second Committee on Caloric Requirements of the Food and Agriculture Organisation of the United Nations (1957), in the chapter entitled "Further Research", states bluntly:

"Ageing and Calorie Requirements.

Present knowledge of the influence of ageing on the quantity of food eaten and energy expenditure is deficient and further investigations are needed..." The only thoroughly satisfactory type of investigation of this problem is the combined survey of food intake and energy expenditure conducted on various age groups of the population involved. Surveys of food intake only may suffice for populations to whom food is abundantly available and whose members show no evidence of changes in body weight.

The technique of the combined survey of food intake and energy expenditure is now well documented in the scientific literature (e.g. Passmore, Thomson & Warnock 1952; Garry, Passmore, Warnock & Durnin, 1955; Edholm, Fletcher, Widdowson & McCance, 1955). The surveys all date from after the introduction of the Max-Planck respirometer. This instrument, or something comparable, (e.g. the integrating motor pneumotachograph (Wolff, 1958)) is a more or less essential piece of equipment for the measurement of energy expenditure under field conditions. These surveys have all been carried out on male subjects, mostly of the younger age groups. There is very little factual information available on the calorie requirements of normal, healthy women. A large proportion of the available information is in the form of data on food intake; this data has often been obtained by techniques whose validity is at least questionable. Even if these figures for food intake had always been obtained with the use of a satisfactory technique (i.e. by the individual inventory method) their suitability as a measure of energy requirement should not be accepted uncritically in that it is possible that energy intake may be less than, or exceed, energy expenditure. Provided that an individual's body weight is not abnormally high or low energy expenditure is a better measure of energy requirement than is energy intake. Ideally measurements should be made of both the intake and expenditure of energy, and, if these measurements agree we can say that figure represents the actual energy requirement.

Smedley & Milner (1910) measured the food intake of a group of women in an old peoples' home in Philadelphia. No details of the ages of the individual subjects are given although it is stated that their ages ranged from 65 years to 100 years. The food consumption was measured for the group only (not for individuals) on the basis of an inventory of the kitchen supplies before and after the survey, and an account of foods brought into the kitchen during the survey. The average daily food intake of the women was 1882 kilocalories per head. Knight, Pratt & Langworthy (1910) using the same technique as Smedley & Milner conducted two surveys of the food intake of women in Baltimore. In the first, they studied women living in the city almshouse. No details of the subjects are given except that "some were still working, although the majority were past middle life.". The average food intake of this group was 1924 kilocalories per head per day. In the second survey the women were the inhabitants of a "private asylum". The mean age of these women was 76 years and their mean daily energy intake was 2,206 kilocalories per head.

In 1914 Becker & Hämäläinen measured the energy expenditure of women performing various light industrial activities. From these measurements, and on the assumption that the women spent eight hours per day at work, these authors concluded that the daily energy expenditure of a woman sitting doing light unskilled work was 1,800 Kcal; the daily energy expenditure of a seated machinist, or of a bookbinder was 1900 to 2100 kcal, while a charwoman expended between 2,600 and 3.400 kilocalories per day.

Tigerstedt (1916) carried out a large scale survey of the food intake of families in rural Finland. The women of these families can be divided into two age groups: 18 young women, mean age 22 years (range 16 to 30), mean body weight 63 kg, working as maids, cooks and housekeepers whose mean daily food intake provided 2061 kilocalories per head, and 23 middle-aged women, mean age 45 years (range 30 to 50) mean body weight 66 kg, who were housewives or who did light work in the garden or tending livestock and whose mean daily food intake was 2057 kilocalories per head. Schutz (1917) published an account of the food intake of the members of a single family living in Konigsberg. At the time of this study the housewife was in her final month of pregnancy. She was 30 years old and weighed 71 kg: her mean daily energy intake was 2327 kcal. The family maid, aged 37 years and weighing 62 kg consumed 2412 kcal per day, and the housewife's mother who was 55 years old and whose weight was 66 kg had a daily energy intake of 1927 kilocalories.

Rosenheim (1919) and Greenwood, Hodson & Tebb (1919) used the Douglas bag technique to study the energy expenditure of women engaged in various industrial tasks in a munitions factory. Rosenheim studied only machine-tool operators, and from his measurements of metabolic rate, and assuming that the women spent eight hours per day at work, and had eight hours free time and eight hours sleep he concluded that their mean daily energy expenditure was 2,600 kcal per head. Greenwood *et al*. (1919) studied women engaged in a variety of tasks, and divided the subjects into four groups according to their level of energy expenditure at work. These writers assumed the non-working time and energy expenditure was similar for all subjects. The mean daily energy expenditure of the individuals in the four groups was 2810, 3120,3555 and 3805 kcal, on working days: the overall mean daily energy expenditure on working days was 3322 kilocalories per head. When the energy expenditure was computed for a full week (i.e. including the non-working week-end) this figure was reduced to 3039 kcal per head per day.

Cathcart & Murray (1936) provided figures for the food intake of students of domestic science in Glasgow. The mean age of this group of women was 21 years, and the mean weight was 56 kg; the average daily intake of food provided 2,035 kcal per head. The authors expressed surprise at what they considered to be a low energy intake, but point out that the body weight of the subjects was not unduly low. The authors also state that as the data for the food intake was collected "by schedule.... the results cannot lay claim to absolute accuracy.".

In 1936 Widdowson & McCance used the individual inventory technique of dietary survey to study the food intake of women of different ages. They showed a decrease in the energy intake with increasing age, but were unable to demonstrate that this decrease was statistically significant. (This in part at least may be due to the uneven age distribution of the subjects). These authors obtained the following figures for the mean daily intakes of women of three age groups:

Age 19 - 29 years : 2293 kcal per head

Age 30 - 48 years : 2125 kcal per head

Age 50 - 62 years : 1937 kcal per head.

Orr & Leitch (1937) reviewed the technique of computing energy requirements on the basis of "(24 hours at B.M.R. + 10% for specific dynamic action) + (8 hours net metabolic cost of work) + (8 hours net cost of recreation)". Because of its artificial and arbitary nature, this technique has largely fallen into disrepute, especially so with the introduction of time studies of activities and the increased ease of measurement of metabolic rate. Orr and Leitch could find little information dealing with women, but they decided that the energy requirement of a housewife weighing 54.5 kg would be 2,100 kcal per day; similar values were suggested for a typist and for a woman engaged in bookbinding.

Shortly after the end of the war Droese, Kofranyi, Kraut & Wildemann (1949) published the results of a study of the energy expenditure of three German housewives. The metabolic cost of the various activities of the subjects was measured using the Douglas bag or Max-Planck respirometer, and records were kept of the time spent by the women at their different activities. The results of Droese et al are summarised below:

Subject No.1: Age 44 years, weight 65 kg, 3 children in family - mean daily energy expenditure 2987 kcal.

Subject No.2: Age 43 years, weight 84 kg. 4 children - 3070 kcal per day.

Subject No.3: Age 55 years, weight 80 kg, 1 child - 3088 kcal per day.

As can be seen the body weights of two of these women are very high: this must account for at least part of their high energy expenditure.

Recently Thomson (1958, 1959a, 1959b) has reported on the food intake of pregnant women but these obviously constitute an especial class outwith the scope of this thesis.

2. INTRODUCTION TO EXPERIMENTAL STUDIES

In order to obtain some information on the energy requirements of women of different ages in this country we undertook a series of experiments on women of three separate age groups. The three groups of women consisted of:

a. 12 young women, mean age 20 years.

b. 12 middle-aged women, mean age 51 years (these were the mothers of the young women).

c. 10 elderly women (Old Age Pensioners) mean age 65 years.

In these experiments the expenditure of energy of these women was measured and their food intake studied by the individual inventory dietary survey technique. Each individual was studied for a period of seven days. (Although the latter group of subjects was made up of ten women we were only able to study the energy expenditure of eight of them, the remaining two women only took part in the food intake side of the investigation).

The determination of the expenditure of energy was made by a combination of indirect calorimetry and a detailed time-study of the various separate activities of the subjects. The apparatus and techniques used in these determinations are described in detail in the first part of this thesis. The results of these investigations are divided into three sections: i. a comparison of the results found in the three groups of subjects: ii. a statistical assessment of the accuracy of the techniques employed, in particular, an evaluation of the differences between the measured expenditure and the intake of energy of the subjects: iii. an inquiry into the existence, extent and possible causes of an age-related decrease in the gross daily energy metabolism of the women.

TABLE 5a - YOUNG WOMEN

Time Spent in Week:- Minutes

	Bed	Sit	Stand	Sitting Work	Standing Work	Walk	Personal Necessities	Shop	Other Activities	
Jean Barrie	3696	2898	295	-	2168	7o5	318	-	-	
Margt. Christie	3845	2208	771	480	2271	185	320	-	-	
Elma Drummond	3646	1927	518	-	2396	1272	225	-	96	88=Housework 8=Running
Margt. Duff	3705	2410	775	-	2475	368	84	36	227	165=Housework 62=Polishing
Muriel Duncan	3646	2369	758	-	2382	334	361	110	120	Badminton
Sheila Galston	3806	2732	440	-	2402	496	171	17	16	Dusting
Nada Hamilton	3744	2374	1655	1799	-	220	245	43	-	
Evelyn Jack	4350	2595	440	-	1976	3o5	160	130	124	97=Dancing 27=Housework
Nan McQuarter	3573	2252	1347	1640	177	623	354	37	77	Slow Walk
Meta Simpson	3593	2202	700	-	2596	679	113	-	195	Special Walk
Rita Stevenson	3362	2655	957	-	1446	1007	367	-	286	182=Dancing 104=Running
Janette Whiteside	3847	3103	529	-	1597	604	278	122	-	

TABLE 5b - MIDDLE AGED WOMEN

Time Spent in Week:- Minutes

	Bed	Sit	Stand	House	Walk	P/Nec	Shop	Other Activities	
Mrs. Barrie	2979	3239	2441	90	520	326	215	270	180 = Other Housework 90 = Laundry
" Christie	5140	2391	1792	100	322	160	175	-	
" Drummond	3627	2422	1911	1188	267	450	195	20	Heavy Housework
" Duff	3456	2935	2798	156	135	182	388	30	Heavy Housework
" Duncan	3512	3709	1850	515	272	186	36	-	
" Galston	3380	2794	2737	435	38	131	180	385	160 = Heavy Housework 225 = Laundry
" Hamilton	3347	2351	3241	525	280	72	106	138	128 = Exercises 10 = Swimming
" Jack	3797	2925	2341	710	89	218	-	-	
" McQuarter	3254	3107	2793	80	602	96	148	-	
" Simpson	3306	2737	2155	719	762	81	170	150	Laundry
" Stevenson	3024	3180	2538	740	141	161	145	151	63 = Heavy Housework 88 = Laundry
" Whiteside	3602	2792	2012	302	699	160	268	245	212 = Additional work 33 = Country Dancing

TABLE 5c - ELDERLY WOMEN

Time Spent in Week:- Minutes

	Bed	Sit	Stand	House Work	Walk	P/Nec	Shop	Other Activities	
Mrs. Burt	4670	3010	370	500	990	230	190	120	80 = Heavy Housework 40 = Dancing
" Frame	3702	3107	1772	741	348	191	209	10	10 = Coal
Miss Hampsay	3791	2863	940	1747	390	259	90	-	
" A.Muir	3930	3364	1686	240	620	150	90	-	
" J.Muir	3717	3322	1301	1058	248	347	87	-	
Mrs. Skinner	4822	3401	1208	129	216	153	31	120	60 = Exercises 60 = Heat Treatment
" Smith	3945	3293	1770	256	5700	246	-	-	
Miss Wilson	4030	3308	903	848	370	255	238	128	128 = Heavy Housework

ADULT DAUGHTERS.

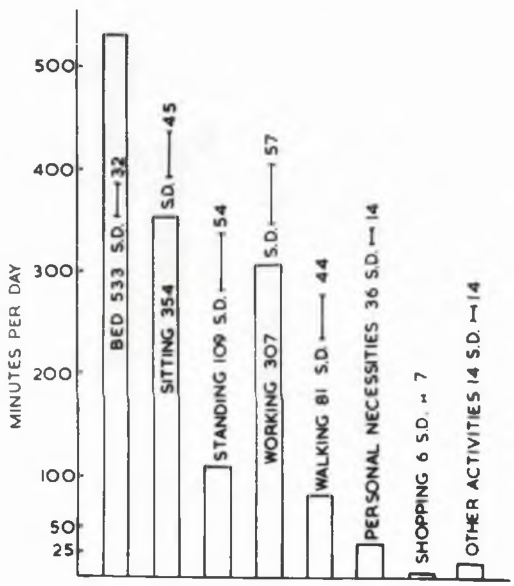


Fig. 38 a.

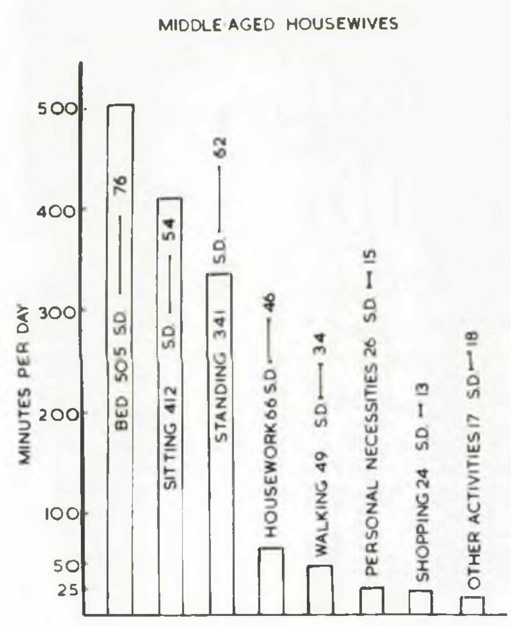

MIDDLE AGED HOUSEWIVES
MINUTES PER DAY
500
400
300
200
100
50
25
BED 505 S.D. 76
SITTING 412 S.D. 54
STANDING 341 S.D. 62
HOUSEWORK 66 S.D. 46
WALKING 49 S.D. 34
PERSONAL NECESSITIES 26 S.D. 15
SHOPPING 24 S.D. 13
OTHER ACTIVITIES 17 S.D. 18

Fig. 38 b.

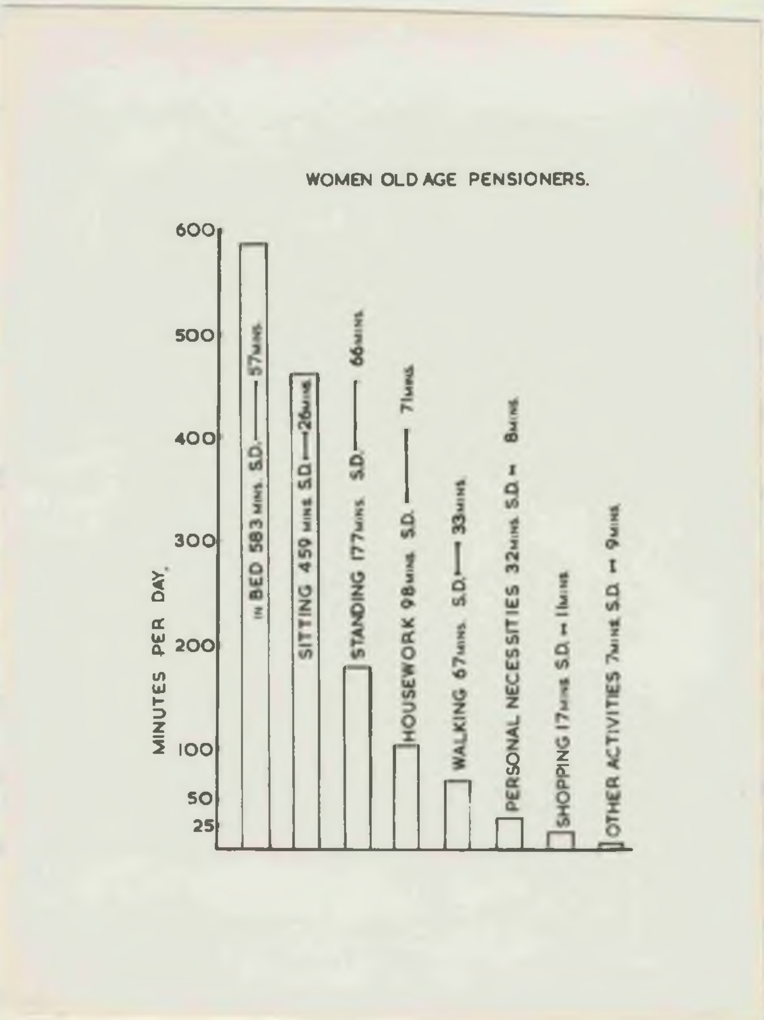

WOMEN OLD AGE PENSIONERS.
MINUTES PER DAY.
600
500
400
300
200
100
50
25
IN BED 583 MINS. S.D. —— 57MINS.
SITTING 459 MINS S.D. ——26MINS.
STANDING 177MINS. S.D. —— 66MINS.
HOUSEWORK 98MINS. S.D. —— 71MINS.
WALKING 67MINS. S.D. —— 33MINS.
PERSONAL NECESSITIES 32MINS. S.D. — 8MINS.
SHOPPING 17MINS S.D. — 11MINS.
OTHER ACTIVITIES 7MINS S.D. — 9MINS.

Fig. 38 c.

RESULTS AND DISCUSSION

3. COMPARISON OF THE GROUPS

Analysis of 'Diary Cards'

The number of minutes which each subject spent in her various activities in the seven days of the survey are shown in tables 5a,b and c. The mean daily values, and their standard deviations, for the three groups are shown in the forms of histograms in figs. 38a,b and c. On the average, each day the middle-aged housewives spent one half-hour longer at rest (i.e. in bed and sitting) than did the young women, and two hours less than did the elderly subjects. The direction of these differences is, of course, reversed when we consider the other, and more strenuous activities; the elderly women spent $6\frac{1}{2}$ hours per day in personal necessities, standing, walking, shopping and at housework, compared with $8\frac{1}{2}$ hours per day spent in these activities by the middle-aged women, and 9 hours per day by the young.

It can be seen that the activities listed as "bed", "sitting" and "standing" occupy a very large proportion of the total in the two older groups of subjects; in the young women "working" is also an activity of major importance. Thus, it is evident that the accuracy of our estimate of daily energy expenditure will be mainly dependent on the accuracy of our estimate of the metabolic cost (calories per minute) of the performance of these activities, and of the time spent in these activities.

TABLE 6a - YOUNG WOMEN

SUBJECT	SURFACE AREA sq. m.	B.M.R. kcal/sq.m/hr
Jean Barrie	1.55	35.3
Margaret Christie	1.50	35.2
Elma Drummond	1.69	36.9
Margaret Duff	1.57	35.3
Muriel Duncan	1.64	35.2
Sheila Galston	1.64	36.3
Nada Hamilton	1.88	35.2
Evelyn Jack	1.54	35.9
Nan McQuarter	1.80	35.3
Meta Simpson	1.59	35.2
Rita Stevenson	1.39	36.3
Janette Whiteside	1.48	36.3

TABLE 6b - MIDDLE AGED WOMEN

SUBJECT	SURFACE AREA Sq. m.	B.M.R. kcal/sq.m/hr.
Mrs. Barrie	1.70	33.0
" Christie	1.67	33.7
" Drummond	1.74	32.6
" Duff	1.73	33.8
" Duncan	1.63	33.8
" Galston	1.61	34.4
" Hamilton	1.63	33.5
" Jack	1.68	34.5
" McQuarter	1.70	33.5
" Simpson	1.69	33.8
" Stevenson	1.70	33.9
" Whiteside	1.46	34.5

TABLE 6c - ELDERLY WOMEN

SUBJECT	SURFACE AREA Sq. m.	B.M.R. kcal/sq.m/hr.
Mrs. Burt	1.67	32.2
" Frame	1.44	32.1
Miss Hampsey	1.56	32.7
" A.Muir	1.75	32.3
" J.Muir	1.50	32.1
Mrs. Skinner	1.78	32.1
" Smith	1.32	31.9
Miss Wilson	1.64	32.7

Estimate of Energy Expenditure

Bed. The mean expenditure of energy for the time spent in bed is assumed to be equal to the basal metabolic rate (B.M.R.) of the individual concerned. The rationale of the use of the basal metabolic rate for the energy expenditure while in bed is discussed by Passmore & Durnin (1955) and in the F.A.O. Publication on Calorie Requirements (1957). The individual values for the B.M.R.'s were calculated from the surface area (Tables 6a,b, and c) and age of each subject according to the standards of Fleish (1954). Surface area was evaluated from height and weight (see tables 4a,b and c) by means of the nomogram of Weir (1949) based on the formula of Du Bois & Du Bois (1916). The individual metabolic costs (calories per minute) of being in bed, and of all the other various activities, for all three groups of subjects are given in tables 7a,b and c.

Sitting and Standing. Direct measurements of the metabolic costs of these activities were made on nearly all subjects using the Max-Planck respirometer. Analysis of the samples of expired air was carried out mostly using the Haldane apparatus or accasionally the Pulmo-analyser, and the energy expenditure was calculated by the method of Weir (1949). These measurements were performed on two separate occasions on each subject. The subjects were encouraged to behave as "naturally" as possible during the measurements, i.e. to sit reading or sewing and to stand doing something (e.g. light household tasks) and not just to sit or stand perfectly still. The values for the energy expenditure while sitting and standing shown in table 7a,b and c are the means of the separate determinations on each individual. The separate values for pulmonary ventilation, oxygen extraction and energy expenditure while sitting and standing are given in tables 8 and 9a,b and c. These latter tables also show the group means for these measurements. The mean energy expenditure while sitting is practically identical in all three groups of subjects. The mean expenditure when standing is similar in the two older groups of subjects though it is a little lower in the case of the young women. The possible implications of these values is discussed later.

'Housework' (all groups) and 'working' (young women). Direct measurements of the energy expenditure were made in some cases, but where this was not practicable estimates were made, based on the energy cost of standing and adjusted to the build of the individual concerned, and

TABLE 7a - YOUNG WOMEN

ENERGY EXPENDITURE:- kcal/min.

	Bed	Sit	Stand	Sit Work	Stand Work	Walk	P/Nec	Shop	Other Activities
Jean Barrie	0.91	1.1	1.3	-	2.0	3.0	2.6	-	-
Margt.Christie	0.88	1.1	1.5	1.7	2.2	3.6	1.6	-	-
Elma Drummond	1.04	1.5	1.8	-	2.8	3.5	3.0	-	3.4
Margt. Duff	0.92	1.0	1.2	-	2.4	3.0	2.4	2.1	3.27
Muriel Duncan	0.96	1.2	1.4	-	2.8	3.4	1.8	2.4	4.0
Sheila Galston	0.99	1.3	1.5	-	3.0	4.0	3.0	2.8	3.5
Nada Hamilton	1.10	1.3	1.8	2.0	-	3.8	2.7	2.8	-
Evelyn Jack	0.92	1.0	1.2	-	1.8	3.1	2.4	2.2	3.52
Nan McQuarter	1.06	1.3	1.6	2.0	2.4	3.6	2.4	2.7	3.1
Meta Simpson *	0.80	0.8	0.9	-	2.7	4.0	1.8	-	2.5
Rita Stevenson	0.84	1.3	1.5	-	2.7	3.5	3.0	-	5.45
Janette Whiteside	0.90	0.9	1.2	-	3.0	2.2	2.2	2.1	-

* The figure for "bed" for Meta Simpson was adjusted to 0.80 kcal/min. to be in accordance with other measurements of metabolic rate. Her calculated B.M.R. is .93 kcal/min.

TABLE 7b – MIDDLE AGED WOMEN

ENERGY EXPENDITURE:- kcal/min.

	Bed	Sit	Stand	House	Walk	P/nec	Shop	Others
Mrs. Barrie	0.94	1.1	1.3	3.6	3.6	1.7	2.5	3.91
" Christie	0.94	1.2	1.4	2.8	3.5	1.8	2.5	–
" Drummond	0.95	1.2	2.1	2.8	3.0	2.1	2.0	5.0
" Duff	0.97	1.2	2.0	4.0	3.0	2.6	2.1	5.0
" Duncan	0.92	1.2	2.2	4.0	3.3	3.0	2.4	–
" Galston	0.92	1.2	1.4	3.3	3.3	2.8	2.5	4.3
" Hamilton	0.91	1.1	1.7	2.8	3.8	2.8	2.6	3.14
" Jack	0.97	1.3	1.5	3.0	3.6	2.0	–	–
" Mcquarter	0.95	1.1	1.4	4.0	3.2	2.8	2.3	–
" Simpson	0.95	1.1	2.0	3.5	2.9	2.6	2.0	4.0
" Stevenson	0.96	1.3	1.7	3.2	3.8	2.0	2.7	6.92
" Whiteside	0.84	1.2	1.9	3.5	3.3	2.8	2.0	3.6

TABLE 7c - ELDERLY WOMEN

ENERGY EXPENDITURE:- kcal/min.

	Bed	Sit	Stand	House	Walk	P/Nec	Shop	Others
Mrs. Burt	0.90	1.2	1.3	3.4	3.2	2.5	2.3	4.3
" Frame	0.78	1.0	1.9	2.6	2.9	3.6	2.4	5.0
Miss Hampsay	0.85	0.9	1.3	2.5	3.1	2.5	2.2	-
" A. Muir	0.94	1.6	2.4	3.4	3.2	4.6	2.8	-
" J. Muir	0.80	1.4	1.8	3.4	2.9	3.4	2.4	-
Mrs. Skinner	0.95	1.2	1.4	3.4	3.3	2.7	2.4	2.7
" Smith	0.71	1.0	1.2	3.2	2.5	2.3	-	-
Miss Wilson	0.89	1.5	1.7	3.2	3.3	3.2	2.5	4.1

TABLE 8a - YOUNG WOMEN

SITTING

SUBJECT	Pulmonary Ventilation l./min. S.T.P.	Oxygen Extraction $(O_i - O_e)$ %	Energy Expenditure kcal/min.
Jean Barrie	5.3 6.7	3.42 3.62	0.91 1.21
Margt. Christie	5.4 7.0	3.97 3.20	1.07 1.12
Elma Drummond	6.9 7.4	4.46 4.20	1.54 1.55
Margt. Duff	6.7 5.5	3.04 3.20	1.02 0.88
Muriel Duncan	8.2 6.5	3.45 3.18	1.41 1.03
Sheila Galston	8.6 7.0	3.00 3.60	1.29 1.26
Nada Hamilton	6.8 7.4	3.62 3.90	1.23 1.44
Evelyn Jack	5.6 6.4	3.22 3.17	0.90 1.01
Nan McQuarter	7.0 6.9	4.04 3.50	1.41 1.21
Mets Simpson	5.2 5.7	2.99 2.91	0.78 0.83
Rita Stevenson	5.9 5.9	4.41 4.68	1.30 1.38
Janette Whiteside	4.6 4.5	4.07 3.56	0.94 0.80
Mean	6.4	3.60	1.2

TABLE 8b - MIDDLE AGED WOMEN

SITTING

SUBJECT	Pulmonary Ventilation l./min. S.T.P.	Oxygen Extraction $(O_i - O_e)$ %	Energy Expenditure kcal/min.
Mrs. Barrie	6.1 6.0	3.49 3.65	1.06 1.10
" Christie	6.9 6.6	3.66 3.50	1.26 1.16
" Drummond	4.8 6.3	4.52 4.40	1.08 1.39
" Duff	7.3 6.9	3.35 3.43	1.22 1.18
" Duncan	6.9 6.7	3.66 3.41	1.26 1.14
" Galston	7.1 7.0	3.34 3.51	1.19 1.23
" Hamilton	4.9 6.4	3.63 4.10	0.89 1.31
" Jack	No Measurements Possible		
" McQuarter	6.7 6.5	3.03 3.90	1.02 1.27
" Simpson	7.1 5.9	3.25 3.23	1.15 0.95
" Stevenson	6.2 6.0	4.27 4.38	1.32 1.31
" Whiteside	7.0 5.3	3.54 4.45	1.24 1.18
Mean	6.4	3.71	1.2

TABLE 8c - ELDERLY WOMEN

SITTING

SUBJECT	Pulmonary Ventilation l./min. S.T.P.	Oxygen Extraction $(O_i - O_e)$ %	Energy Expenditure kcal/min.
Mrs. Burt	5.8 5.7	4.30 4.30	1.25 1.23
" Frame	4.9 4.8	4.09 3.76	1.00 0.90
" Hampsay	3.6 3.9	4.85 4.56	0.87 0.89
Miss A. Muir	7.3 13.0	3.30 3.07	1.20 2.00
" J. Muir	7.8 7.4	3.24 4.03	1.26 1.49
Mrs. Skinner	No Measurements Possible		
" Smith	5.3 5.8	3.86 3.30	1.02 0.96
Miss Wilson	7.5 7.4	3.95 3.99	1.48 1.48
Mean	6.4	3.90	1.2

TABLE 9a - YOUNG WOMEN

STANDING

SUBJECT	Pulmonary Ventilation l./min. S.T.P.	Oxygen Extraction $(O_i - O_e)$ %	Energy Expenditure kcal/min.
Jean Barrie	6.1 7.1	3.91 3.99	1.19 1.42
Margt. Christie	6.1 7.5	4.18 4.82	1.27 1.81
Elma Drummond	8.8 8.3	4.23 4.41	1.86 1.83
Margt. Duff	6.8 7.1	3.36 3.60	1.14 1.28
Muriel Duncan	8.9 7.2	3.06 4.00	1.36 1.44
Sheila Galston	8.5 9.0	3.90 3.10	1.66 1.40
Nada Hamilton	9.5 9.1	3.78 4.02	1.80 1.83
Evelyn Jack	7.1 5.5	4.21 3.35	1.49 0.92
Nan McQuarter	8.4 7.9	4.40 3.65	1.85 1.44
Meta Simpson	6.1 5.3	3.17 3.34	0.97 0.89
Rita Stevenson	6.3 6.7	4.73 4.64	1.49 1.55
Janette Whiteside	5.9 5.5	4.30 4.22	1.27 1.16
Mean	7.3	3.93	1.4

TABLE 9b - MIDDLE AGED WOMEN

STANDING

SUBJECT	Pulmonary Ventilation l./min. S.T.P	Oxygen Extraction $(O_i - O_e)$ %	Energy Expenditure kcal/min.
Mrs. Barrie	6.2 7.1	3.68 4.17	1.14 1.48
" Christie	7.2 6.9	4.21 3.78	1.52 1.30
" Drummond	9.7 9.2	4.73 4.30	2.29 1.98
" Duff	9.1 9.5	4.26 4.46	1.94 2.12
" Duncan	10.1 9.6	4.58 4.41	2.31 2.12
" Galston	6.2 8.4	3.90 3.85	1.21 1.62
" Hamilton	8.3 8.2	4.03 4.13	1.67 1.69
" Jack	No Measurements Possible		
" McQuarter	8.1 7.9	3.47 3.54	1.41 1.40
" Simpson	9.1 9.5	4.24 4.43	1.93 2.10
" Stevenson	No Measurements Possible		
" Whiteside	8.5 8.6	4.38 4.41	1.86 1.90
Mean	8.4	4.10	1.7

TABLE 9c - ELDERLY WOMEN

STANDING

SUBJECT	Pulmonary Ventilation l./min. S.T.P.	Oxygen Extraction (O_i-O_e) %	Energy Expenditure kcal/min.
Mrs. Burt	6.6 6.6	3.96 4.08	1.31 1.35
" Frame	8.6 8.9	4.34 4.28	1.87 1.90
Miss Hampsay	6.0 5.4	4.52 4.61	1.36 1.24
Miss A. Muir	13.6 16.8	3.61 2.83	2.45 2.38
Miss J. Muir	10.4 8.7	3.92 3.61	2.04 1.57
Mrs. Skinner	No Measurements Possible		
" Smith	7.3 6.2	3.86 3.38	1.41 1.05
Miss Wilson	7.4 7.2	4.66 4.69	1.72 1.69
Mean	8.6	4.04	1.7

TABLE 10

ENERGY EXPENDITURE: - kcal/mins.

Subject	Weight	Cooking	Wash Up	Set Table	Dust	Make Bed	Laundry
C	50kg	2.1	2.7	2.8	3.5	3.8	2.5
F	56kg	2.6	2.7	3.1	3.5	4.6	3.1
K	64kg	2.8	3.1	3.6	3.5	4.3	3.4
McK	70kg	2.6	3.2	3.4	3.5	4.2	3.2

the nature of the tasks involved. To facilitate the making of these estimates direct measurements were made of energy expended during the performance of various household activities by four experienced housewives of various body weights. These four housewives were not taking part in the general survey. The results of these measurements are given in table 10.

Walking. Again direct measurements were made in some cases, but for the majority of subjects the energy cost of walking was derived from the figures of Passmore & Durnin (1955). These values relate body weight and speed to energy expenditure while walking. The speed of walking was judged from the nature and appearance of the individual concerned, from her type of walking, and from her own estimate.

Personal Necessities. The amount of energy expended per minute while washing, dressing, etc. (grouped under the heading "personal activities") was estimated by the method used by Passmore, Thomson & Warnock (1952). i.e. by multiplying the personal energy. cost of standing by 1.9 for each individual.

Shopping. For each subject the metabolic cost of this activity was considered to be equivalent to the mean of her personal values for "walking" and "standing".

Other activities. The items grouped under this heading consisted of either heavier forms of housework (carrying coal, washing stone staircases, etc.) or of some recreational pastime which could not reasonably be classed as sitting or standing (e.g. dancing, playing badminton, etc.). The estimates of energy expenditure for "other activities" are based on the exact nature of the activity concerned and the physique of the individual; in some cases direct measurements of metabolic cost were made. The values shown in tables 7a,b and c for the energy cost of "other activities" are shown more from the point of view of uniformity of presentation rather than for their usefulness in any further calculations. (These figures were arrived at as follows. Suppose that there were four separate activities A, B, C and D which had been jointly classified as "other activities", and that the total time spent in each of these, during the course of the week, was a, b, c and d respectively. If the energy cost of these acitivities were separately estimated to be p, q, r and s kcal./min respectively, then the total weekly energy expenditure on other activities would be:

$$ap + bq + cr + ds \text{ kcal}$$

and the value listed in table 5 would be:

$$\frac{ap + bq + cr + ds}{a + b + c} \text{ kcal./minute.})$$

Tables 11a, b and c show, for each subject, I, the energy expended in each of her various activities for the seven days of the survey; II, the total weekly energy expenditure; and III, the mean daily energy expenditure. The overall mean daily expenditures of each group of subjects are also shown in these tables. The mean <u>daily</u> values and standard deviations for the energy expended at the various activities by the three groups of subjects are shown, in histogramatic form in

TABLE 11a - YOUNG WOMEN

ENERGY EXPENDITURE OVER SEVEN DAYS:- kcal

	Bed	Sit	Stand	Sit Work	Stand Work	Walk	P/Nec	Shop	Other	Total	Daily Mean
Jean Barrie	3363	3188	384	-	4336	2115	827	-	-	14213	2030
Margt.Christie	3384	2429	1157	816	4996	666	512	-	-	13960	1994
Elma Drummond	3792	2891	932	-	6709	4452	675	-	326	19777	2825
Margt. Duff	3408	2410	930	-	5940	1104	202	76	742	14812	2116
Muriel Duncan	3500	2843	1061	-	6670	1136	650	264	480	16604	2372
Sheila Galston	3768	3415	660	-	7206	1984	513	48	56	17650	2521
Nada Hamilton	4118	3086	2979	3598	-	836	662	120	-	15399	2200
Evelyn Jack	4002	2595	528	-	3557	946	384	286	436	12734	1819
Nan McQuarter	3787	2928	2155	3280	425	2242	850	100	239	16006	2287
Meta Simpson	2876	1828	630	-	7009	2716	203	-	488	15750	2250
Rita Stevenson	2824	3584	1436	-	3904	3525	1101	-	1559	17933	2562
Janette Whiteside	3462	2948	635	-	4791	1812	612	256	-	14516	2074

Overall Mean 2254

TABLE 11b - MIDDLE AGED WOMEN

ENERGY EXPENDITURE OVER SEVEN DAYS:- kcal

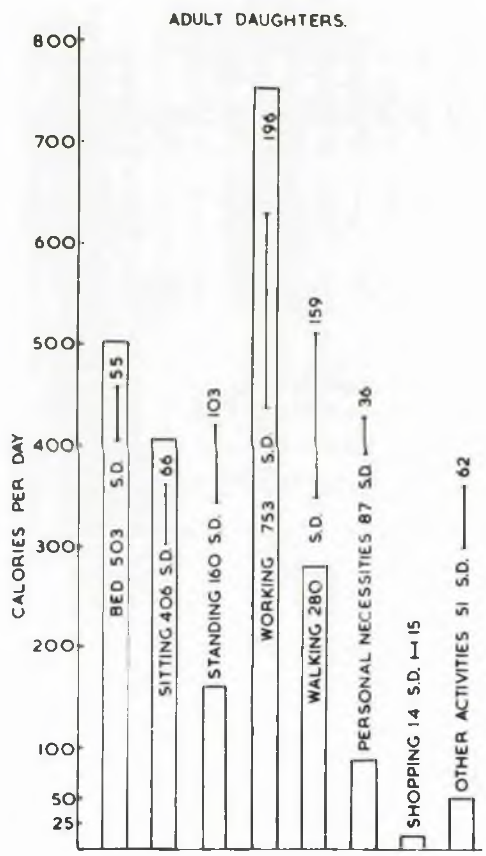
	Bed	Sit	Stand	House	Walk	P/Nec	Shop	Others	Total	Daily Mean
Mrs. Barrie	2800	3563	3173	324	1872	554	538	1056	13880	1983
" Christie	4832	2869	2509	280	1127	288	438	-	12343	1763
" Drummond	3446	2906	4013	2732	801	945	390	100	15333	2190
" Duff	3352	3522	5596	624	405	473	815	150	14937	2134
" Duncan	3231	4451	4070	2060	898	558	86	-	15354	2193
" Galston	3100	3353	3832	1436	125	367	450	1656	14329	2047
" Hamilton	3046	2586	5544	1470	1064	202	276	433	14621	2089
" Jack	3683	3803	3512	2130	320	436	-	-	13884	1983
" McQuarter	3091	3418	3910	320	1926	269	340	-	13274	1896
" Simpson	3141	3011	4310	2517	2210	211	340	600	16340	2334
" Stevenson	2903	4134	4315	2368	536	322	392	1045	16015	2288
" Whiteside	3026	3350	3823	1057	2307	448	536	885	15432	2205

Overall Mean 2092

TABLE 11c - ELDERLY WOMEN

ENERGY EXPENDITURE OVER SEVEN DAYS:- kcal

	Bed	Sit	Stand	House	Walk	P/Nec	Shop	Others	Total	Daily Mean
Mrs. Burt	4203	3612	481	1700	3168	575	437	510	14686	2098
" Frame	2888	3107	3367	1927	1008	688	502	50	13538	1934
Miss Hampsay	3222	2577	1222	4368	1209	648	198	–	13444	1921
" A. Muir	3694	5382	4046	816	1984	690	252	–	16865	2409
" J. Muir	2974	4651	2342	3597	719	1180	209	–	15672	2239
Mrs. Skinner	4581	4081	1691	439	713	413	74	324	12316	1759
" Smith	2801	3293	2124	819	1425	566	–	–	11028	1575
Miss Wilson	3587	4962	1535	2714	1221	816	595	525	15955	2279
							Overall Mean		14188	2027



ADULT DAUGHTERS.
CALORIES PER DAY
800
700
600
500
400
300
200
100
50
25
BED 503 S.D. 55
SITTING 406 S.D. 66
STANDING 160 S.D. 103
WORKING 753 S.D. 196
WALKING 280 S.D. 159
PERSONAL NECESSITIES 87 S.D. 36
SHOPPING 14 S.D. 15
OTHER ACTIVITIES 51 S.D. 62

Fig. 39 a.

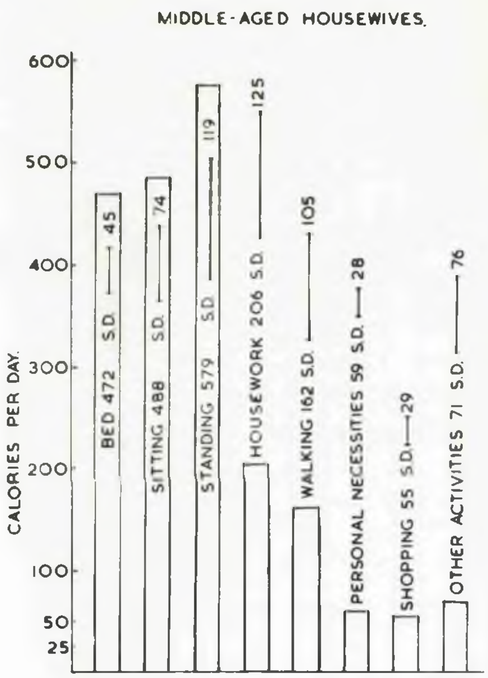

MIDDLE-AGED HOUSEWIVES.
CALORIES PER DAY.
600
500
400
300
200
100
50
25
BED 472 S.D. 45
SITTING 488 S.D. 74
STANDING 579 S.D. 119
HOUSEWORK 206 S.D. 125
WALKING 162 S.D. 105
PERSONAL NECESSITIES 59 S.D. 28
SHOPPING 55 S.D. 29
OTHER ACTIVITIES 71 S.D. 76

Fig. 39 b.

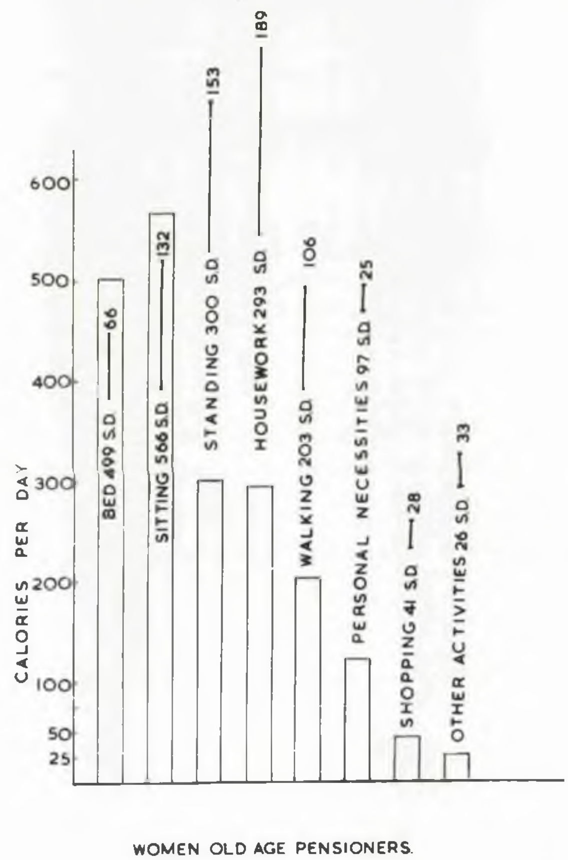

CALORIES PER DAY
600
500
400
300
200
100
50
25
BED 499 S.D. 66
SITTING 566 S.D. 132
STANDING 300 S.D. 153
HOUSEWORK 293 S.D. 189
WALKING 203 S.D. 106
PERSONAL NECESSITIES 97 S.D. 25
SHOPPING 41 S.D. 28
OTHER ACTIVITIES 26 S.D. 33
WOMEN OLD AGE PENSIONERS.

Fig. 39 c.

TABLE 12a - YOUNG WOMEN

DAILY ENERGY EXPENDITURE:- kcal

	Snn.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Mean	Stan. Dev.
Jean Barrie	1791	2118	1984	2160	1961	2076	2122	2030	119
Margt. Christie	1645	2056	2115	2057	2040	2143	1909	1995	159
Elma Drummond	2593	2796	2916	2964	2909	2879	2725	2826	121
Margt. Duff	1602	2229	2294	2256	2250	2222	1959	2116	234
Muriel Duncan	1704	2788	2525	2391	2492	2521	2183	2372	320
Sheila Galston	1904	2769	2713	2615	2771	2578	2305	2522	292
Nada Hamilton	1850	2279	2350	2244	2234	2237	2207	2200	149
Evelyn Jack	1739	1894	1867	1830	1918	1383	2102	1819	205
Nan McQuarter	1974	2335	2395	2461	2267	2392	2181	2286	153
Meta Simpson	1620	2632	2458	2263	2272	2408	2096	2250	301
Rita Stevenson	1756	2976	2638	2917	2830	2289	2532	2562	396
Janette Whiteside	1691	2031	2049	2054	2079	2398	2219	2074	198

Overall Mean 2254 264

TABLE 12b - MIDDLE AGED WOMEN

DAILY ENERGY EXPENDITURE:- kcal

	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Mean	Stan. Dev.
Mrs. Barrie	1957	2153	1899	2024	2108	1963	1896	1983	89
" Christie	1354	1433	1818	2249	1807	1893	1792	1763	276
" Drummond	1882	2235	2326	2190	2282	2197	2224	2191	134
" Duff	1865	2295	2247	2190	2245	2205	1892	2134	165
" Duncan	2234	2176	2374	1988	2442	2089	2052	2194	156
" Galston	1781	2455	1941	2082	2212	1918	1940	2047	209
" Hamilton	1889	2076	2193	2168	1939	2172	2184	2089	117
" Jack	2017	2011	2012	1805	1821	1993	2226	1983	131
" McQuarter	1593	1960	1924	1878	1888	2166	1865	1896	156
" Simpson	2083	2339	2379	2535	2411	2278	2317	2335	128
" Stevenson	2057	2304	2440	2310	2140	2382	2383	2288	129
" Whiteside	2160	2287	2322	2284	2176	2054	2152	2205	89
						Overall Mean		2092	159

TABLE 12c - ELDERLY WOMEN

DAILY ENERGY EXPENDITURE:- kcal

	Sun.	Mon.	Tues.	Wed.	Thurs.	Frid.	Sat.	Mean	Stan. Dev.
Mrs. Burt	2078	2115	2209	1936	2009	2218	2121	2098	94
" Frame	1725	1883	1955	1974	2060	1857	2082	1934	115
Miss Hampsay	1556	2118	1884	1787	1967	2098	2041	1922	185
" A. Muir	2354	2224	2534	2276	2504	2444	2529	2409	117
" J. Muir	1944	2462	2305	2368	2196	2241	2154	2239	147
Mrs. Skinner	1718	1753	1823	1686	1841	1666	1829	1759	67
" Smith	1546	1489	1551	1613	1871	1548	1410	1575	134
Miss Wilson	2101	2167	2212	2282	2602	2400	2189	2279	159
							Overall Mean	2027	263

TABLE 13a - YOUNG WOMEN

DAILY CALORIE INTAKE:-kcal

	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Mean	Stan. Dev.
Jean Barrie	1820	1520	1632	1704	2314	1787	1664	1777	238
Margt. Christie	1317	1583	1416	2538	2317	1938	1780	1841	422
Elma Drummond	1325	2686	1909	2053	1820	2203	2079	2011	381
Margt. Duff	2212	1893	2382	2459	2400	1526	1689	2080	348
Muriel Duncan	2104	2209	2346	2651	2336	2234	2757	2377	222
Sheila Galston	3023	2441	2595	2813	2763	2851	2415	2700	208
Nada Hamilton	1509	1990	2914	2356	2465	2723	2367	2332	432
Evelyn Jack	1676	2442	2568	2488	2255	1337*	1382*	2021	499
Nan McQuarter	1823	1608	2255	1779	1883	1598	2051	1857	218
Meta Simpson	2943	2181	2339	1911	2000	2459	2702	2362	344
Rita Stevenson	3070	2833	2899	2993	2931	2335	1978	2720	375
Janette Whiteside	2532	2840	2636	2040	2592	2691	2553	2532	232
						Overall Mean		2218	314

*Mild Attack of gastritis, recovery complete by Saturday afternoon.

TABLE 13b - MIDDLE AGED WOMEN

DAILY CALORIE INTAKE:- kcal

	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Mean	Stan. Dev.
Mrs. Barrie	2288	1951	2263	1943	2044	1951	1742	2026	206
" Christie	855*	1467	2040	2094	2155	1773	2214	1915	596
" Drummond	1997	1987	2377	1867	1978	2057	2419	2097	197
" Duff	2187	1841	1660	2067	1650	2035	2553	1999	295
" Duncan	2545	1966	3093	1836	2327	1690	3035	2356	522
" Galston	2823	1946	1698	2364	1994	2664	2244	2248	373
" Hamilton	1900	2157	2598	2757	1907	2337	2054	2244	310
" Jack	1185	1473	1854	1798	1745	1425	1669	1593	223
" McQuarter	2405	1688	2063	1150	1909	1760	2172	1878	374
" Simpson	2270	2066	2064	2077	1818	2112	1624	2004	198
" Stevenson	2954	2397	2694	1822	2116	2363	2699	2435	357
" Whiteside	2108	2542	2173	2906	2360	2412	2381	2412	243
							Overall Mean	2101	239

* Spent all day Sunday in bed: feeling off colour!

TABLE 13c - ELDERLY WOMEN

DAILY CALORIE INTAKE:- kcal

	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Mean	Stan. Dev.
Mrs. Brown	457	1019	2459	2256	954	1453	1785	1483	675
" Burt	1836	2163	2021	2023	2119	1879	1634	1953	170
" Frame	1766	1460	2510	1934	1995	1816	1797	1897	296
Miss Hampsay	1854	1603	1777	2222	1713	1762	1552	1783	203
" A. Muir	2541	1973	1875	2030	2075	2396	2897	2256	342
" J. Muir	2199	1645	2118	1811	1925	2672	2138	2072	306
Mrs. Skinner	1187	1132	2006	1887	2116	2157	1517	1715	401
" Smith	1014	1526	811	834	1256	767	1339	1078	276
Miss Spiers	1884	1661	2596	2451	2594	2164	1880	2176	353
" Wilson	1746	2466	1881	1865	2337	2219	2319	2119	261
						Overall Mean		1853	340

Figs. 39 a, b and c (cf. Figs. 38a, b and c for times spent at activities).

The individual expenditures of energy on each day of the surveys are shown in tables 12a, b and c. These tables also show the individual and group mean daily energy expenditures and their standard deviations. The seven days' expenditures are shown in these tables from Sunday to Saturday, although in fact the individual surveys always began on a week-day. For administrative convenience this day was not always the same. (e.g., in the case of the elderly women: Mrs. Burt, Miss Hampsey, Miss A. Muir and Miss J. Muir began their individual surveys on a Monday, Mrs. Skinner and Mrs. Wilson on a Tuesday, etc.).

Measurement of food intake

The daily energy intakes of the members of the three groups of subjects, as determined from the seven-day individual dietary surveys, are given in tables 13a, b and c. The individual daily mean values and their standard deviations, together with the overall group mean daily values and standard deviations, are also shown in these tables.

The individual and group mean daily values and standard deviations for the intakes of protein, fat, carbohydrate, calories, calcium, iron, vitamins A, B, riboflavin, Niacin, C and D are given in tables 14a, b and c. The daily intakes of nutrients recommended by the British Medical Association (1950), Report of the Committee on Nutrition, London. are also given in these tables. On the basis of the B.M.A. recommendations it would appear that all groups of subjects were receiving from their diets adequate amounts of protein, vitamin B_1, niacin and vitamin C;

TABLE 14a - YOUNG WOMEN

MEAN DAILY INTAKE

	Protein	Fat	Carbo-hydrate	Calories	Calcium	Iron	Vitamin A	Vitamin B	Riboflavin	Niacin	Vitamin C	Vitamin D
	g	g	g		mg	mg	iu	µg	µg	mg	mg	mg
rrie	63.9	72.8	218.7	1777	826	11.2	4604	950	1293	9.7	55.4	49
Christie	55.8	85.5	209.7	1841	577	10.1	2036	729	1022	7.3	35.6	76
rummond	49.3	98.5	239.5	2011	498	8.1	2347	954	881	7.6	23.1	55
Duff	57.2	76.2	292.1	2080	484	10.6	2200	783	858	7.5	20.9	65
Duncan	78.1	107.2	275.4	2377	823	15.5	2536	944	1314	10.8	29.8	51
Galston	73.9	122.4	326.6	2700	853	12.9	2078	1118	1117	9.9	32.2	97
ilton	79.4	100.3	280.5	2322	813	13.1	4571	1132	1337	11.6	71.1	81
Jack	68.9	96.8	225.5	2021	521	12.0	1913	785	939	8.7	44.9	73
uarter	78.1	92.9	175.2	1857	470	15.7	3193	1053	985	9.9	20.3	145
mpson	69.6	108.6	278.8	2362	847	11.4	2392	957	1167	8.6	17.1	57
evenson	65.1	114.8	357.2	2720	612	14.8	4526	865	905	8.3	22.8	76
Whiteside	81.0	88.3	362.4	2532	712	17.5	2437	768	1087	10.2	25.6	73
	69.4	97.0	270.1	2218	570	12.7	2903	920	1075	9.2	33.9	75
d Deviation	9.9	14.3	56.4	314	181	2.6	996	132	166	1.3	15.3	25
recommendation rie intake -3000	58-66				800	12.0	5000	800-900	1200-1400	8.9	20-30*	

*20mg Vitamin C/day adequate but 30mg/day provided good margin of safety, at both levels of calorie intake.

TABLE 14b - MIDDLE AGED WOMEN

MEAN DAILY INTAKE

	Protein g	Fat g	Carbo-hydrate g	Calories	Calcium mg	Iron mg	Vitamin A iu	Vitamin B µg	Riboflavin µg	Niacin mg	Vitamin C mg	Vitamin D mg
arrie	67.4	103.3	208.9	2020	645	12.4	4645	813	907	8.7	16.3	78
ristie	53.1	90.8	224.7	1915	653	10.0	3355	723	961	8.9	21.9	94
rummond	58.3	108.8	225.2	2097	680	9.3	4336	877	891	7.9	39.7	98
uff	71.2	75.4	264.1	1999	515	13.2	2426	815	961	10.3	46.3	62
uncan	71.9	104.6	266.5	2356	691	13.7	2899	925	1133	10.3	38.5	83
alston	72.2	102.2	262.0	2248	925	12.7	3678	951	1272	7.7	25.6	114
amilton	56.7	94.7	294.5	2244	982	9.6	4778	1047	1166	7.8	127.5	74
ack	68.8	77.6	151.7	1593	839	10.1	2963	1116	1472	7.7	24.7	86
cQuarter	79.6	85.6	119.8	1878	426	17.0	5903	982	911	9.7	28.6	103
impson	48.1	83.5	266.9	2004	471	10.5	3665	841	895	6.8	10.3	42
tevenson	64.1	122.2	271.9	2435	772	13.1	6113	840	1147	7.8	20.3	209
hiteside	82.9	89.4	328.7	2412	1005	15.5	4109	980	1224	10.5	47.8	57
n	66.2	94.8	240.0	2101	717	12.3	4073	906	1078	8.4	37.3	92
ard Deviation	10.1	13.2	56.1	239	185	2.3	1103	105	332	1.4	29.4	40
. recommendation alorie intake 00-2250	58-66				800	12.0	5000	800-900	1200-1400	8-9	20-30*	

*20mg Vitamin C/day adequate but 30mg/day provided good safety, at both levels of calorie intake

TABLE 14c - ELDERLY WOMEN

MEAN DAILY INTAKE

	Protein g	Fat g	Carbo-hydrate g	Calories	Calcium mg	Iron mg	Vitamin A iu	Vitamin B µg	Riboflavin µg	Niacin mg	Vitamin C mg	Vitamin D mg
s. Brown	51.1	64.9	173.9	1483	775.9	9.7	3494.5	776.3	1256.5	6.4	22.5	104.7
" Burt	45.1	81.0	264.1	1954	620.0	10.1	3543.0	716.0	976.4	6.1	19.8	94.1
" Frame	62.9	81.4	235.9	1897	748.3	11.9	3274.8	728.6	1142.0	7.0	16.6	62.9
ss Rampsay	65.5	91.1	181.4	1783	571.8	11.2	3876.2	829.9	994.5	11.2	5.7	44.0
" A. Muir	77.5	103.5	255.7	2256	1008.6	13.0	3798.5	1072.4	1304.9	15.0	49.8	69.7
" J. Muir	63.4	101.0	229.9	2072	1079.0	11.3	4634.5	1079.9	1440.9	9.7	94.2	81.9
s. Skinner	54.7	71.9	213.0	1715	750.0	9.3	2179.7	747.4	930.8	6.0	18.4	172.7
" Smith	31.5	46.6	141.9	1078	534.2	3.5	2722.0	393.6	712.2	4.2	6.9	33.1
ss Spiers	63.7	75.8	311.6	2176	1013.7	8.5	2300.1	922.7	961.4	23.4	18.8	35.4
" Wilson	76.5	88.1	274.2	2119	958.7	15.1	2742.2	983.9	1277.9	8.2	72.2	70.9
an	59.2	80.5	288.2	1853	806.0	10.4	3256.9	825.1	1099.8	9.7	32.5	77.8
andard Deviation	13.4	51.1	49.0	340	176	2.9	731	104	210	5.4	28.2	39.1
.M.A. recommendation man, daily intake 500-2000)	44.0/58.0				800.0	12.0	5000	800	900-1200	6.0-8.0	20-30*	

*20mg Vitamin C/day adequate but 30mg/day provides good margin of safety, at both levels of calorie intake

TABLE 15

	Percentage of daily calorie intake from		
	Protein	Fat	Carbohydrate
Young Women	12.5	39.1	48.4
Middle Aged Women	12.7	40.9	46.0
Elderly Women	12.6	38.7	48.7

in addition the young and middle-aged women were receiving adequate iron and the elderly subjects adequate calcium and riboflavin. Small, though almost certainly unimportant, deficiencies existed in the calcium and riboflavin intakes of the two younger groups, and in the iron intake of the elderly women. All the groups of subjects received less vitamin A than is recommended by the B.M.A. Committee on Nutrition: the young received 2900 I.U. per day, the middle-aged 4100 I.U. per day and the elderly women 3300 I.U. per day; the recommended allowance is 5000 I.U. per day in all cases.

Table 15 shows how very similar were the diets of the three groups of women with respect to the ration of protein, fat and carbohydrate in them. The proportion of the calorie intake from protein is very close to 12.5%, the figure used in Weir's (1949) method of calculation of metabolic rate.

Discussion

The results presented above show broad agreement with the findings of the majority of the authors cited in the introduction. Smedley & Milner (1919) and Knight et al. (1910) were dealing with women older than those taking part in this study. The intakes of energy of the women studied by the American workers are slightly higher than those of the elderly women from Paisley, indeed, in the case of the inhabitants of the "private asylum" this difference was 350 kcal. per head per day. This difference may, in part at least, be a reflection of the socio - economic factors involved; it will be remembered that a difference of this magnitude also existed between the women in the asylum and those in the city almshouse.

The energy expenditure of the young women studied in the present experiments (2254 kcal per day) is between the upper level of expenditure of the bookbinder or machinist (2,100 kcal per day) and the lower level of expenditure of the caretaker (2.300 kcal per day) studied by Becker & Hämäläinen (1914). Such a situation seems reasonable when the work of shop assistants is compared with that of a machinist and a caretaker.

The agreement between the intakes of energy of the young women in the present study (2218 kcal per day) and in that of Tigerstedt, 1916 (2062 kcal per day) is not as good as it appears at first sight as the body weight of Tigerstedt's subjects was 10 kg greater than was that of our young women. In the case of the middle-aged subjects our findings are considerably nearer to those of Tigerstedt, although once again the Finnish women consumed less than did their Scottish counterparts. These descrepencies may be due to a slightly lower standard of living on the part of rural families living in Finland in 1916 as compared with the Glasgow families in 1956.

The estimates made by Rosenheim (1919) and Greenwood <u>et al</u>. (1919) of the energy expenditure of the munitions workers are much higher than any of the present estimates. This is almost certainly not a serious comment on the accuracy of either estimate in that the tasks involved are not at all comparable. The food intake of the women students studied by Cathcart & Murray (1936) is about 200 kcal per head per day lower than that of the young women who took part in the present study, although the mean age and body weight of the two groups are almost identical.

There is excellent agreement between the figures for the intakes of energy of the three groups of subjects reported on in this work and the three comparable groups studied by Widdowson & McCance (1936). It will be remembered, too, that these authors used the same technique of dietary survey as that employed in this study. The estimate of energy expenditure of a housewife (2100 kcal per day) made by Orr & Leitch (1937) is fairly close to our figures, although it may be a little low. There is a difference of nearly 1,000 kcal per day between our figures and those of Droese et al. (1949) for the energy expenditure of middle-aged housewives. The difference in body weight between the German women and the subjects of the present study (mean weights 76 kg and 64 kg) are insufficient to wholly account for the difference in their energy expenditures (40 kcal/kg per day for the German women and 33 kcal/kg per day for the Glasgow subjects). Part of this difference no doubt may lie in the fact that there were young children in the German families (3,4 and 1 respectively) whereas only one subject (Mrs. Stevenson) in the present study was so encumbered. Mrs. Stevenson had two small children and her mean daily energy expenditure was high compared with that of the other housewives: 2383 kcal compared with the mean energy expenditure of the group which was 2092 kcal per day. However it should be noted that Mrs. Stevenson was also the heaviest of the Glasgow housewives studied: 73.5 kg as compared with the group average of 64 kg. When this subject's energy expenditure is expressed per unit body weight it is less than the mean for the German women; in fact it is very close to that for the Glasgow housewives. Thus it appears that the Glasgow housewives simply expended less energy, i.e. did not work as hard as did their German counterparts.

As mentioned in the introduction, the energy requirement of an individual or of a group of comparable individuals, is the same as the energy intake or expenditure if these are equal, and if the body weight of the individual or group is not abnormal. If the intake and expenditure of energy are dissimilar energy expenditure is probably the better indicator of energy requirement, again with the proviso that body weight is not abnormal. Abnormal weight can exert an influence on total daily energy expenditure in two ways. Firstly, abnormal weight may affect the metabolic rate during the performance of particular activities. For example, Benedict (1915) found that after a period of fasting which caused a reduction of 20% in the body weight there was a depression of 30% in the resting metabolic rate. Similarly Passmore & Durnin (1955) showed that energy expenditure increased with increasing body weight during the performance of an activity such as walking at constant speed.

Secondly, abnormal weight may cause a change in the overall pattern of physical activity. For example, overweight individuals may restrict the distance they walk each day (although whether this is the cause or the effect of their obesity is debatable).

This second effect will almost invariably cause a depression in the total daily expenditure, whereas the first effect may cause either depression or elevation, depending upon the direction of the abnormality in body weight. It is possible that in some cases these two effects may be self-cancelling, although in other cases they will be additive.

There is reasonably close agreement between the mean energy intake and expenditure of each group of subjects reported on in the present survey. Furthermore there appear to be no abnormally heavy subjects in any of the groups, and only one exceptionally light woman (Mrs. Smith, 41.75 kg) in the group of elderly women. Thus the figures for the energy intake and expenditure of these groups of subjects are probably a good indication of their actual energy requirements. It is obviously quite pointless, and indeed it may even be misleading (Durnin, 1958), to quote anything but "rounded-off" values for energy requirements. We may state that the daily energy requirements of the groups studied in this work are as follows:

Young women, mean age 20 years working as shop assistants: 2,250 kcal.

Middle-aged women, mean age 50 years, working as housewives: 2,100 kcal.

Elderly women, mean age 65 years, working as housewives: 1,950 kcal.

4. STATISTICAL ASSESSMENT OF TECHNIQUE

Introduction

Underlying these surveys of energy expenditure and food intake is the basic physiological assumption that normal healthy people are in approximate energy balance over a period of seven days. That is, that for any one subject, over the course of one week the algebraic sum of the daily differences between energy output and intake is zero.

$$(E_1 - I_1) + (E_2 - I_2) + \ldots\ldots\ldots\ldots(E_7 - I_7) = 0$$

Where E_1, E_2 ....E_7 is the energy expended each day of the survey and I_1 , I_2 ....I_7 is the energy intake each day.

This assumption refers only to people living in a modern civilised community where food is plentiful and work is of an even nature throughout the year. It obviously cannot be applied to primitive rural communities where food may be plentiful at and after the harvest (and intake exceeds expenditure) and scarce before it (and expenditure exceeds intake); such a situation has been described by Fox (1953). Nor would the assumption be tenable if it were made with regard to periods of only one or two days, as was shown by Durnin (1957a). It does, however, seem reasonable to suppose that in a period of seven days, for people living the somewhat ordered and routine type of existance which is common in Western civilisation, that the daily differences between caloric expenditure and intake would be self cancelling. Certainly, there is no <u>a priori</u> evidence to contradict this assumption: The laws of conservation of energy apply to human beings and normal, healthy people neither gain nor loose body weight.

Thus, on the basis that the above assumption about energy balance is correct, we should be able to test the accuracy of the techniques employed to measure energy expenditure and food intake by comparing the results of the two types of measurement. As these two are, in effect, independent measures of the same entity, their results should be identical. If a statistically significant difference is found to exist between the two measurements, we can say that either, or both, of the measurements is inaccurate. Such a difference does not, per se, allow us to decide which of our measures is inaccurate. Even if no significant difference is found we cannot be absolutely certain of the accuracy of our techniques, though our confidence in them would be considerably enhanced. It is possible, though unlikely, that both measurements are systematically in error, in the same (algebraic) sense and to the same extent.

Results

For the purposes of a statistical evaluation of the techniques the individual mean weekly energy expenditures and intakes of the 32 women described above were used. In addition similar data on 45 men were assembled from the literature. These figures had been obtained by the same methods as had those for the women. The data on the men were obtained from the following sources.

Garry et al., 1955

Edholm et al., 1955

Durnin & Brockway, 1959

The values used in the subsequent calculations are shown in table 16.

TABLE 16

Authors	Subject Group	Expenditure kcal	Intake kcal
Present Study	Young Women	2030	1777
		1994	1841
		2825	2011
		2116	2080
		2372	2377
		2521	2700
		2200	2332
		1819	2021
		2287	1857
		2250	2362
		2562	2720
		2074	2532
	Middle Aged Women	1983	2026
		1763	1915
		2190	2097
		2134	1999
Present Study	Middle Aged Women (cont.)	2193	2356
		2047	2248
		2089	2244
		1983	1593
		1896	1878
		2334	2004
		2288	2435
		2205	2412
	Elderly Women	2098	1953
		1934	1897
		1921	1783
		2409	2256
		2239	2072
		1759	1715
		1575	1078
		2279	2119

TABLE 16 (cont.)

...ors	Subject Group	Expenditure kcal	Intake kcal
...y et al.	Miners	3430	3560
		2970	3560
		3150	3890
		3060	4270
		3660	3090
		3370	3100
		3870	4160
		3530	4010
		3140	4110
		3420	4050
		3570	4420
		3780	3990
		3700	4600
		4560	4380
		4090	5410
		4320	3990

Authors	Subject Group	Expenditure kcal	Intake kcal
Garry et al.	Miners (cont.)	3660	4180
		3670	3320
		4510	4480
	Clerks	2350	2810
		2380	2500
		2330	2850
		2820	3360
		2800	3360
		3150	3130
		2760	2620
		3100	3250
		3060	2730
		3290	3830

Authors	Subject Group	Expenditure kcal	Intake kcal
Edholm et al.	Military Cadets	3546	3140
		3377	3071
		3482	3788
		4097	3452
		3236	3589
		3191	4107
		3620	3250
		3077	2993
		2978	3339
		3548	3917
		3246	3063
		3588	3482
Durnin & Brockway	Young Men (Students)	3245	2953
		2682	2847
		3539	2939
		3248	3290

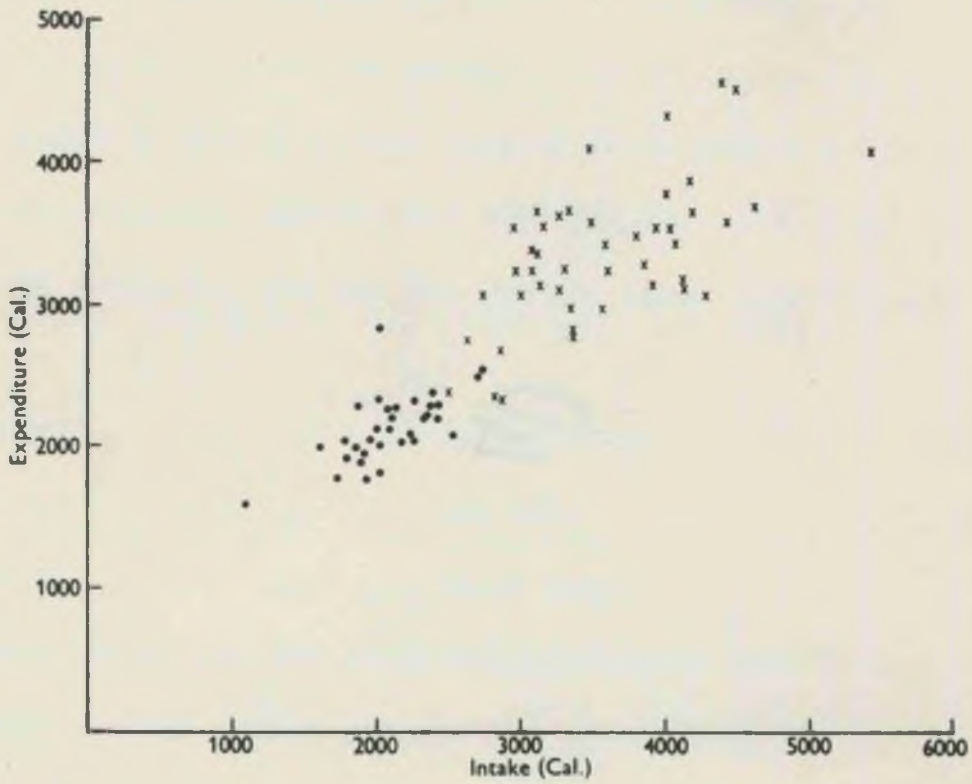
A scatter diagram (Fig.40) was constructed by plotting, for each individual, mean daily energy expenditure against mean daily food intake. The regression equations of energy expenditure on food intake were then calculated for a, all subjects, b, the male subjects only, and, c, the women only. These equations were:

$E = 0.566I + 1177$ .. .. a

$E = 0.510I + 1545$ .. .. b

$E = 0.485I + 1117$ c

Where E and I are the mean daily energy expenditure and food intake respectively (measured in Calories).



X MEN

&

● WOMEN

Fig. 40.

The corresponding regression equations of food intake on energy expenditure were:

$$I = 0.831E + 579 \quad .. \; .. \; .. \; .. \; .. \; .. \; .. \; .. \; \underline{a}$$

$$I = 0.777E + 952 \quad .. \; .. \; .. \; .. \; .. \; .. \; .. \; .. \; \underline{b}$$

$$I = 0.841E + 295 \quad .. \; .. \; .. \; .. \; .. \; .. \; .. \; .. \; \underline{c}$$

The slopes of the three regression lines of expenditure on intake do not differ significantly from one another, and all intercept the vertical (expenditure) axis at points significantly different from the origin. The product-moment correlation coefficients were also calculated for all subjects, and for the men and women separately; these were:

$r = 0.69$ ... ... all subjects

$r = 0.63$ ... ... men only

$r = 0.64$ ... ... women only.

These coefficients, which are all statistically highly significant, show the existence of some degree of positive correlation between our measurements of food intake and of energy expenditure.

In addition to the regression equations and correlation coefficients, the data were analysed in terms of the mean differences between the estimates of food intake and energy expenditure. The results of this analysis are given in table 17. In the case of "all subjects" it can be seen that the mean daily intake of calories exceeds the mean daily expenditures by 98 calories. This figure differs significantly from zero at the 5% level. The standard deviation of this mean difference is 425 calories. On the usually made assumption the 95% of a population lie within the range of the mean plus or minus twice its standard deviation, we would expect to find that the difference between energy expenditure and food intake, as measured by the techniques described in this thesis, would be within the range of from - 752 to + 948 calories per day in 95% of the individuals studied, and that, for the whole group the overall mean difference between energy output and intake would be significantly different from zero.

Discussion

The differences between the energy intake and the energy expenditure of the women were also analysed separately with respect to the three groups of subjects described in this thesis. The results of this analysis are given in table R.16. The mean differences between the energy intake and expenditure of the young and middle aged subjects do not differ significantly from zero, but this difference is significant in the case of the elderly women, whose expenditure exceeds intake by 168 Calories.

TABLE 17

	Mean difference Intake - Expenditure Calories	Value of "t"	Significance of Difference from zero	Standard Deviation Calories	Range of mean $\pm$ twice standard Deviation
All subjects	+ 98	2.04	at 5% level	425	-752 to + 948
Men Only	+ 201	2.89	at 5% level	492.5	-784 to + 1186
Women Only	- 42	0.95	Not significant	255	-552 to + 468

Thus, our techniques appear to have been satisfactory in the cases of the two younger groups of women, but in the case of the elderly women our estimate of energy expenditure is higher than that of energy intake for every subject. It may have been that these women were not consuming enough food to meet their energy requirement, although this seems unlikely: the body weights certainly do not suggest that such a state has been in existance for any length of time. It is more probable that the elderly women were less accurate in the keeping of their records of activity (i.e. the "diary cards") or of food intake. They may, for example, have been relatively unfamiliar with the use of scales, which could have led to errors in the weighing of their food. Nevertheless, it is difficult to envisage errors of this nature leading to a consistent over-estimate of energy expenditure or under estimate of energy intake.

TABLE 18

	Mean difference Intake – Expenditure Calories	Value of "t"	Significance of difference from zero	Standard Deviation Calories
Young Women	– 37	0.380	N.S.	338
Middle Aged Women	+ 7	0.112	N.S.	215
Elderly Women	– 168	2.703	at 5% level	176

5. THE DECREMENT IN ENERGY EXPENDITURE WITH AGE

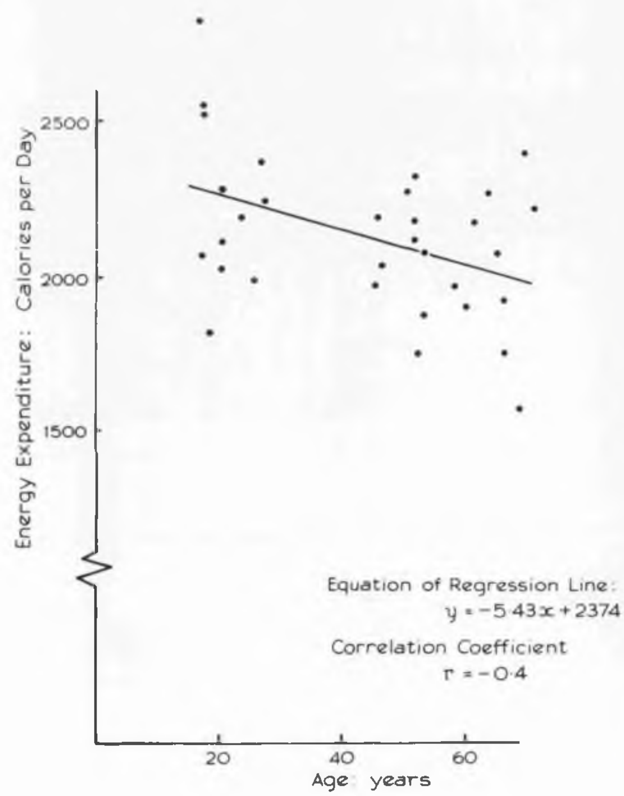
Introduction

Information about the reduction in the body's requirement for energy with advancing age is still limited. The F.A.O. Committee on Calorie Requirements (1950) suggested a decrease in the daily calorie allowance of 7½% per decade over the age of 25 years. While the joint F.A.O./W.H.O. Expert Committee on Nutrition (1955) considered that this reduction was too great, at least for the population of the United Kingdom; the latter committee suggested a figure of 3% per decade. Durnin (1957, b) presented more evidence suggesting that 3% per decade was a decrement more suited to the British population. A subsequent report of the F.A.O. Committee on Calorie Requirements (1957) agrees with the 3% decrement up to the age of 45 years, but favoured the retention of a decrement in calorie allowance of 7½% per decade for ages from 45 to 65 years.

To throw some further, though due to the small number of subjects involved, admittedly feeble light on this problem a statistical analysis was made of the measurements of energy expenditure presented above.

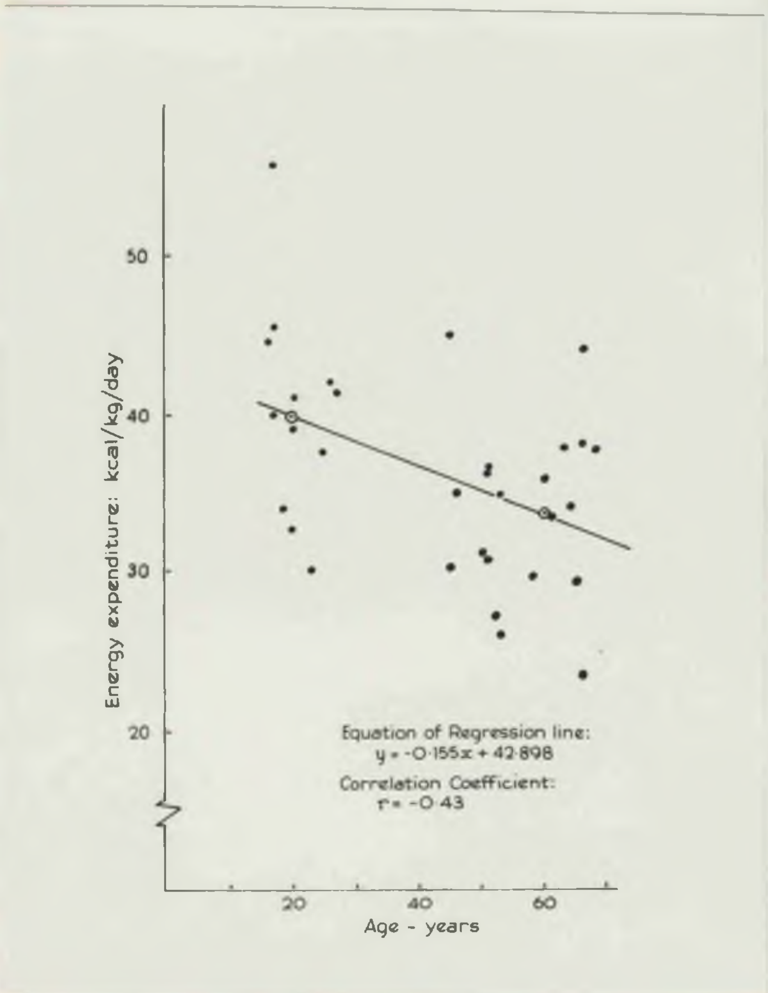
Results

In addition to an analysis using gross daily energy expenditure the data were analysed so that variations in energy expenditure due to differing body size were eliminated. This was done in two ways: firstly, the energy expenditure was expressed as that per unit body weight (kcal kg/day) and secondly, it was expressed as that per unit body surface area (kcal/sq.m/day). Scatter diagrams (Figs. 41a, b and c)



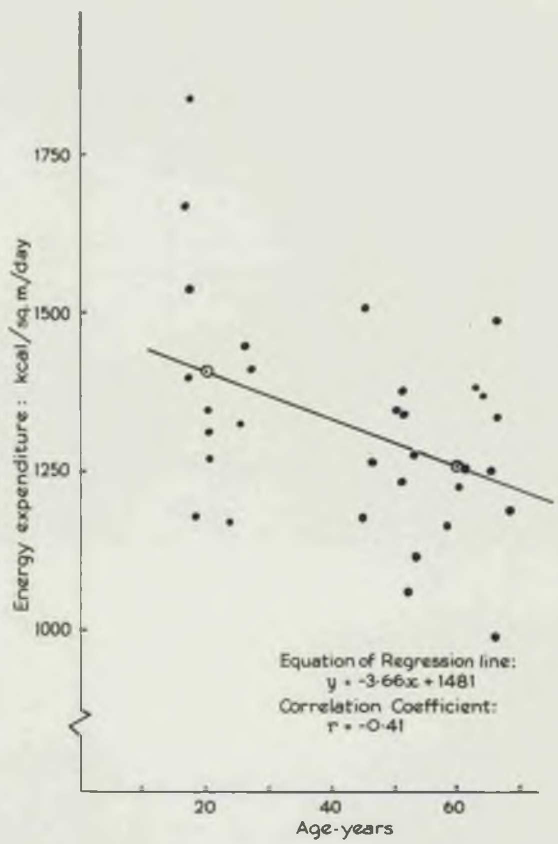
2500
2000
1500
Energy Expenditure: Calories per Day
Equation of Regression Line:
y = −5·43x + 2374
Correlation Coefficient
r = −0·4
20
40
60
Age: years

Fig. 41 a.



Energy expenditure: kcal/kg/day
50
40
30
20
Equation of Regression line:
y = -0·155x + 42·898
Correlation Coefficient:
r = -0·43
20
40
60
Age - years

Fig. 41 b.



Energy expenditure : kcal/sq.m./day
1750
1500
1250
1000
Equation of Regression line:
y = -3·66x + 1481
Correlation Coefficient:
r = -0·41
20
40
60
Age-years

Fig. 41 c.

were drawn plotting

(a) gross daily energy expenditure

(b) daily energy expenditure per unit body weight and

(c) daily energy expenditure per unit surface area against age. The equations of the straight regression lines, and their respective product-moment correlation coefficients, for these three set data were calculated. The equations and coefficients are given in table 19. The product-moment correlation coefficients, which are of similar magnitude in each case, are small, but all are statistically significant at the 5% level. The regression lines imply an age-related decrement in energy expenditure of from 2½% to 4% (depending on the standard used when expressing the expenditure) per decade of the energy expenditure at the age of 20 years.

Discussion

It is of interest to examine the sources of the differences in energy expenditure between the groups, particularly with regard to the young and elderly women. (The mean daily energy expenditure of the young women was 2,254 kcal and that of the elderly women was 2,027 kcal.- see tables 11a, b and c). Table 20a, b and c shows, for each group of subjects, the mean rate of expenditure of energy for the four principal activities (bed, sitting, standing and working) expressed as (a) gross calories per minute, (b) Calories per kilogram per minute and (c) Calories per square metre per minute. It will be remembered that the values for "bed" are derived from Fleisch's standards for basal

TABLE 19

ENERGY EXPENDITURE

Standard	Regression equation (1)	Correlation coefficient "r"	Level of statistical significance of "r"	Calorie decrement per decade (2)
Gross (kcal/day)	$y = -5.43x + 2374$	- 0.40	5%	2.5%
Body Weight (kcal/kg/day)	$y = -0.155x + 42.898$	- 0.43	5%	4%
Surface Area (kcal/sq.m/day)	$y = -3.66x + 1481$	-0.41	5%	2.5%

(1) Where "x" is age and "y" is energy expenditure.

(2) Decrement based on energy expenditure at age of 20 years.

TABLE 20a

Mean gross Energy Expenditure:- kcal/min.

	Bed	Sitting	Standing	Working
Young Women	0.94	1.2	1.4	2.5
Middle Aged Women	0.94	1.2	1.7	3.3
Elderly Women	0.85	1.2	1.7	3.1

TABLE 20b

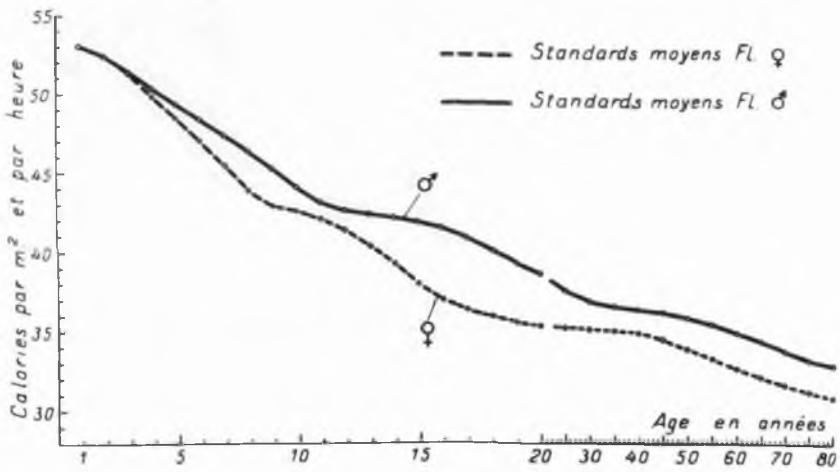
Mean Energy Expenditure:- kcal/kg/min.

	Bed	Sitting	Standing	Working
Young Women	0.017	0.021	0.025	0.044
Middle Aged Women	0.015	0.019	0.026	0.051
Elderly Women	0.014	0.020	0.028	0.051

TABLE 20c

Mean Energy Expenditure:- kcal/sq.m./min.

	Bed	Sitting	Standing	Working
Young Women	0.584	0.745	0.870	1.553
Middle Aged Women	0.566	0.723	1.024	1.988
Elderly	0.538	0.759	1.076	1.962



Standards moyens du facteur Cal./m² en fonction de l'âge et du sexe selon *A. Fleisch*.

Fig. 42.

metabolic rate. As can be seen from Fig.42 these standards reveal a definite age-related decline in B.M.R., so that, despite virtually identical surface areas of the two groups the mean energy expenditure of the young women in "bed" is higher than that of the elderly subjects. The values for "sitting" in table 20a, b and c are the results of measurements of energy expenditure, and it can be seen that the mean gross values for the three groups of subjects are identical. When these results are expressed on a basis of bodyweight, however, there is an apparent small decrease in the metabolic rate of the older subjects when sitting, but when expressed on a basis of surface area there is a small increase in the case of the elderly women. The values for the metabolic rate while standing show an increase with age which is apparent on no matter what basis the energy expenditure is expressed. The figures for the energy expenditure of the young women when "working" are not strictly comparable with those for the older groups as "working" for the young women means their work in the departmental store, and for the two older groups "working" refers to housework. For these two groups of women we find a decrease in energy expenditure with age if the former is expressed in gross terms, or on a basis of surface area, and no difference if the expenditure is expressed on a basis of body weight. In summary, the figures presented in table 20a, b and c suggest the following changes in metabolic rate with increasing age:

1. Decrease when "in bed".
2. No change when sitting.
3. Increase when standing.

The changes appear to be of physiological origin; we can also list a fourth change which is more probably due to the nature of the exercise involved i.e.

4. Increase in the metabolic rate when working, as between the young and middle aged subjects, and decrease as between the middle-age and elderly women. The difference between the "working" metabolic rate of the young and middle-aged women is larger than that of the middle-aged and elderly subjects; thus the metabolic rate of the elderly women when working is higher than that of the young women.

The decline in basal metabolic rate is a well documented phenomenon (Fleisch's standards for B.M.R. are, in fact, averages derived from the large amount of work published by various authors ranging from Aub & Du Bois (1917) to Husby (1948), and two possible explanations for this can be suggested. Firstly there may be a true reduction in the metabolic rate of individual cells and tissues due to a "running down" of the physico-chemical processes involved. For example Shock, Watkin & Yiengst (1954) have shown that renal function decreases with advancing age regardless of whether the former is expressed in gross terms or per unit total body water. On the other hand, these same authors found that when basal oxygen consumption per unit total body water was plotted against age (from 19-91 years) no decline in oxygen consumption was revealed. This finding is implied in the second possibility, namely that the metabolic rate of the individual cells and of a given weight of any particular functional tissue may remain constant while changes in body composition occur in such a manner that the ratio of active to inactive tissue decreases without concommittant alteration in body weight. That is, the amount of relatively inactive tissues such as fat and fibrous material may increase at the expense of muscle and other tissues of higher metabolic rate. As most of the existing studies on B.M.R. have been made without reference to body composition, except in the broadest sense of height, weight and surface area, we are not in a position to choose between these alternative explanations.

The absence of an age related change in the metabolic rate of the subjects when sitting can also be interpreted in two different ways. It could be regarded simply as "no change", sitting being merely a transitional stage between the basal state and standing, where the metabolic rate of the former is lower and of the latter is higher in old age. Alternatively we can accept the view, more popular in the past than at present, that the instantenous metabolic rate can be regarded as being composed of two fractions, viz., a basal component and are due to the additional energetic cost of the particular activity being undertaken. This being so, and assuming the decrease in B.M.R. there is an apparent <u>increase</u> in the metabolic rate of the elderly subjects when sitting.

One possible explanation of the age-associated increase in the metabolic rate when standing might be that there is a decrease in the efficiency of the postural mechanism, possibly in the neuro-muscular systems involved. This suggestion would be in accord with that of

Durnin & Miculicic (1956) who found that elderly men used more energy when walking than did young men, although they showed no difference in the performance of an arm exercise when seated. It is however not profitable to speculate at great length on the underlying causes of the changes in metabolic rate which are reported here. While our measurements were made with every possible care it must be remembered that they were made under field conditions, and that they could not be controlled with the precision which must be demanded in the studies of standardised metabolic rate per se.

Whatever the causes of the changes in metabolic rate discussed above the magnitude of them is insufficient to account for the differences in the mean gross daily energy expenditure of the three groups of women. In table 21 the activities of the subjects are presented under three headings, viz. "in bed and sitting" "standing and working" and "all other activities", and the mean amount of energy expended daily by each group of subjects on these different classes of activity is shown. Comparing the young with the elderly women we find that the former expended 156 calories per day less in bed and sitting than did the older women, whereas they used 320 calories per day more in standing and working and 65 calories per day more on all other activities. It will be recalled from table 20,a, b and c that the metabolic rate of the elderly subjects in bed was less than, and, when sitting was similar to, that of the young women; and that the metabolic rate of the older subjects was higher for standing and working than was that of the young women. The differences in energy expenditure shown in table 21 obviously can only arise from the

TABLE 21

Mean Energy Expenditure:- kcal/day

	In bed and Sitting	Standing and working	All other activities
Young Women	909	913	432
Middle Aged Women	960	785	347
Elderly Women	1065	593	367

changes in the pattern of daily activities, not from the changes in metabolic rate. Indeed, the latter changes would produce exactly the opposite effect to that shown in table 21, if the times spent at various activities were similar throughout the different groups of subjects. The figures presented in tables R.18 and R.19 show in a conclusive manner that the age-related decrease in energy expenditure, as demonstrated by the women described in this thesis, is due to a change in activity rather than to one in metabolic rate. That is, the elderly subjects spent more time at rest (i.e. in bed and sitting) and less time at the more energetic activities than did the young women.

6. THE DECREMENT IN ENERGY INTAKE

Results

The mean daily levels of energy intake of the thirty four women whose food intakes were studied were used to calculate regression equations comparable with those shown in table 19 for energy expenditure. These three equations and their respective correlation coefficients are shown in table 22. The product moment correlation coefficients are slightly higher when we relate energy intake to age than when we use energy expenditure: in the former case the coefficients attain statistical significance at the 1% level whereas in the latter case they are significant at the 5% level. (The fact that in the former case there are 34 subjects as compared with 32 in the latter partly accounts for the higher level of statistical significance). The final column of table 22 shows the age-related decrement in calorie intake implied by the regression equations. These decrements are calculated as a percentage of the energy intake at the age of 20 years and apply to each decade over the age of 20: the decrements range from 3.2% to 5.4% per decade, depending on the standard of expression of energy intake. The scatter diagrams in Figs. 43a, b and c show the 34 individual mean daily intakes of energy related to age; the intakes are expressed as (a) gross (kcal/day), (b) per unit body weight (kcal/kg/day) and (c) per unit surface area (kcal/sq.m/day).

Discussion

In Fig.44 three pairs of regression lines are drawn. These are the lines of the calculated regression equations of energy expenditure and

TABLE 22

ENERGY INTAKE

Standard	Regression Equation (1)	Correlation coefficient "N"	Level of Statistical significance of "N"	Calorie decrement per decade (2)
Gross (kcal/day)	$y = -7.19x + 2398$	-0.42	1%	3.2%
Body Weight (kcal/kg/day)	$y = -0.217x + 44.77$	-0.52	1%	5.4%
Surface Area (kcal/sq.m/day)	$y = -5.06x + 1513$	-0.42	1%	3.6%

(1) Where "x" is age and "y" is energy intake

(2) Decrement based on energy intake at age 20 years

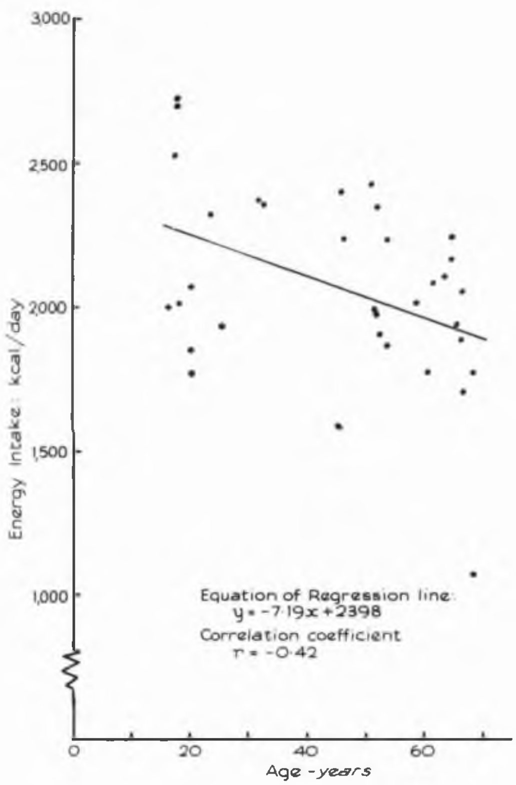

3,000
2,500
2,000
1,500
1,000
Energy Intake: kcal/day
Equation of Regression line:
y = -7·19x + 2398
Correlation coefficient
r = -0·42
0
20
40
60
Age - years

Fig. 43 a.

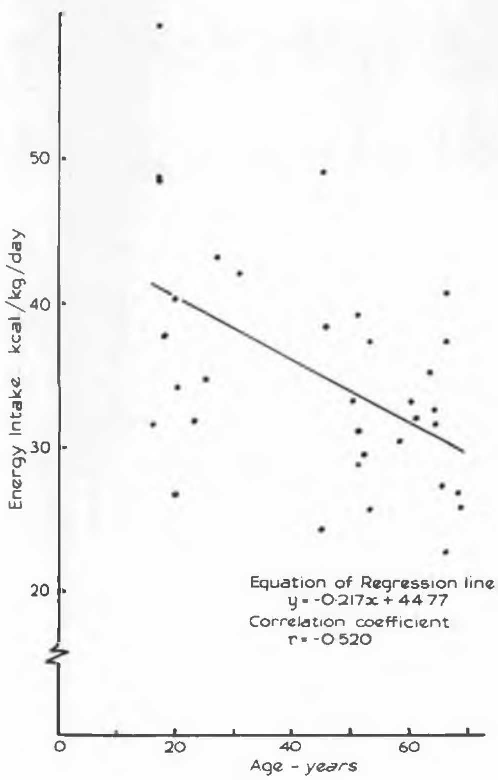
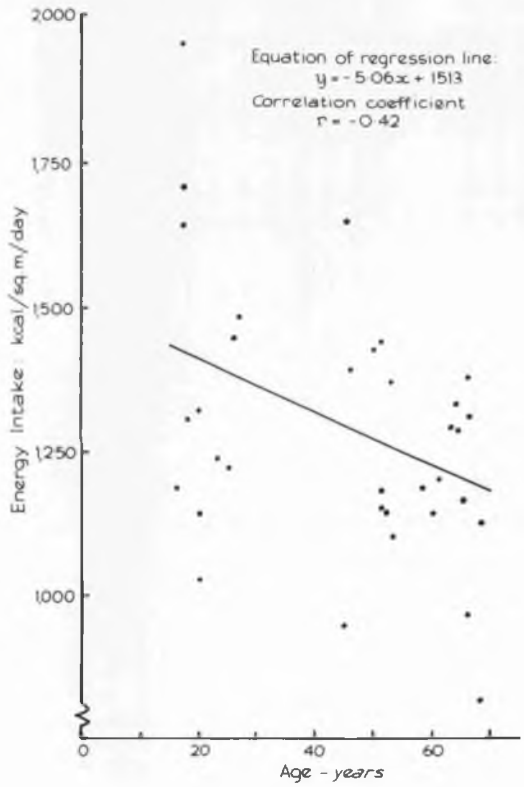
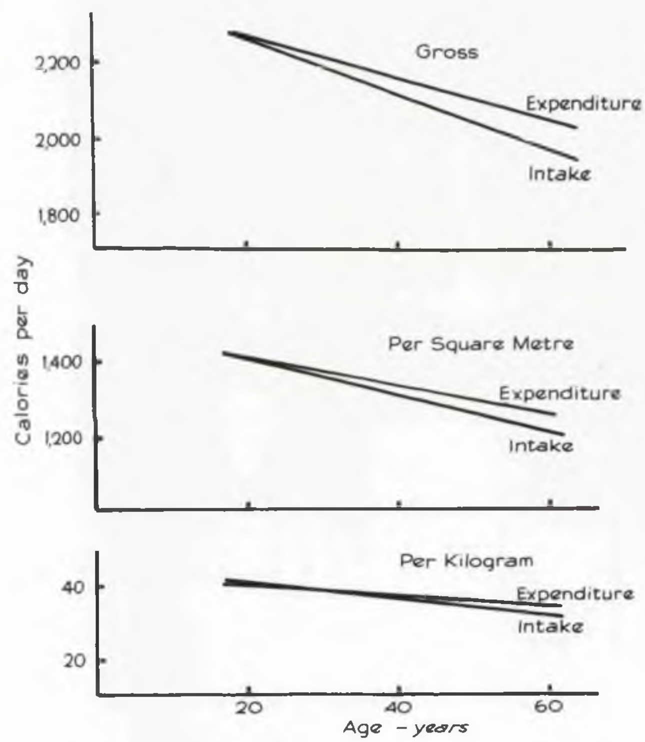

Energy Intake kcal/kg/day
50
40
30
20
0
20
40
60
Age - years
Equation of Regression line
y = -0·217x + 44·77
Correlation coefficient
r = -0·520

Fig. 43 b.



Equation of regression line:
y = - 5·06x + 1513
Correlation coefficient
r = -0·42
2000
1,750
1,500
1,250
1,000
Energy Intake : kcal/sq.m/day
0
20
40
60
Age - years

Fig. 43 c.



Gross
Expenditure
Intake
2,200
2,000
1,800
Calories per day
Per Square Metre
Expenditure
Intake
1,400
1,200
Per Kilogram
Expenditure
Intake
40
20
20
40
60
Age - years

Fig. 44.

TABLE 23

Calorie Decrement per Decade

Standard	Expenditure	Intake	Mean
Gross	2.5	3.2	2.9
Body Weight	4.0	5.4	4.7
Surface Area	2.5	3.6	3.1
Mean	3.0	4.1	

intake. The age-related decrements in calorie requirements shown in tables 19 and 22 are collected together in table .23. It can be seen from Fig.44 and table 23 that the decrement in energy expenditure is less than that in energy intake. This is not unexpected, as it will be remembered (see Table 18) that the energy expenditure of the elderly women exceeded the energy intake by 168 kcal. per day and that this figure is significantly different from zero, whereas the corresponding figures for the two younger groups of women did not differ significantly from zero. It can also be seen from table 23 that the calorie decrements are larger when energy requirements are related to body weight than to surface area. The explanation for this is that although the elderly women were heavier than their young counterparts (by approximately 4 kg) they were not so tall and this resulted in the mean surface area of the elderly women being less than that of the young subjects (1.58 sq.m as compared with 1.61 sq.m).

The experiments described in this thesis obviously support the view that a decrement in calorie requirements of 3% per decade is more suited to the women in this country than is one of $7\frac{1}{2}\%$ per decade. The experiments do not enable a decision to be made as to whether the 3% decrement shown in energy expenditure is more correct than the 4% shown in energy intake, although for most practical purposes this difference would be unimportant. The low values of the correlation coefficients suggest that prediction of individual requirements from age alone would be hazardous in the extreme, none-the-less the statistical significance of these coefficients would appear to justify prediction of mean calorie requirements of various age groups of the population.

SUMMARY

1. The development of indirect calorimetry andits application to human beings is described.

2. An account is given of the functioning properties and use of the existing and especially constructed equipment used in the thesis, the major item of this equipment being the Max-Planck respirometer. This meter and the associated methods of gas analysis provide the basis of one modern technique for the determination in the field on the energy expenditure by human beings. The calibration and maintenance of the respirometer are described, and a modified sampling pump for the respirometer has been devised and tested. The resistance to air flow of the various pieces of respiratory equipment used has been measured. The resistance of this equipment is within the stated limits of tolerance by human beings. Attempts were made to obtain or make masks which could be used instead of a mouthpiece in work of this nature: these attempts were at least partially successful. Chemical and physical technique for the analysis of expired air are also discussed, and the methods of estimating total daily energy expenditure and food intake are described.

3. The scientific literature on the energy requirements of women is reviewed.

4. The total expenditure of energy and intake of food of three groups of women was studied over periods of one week. The three groups of subjects were composed of:

i. 12 young women, mean age 20 years,

ii. 12 middle-aged women, mean age 51 years,

iii. 10 elderly women, mean age 65 years.

5. The mean daily energy expenditure of the groups was:

i. 2254 kcal by the young women,

ii. 2092 kcal by the middle-aged women,

iii. 2027 kcal by the elderly women.

6. The mean daily energy intake of the groups was 2218, 2104 and 1853 kcal respectively. Approximately 12½% of the mean daily energy intake arose from the metabolism of protein. The intakes of protein, minerals and vitamins by the subjects appeared to be adequate.

7. For the purposes of an assessment of the accuracy of the experimental techniques employed in the thesis the difference between the mean daily energy expenditure and intake within each group of subjects is compared statistically.

8. This difference is not statistically significant in the cases of the two younger groups, but it is significant in the case of the elderly women. It is concluded that the accuracy of the technique appears to be reasonably satisfactory, although in the case of the elderly subjects it would appear that the accuracy is capable of improvement.

9. The existance of a decrement in the mean daily energy expenditure with advancing age is investigated. This decrement appears to be in the order of 3% per decade after the age of 20 years.

10. A similar decrement in the energy intake of the women is demonstrated.

11. It is suggested that the cause of the decrement in energy requirement lies in an alteration of the pattern of physical activity (i.e. more time is spent in the less strenuous forms of activity) rather than in an alteration of metabolic rate *per se*.

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APPENDIX A

Record sheet used with the

Max-Planck Respirometer.

Sample No.

NAME .... Place ....

Age ..... Height .... Weight ....

Date .... Time .... Air Temp.............

ACTIVITY Observer

Bar. Press. .... Temp. Expired Air .... Atmos.Corr.Factor.....

AIR METER Final Reading (2)

Initial Reading (1) Difference (2-1) ....

Respirometer No. .... Corr. Factor ....

Duration of Sample ....

Pulmonary Ventilation (BTPS) .... (GAS ANALYSIS (Analyst ....)

(3) (STP) .... CO_2

O_2

True Oxygen (4) .... R.Q. ....

Calorie Value exp. air.

$$\left(\frac{20.93 - \qquad}{.20}\right)$$

$$= \frac{\qquad}{20}$$ (5) ....

Oxygen Consumption $\left(\frac{3 \times 4}{100}\right)$

Calories per min. (3 x 5)

Appendix B

Notes on the solutions used for the absorbtion of oxygen in Haldane's apparatus.

APPENDIX B

Notes on the solutions used for the absorbtion of oxygen use in Haldane's apparatus.

1. Alkaline solution of pyrogallol: 10% (wt/vol.) pyrogallic acid dissolved in the solution of potassium hydroxide of specific gravity 1.55 (450 g. potassium dissolved in 250 ml. distilled water). This is the "classical" oxygen absorbent for use in Haldane apparatus (Haldane & Graham, 1935, Douglas & Priestley 1948). The absorbtion of oxygen by this solution is slow, but "pyro" can absorb a large volume of oxygen and frequent replacement of the solution is avoided. The behaviour of any one "batch" of solution is unpredictable, even when each batch is made up under apparently identical conditions: some batches absorb oxygen more quickly and last longer than do others.

2. Chromous chloride: (Dahlström & Wahland, 1949): prepare the following solutions.

a. 3 M hydrochloric acid. (300 ml.hydrochloric acid, B.P. (36%) made up to 1 litre with distilled water).

b. 0.013 mercuric chloride. (2.08 g mercuric chloride dissolved in 1 litre distilled water).

c. 2 M acetic acid (120 ml. glacial acetic acid made up to 1 litre, with distilled water).

d. Dissolve 250 g chromic chloride <u>without heating</u> in 2 M acetic acid, and make up to 500 ml.

150 g granulated zinc are immersed in 50 ml. 3M hydrochloric acid for 30 seconds in a 1 litre Erlenmeyer flask. The acid is drained off and 50 ml. of 0.013 M mercuric chloride solution is added to the zinc. The mixture is stirred rapidly for three minutes, the liquid drained off and the amalgam washed three times with distilled water. Next, add 100 ml. of 2M chromic chloride solution to the amalgam in the flask. Seal the flask with a rubber stopper and agitate for about five minutes. Three or four times during this period it is advisable to cautiously remove the stopper from the flask to release the pressure. After mixing the resulting liquid should be decanted and stored anaerobically. This is a very effective absorbent of oxygen; it is rapid and can absorb about twenty times its own volume of oxygen. It keeps well under anaerobic conditions. Apart from the volume of oxygen which it can absorb (in this respect "pyro" is superior) chromous chloride has been found to be the most satisfactory of the various absorbents tried.

3. 1.2-4 <u>triacetoxy benzene</u>: dissolve 10 g 1-2-4 triacetoxy benzene in 100 ml. of 18% (wt/vol.) solution of potassium hydroxide. (Gairdner, 1956). This solution absorbs oxygen more rapidly than does "pyro",

but not as rapidly as chromous chloride nor does it absorb as much oxygen as the latter. The keeping properties of the alkaline solution of 1-2-4 triacetoxy benzene are not very good, even when stored under anaerobic conditions.

4. Sodium hydrosulphite: 8 g sodium hydrosulphite (or dithionite) are mixed with 1.5 g anthraquinone-beta-sulphonate and approximately 0.5 g ferric chloride. These dry ingredients are placed in a screw-topped jar, and 50 ml. of hot (50° C) 14% (wt/vol.) solution of potassium hydroxide is added. Solution takes place in three or four minutes; this must take place anaerobically. (Consolazio, Johnson and Marek, 1951). This solution is good from the point of view of speed of oxygen absorption, but is not able to absorb a large volume of oxygen.

Appendix C

Letters used when contacting subjects.

APPENDIX C

1. A copy of the notice shown the young women working in Messrs. Pettigrew & Stephens, Ltd.

"Proposed Investigation into the Energy Expenditure and Food Consumption by Housewives and Shop Assistants.

- - - - - - - - - - - - - -

In 1951 the Medical Research Council set up a committee "to advise and assist in the promotion of research on energy requirements in different forms of work and on diet in relation to these requirements". This committee considered all previous investigations of a similar nature and came to the conclusion that our knowledge of the energy expenditure involved in the various occupations of Britain is very limited indeed.

Probably the largest and certainly one of the most important groups in the community are housewives. Surprisingly enough very little is known about the energy expenditure of housewives in this country. One or two small surveys have been done in Germany and in America but, for various reasons, their results may not be applicable to British women.

The present investigation is being carried out by a small group of doctors and scientists of the Medical School of Glasgow University. The object is to find the energy expenditure and dietary habits of middle-aged housewives (over 50 years of age) and of their daughters. We have chosen shop-assistants as one of the groups (the "daughters") since this is one of the occupations employing large numbers of young girls in this country.

The study will in no way interfere with normal work and recreation and volunteers should find the whole thing an interesting experience. Each subject would be required for one week, and all information will be treated as very strictly confidential.

Mr. Hugh Fraser and the management of this shop have very kindly offered their full co-operation. If you are good enough to think of volunteering, and if you consider that your mother might also assist in this important research, I shall be very pleased to explain in detail what would be necessary before you definitely decide whether or not to be a subject.

J.V.G.A. Durnin, M.A., M.B.Ch.B.,
Lecturer in Physiology,
Glasgow University.

2. Copy of the letter sent to the general practicioners whose patients included the elderly women selected at random from the electoral roll of Paisley.

"Dear Dr.

....

....

For some years the Physiology Department of the University has been doing research on the problem of energy requirements of human beings. Recently, we have become interested in the problems of the energy needs of the elderly. Very little is known of this subject in Britain at present, or indeed of their food intake. Your patient was one of a group selected at random in Paisley. We are very anxious to measure the food intake and the energy expenditure of this group. We have not approached her with a view to obtaining her co-operation as we felt that this would more appropriately be done by you as her medical adviser. We should be very grateful if you could undertake this for us and give her the enclosed leaflet which we hope describes the sort of investigation we have in mind. If your patient is willing to undertake this we shall, of course, go and see her beforehand and explain in full detail precisely what she has to do.

In our experience, the subject finds such studies interesting, without being too inconvenient. A dietician will help her in the recording of her food intake and I, or one of the other physiologists, will also visit her frequently in order to make an estimate of her energy expenditure.

Should you wish to know the precise procedures that we adopt, I would be happy to explain on the telephone. If I do not hear from you, I shall telephone you in a few days' time to learn whether you think your patient will help. I need not tell you how grateful we should be for your assistance.

Yours sincerely,

Dr. J.V.G.A. Durnin.

3. Copy of the note given the elderly women by their local general practicioners.

"Dear ....

I am carrying out some medical research into the food needs of women of your age. This is a very important subject about which we know little at present. Your name has been "drawn out of a hat" and I hope you will be able to help me in this study. We need to know how much food you eat and how much energy you use up in your everyday life. The study will last for the whole of one week.

Not only will the results be, we hope, of great scientific and medical interest, but they will throw a light on the position of the older age groups in this country. I need not tell you how important a subject this is. I think you would also find this a very interesting experience.

If you think you may be willing to help us, I shall be very pleased to call on you, before you finally decide, and explain exactly what you need to do. I am in touch with your doctor who will let me know how you feel about it.

Yours sincerely,

Dr. J.V.G.A. Durnin.