THE BIOLOGICAL EFFECT OF AIR IONS AND ELECTROSTATIC FIELDS

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SUMMARY

Over a number of years while working in the climatic chambers at the R.A.F. Institute of Aviation Medicine it has often been noticed that there is a depressing and tiring effect which is difficult to explain in terms of the more usual climatic parameters of temperature and humidity. Similar symptoms in enclosed air conditioned spaces have been noticed by other people both within the Ministry of Defence and elsewhere. The lethargic feeling resembles that associated with heavy thundery weather and with certain winds of ill repute which are found in some parts of the world and whose effects are difficult to explain in terms of temperature and humidity alone. Because of the electrical disturbances taking place in the atmosphere as a prelude to storms it has been proposed that the reported symptoms in the natural and artificial environment are in some way associated with the local electrical climate.

In Part 1. of this thesis the physics of air ions and electrostatic fields, the two constituents of Man's Physical Environment which have received most attention in this context, are examined to try to understand their role in the natural environment and in situations created

artificially for studying their biological effect. The results of experimental work reported in the literature are reviewed to try to delineate any physiological mechanism which might be sensitive to such a small natural stimulus.

In some countries negative ion therapy is practiced for the alleviation of certain disorders, many of which are psychosomatic in nature, but there are indications that it might be beneficial in post-operative healing and the treatment of burns.

Part 2. deals with two experimental series, the first of which tests the effect of various strengths and configurations of electrostatic fields on the spontaneous activity and growth rate of rats living within the field. The second series examines the effect on the same parameter of living in an ion-free atmosphere.

In both series of experiments the results were found to be negative but increase in air movement was shown to have an inhibitory effect on both spontaneous activity and growth rate. This finding adds weight to a criticism which can be levelled at much of the experimental work reported in the literature, that not sufficient attention is paid to controlling the normal climatic parameters.

ACKNOWLEDGEMENTS.

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To my colleagues, especially Dr. D. M^{c}K. Kerslake and Group Captain T.C.D. Whiteside I would like to express my gratitude for their interest, encouragement and helpful criticism. Also to the many members of this Institute who assisted in the collection of material and in the compilation of this thesis I gratefully acknowledge your help and advice so willingly given.

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CONTENTS

PART 1

CHAPTER 1

INTRODUCTION

INTRODUCTION

Man's environment, to the public health physician is a complex of physical and psycho-social interacting constituents. The various facets on which his well-being depend are summarised in Figure 1.1. by Professor Pogrund (1969) of the University of California, in the City of Los Angeles, where the problems of atmospheric pollution, which is only a small part of the total environment, are probably greater at the moment than anywhere else on earth.

Since the industrial revolution, the physical environment in which we live has been changing rapidly. By using large quantities of fossil fuels we pollute the atmosphere, by the use of synthetic materials we create unnatural electro-static fields about us, and by air conditioning we can produce in our buildings an artificial climate which is controllable within fine limits; changes of particular relevance to the present study. The last named technological adaptation of man has been made necessary by his adventurous nature goading him to burrow in the earth, dive in the sea, venture up mountains and eventually to thrust himself into space, in all of which pursuits he has encountered new hazards of the physical environment. Some of the hazards are dramatic in their manifestations, for example the early balloonists soon discovered the profound effects of lack of oxygen and decrease in air temperature with altitude.

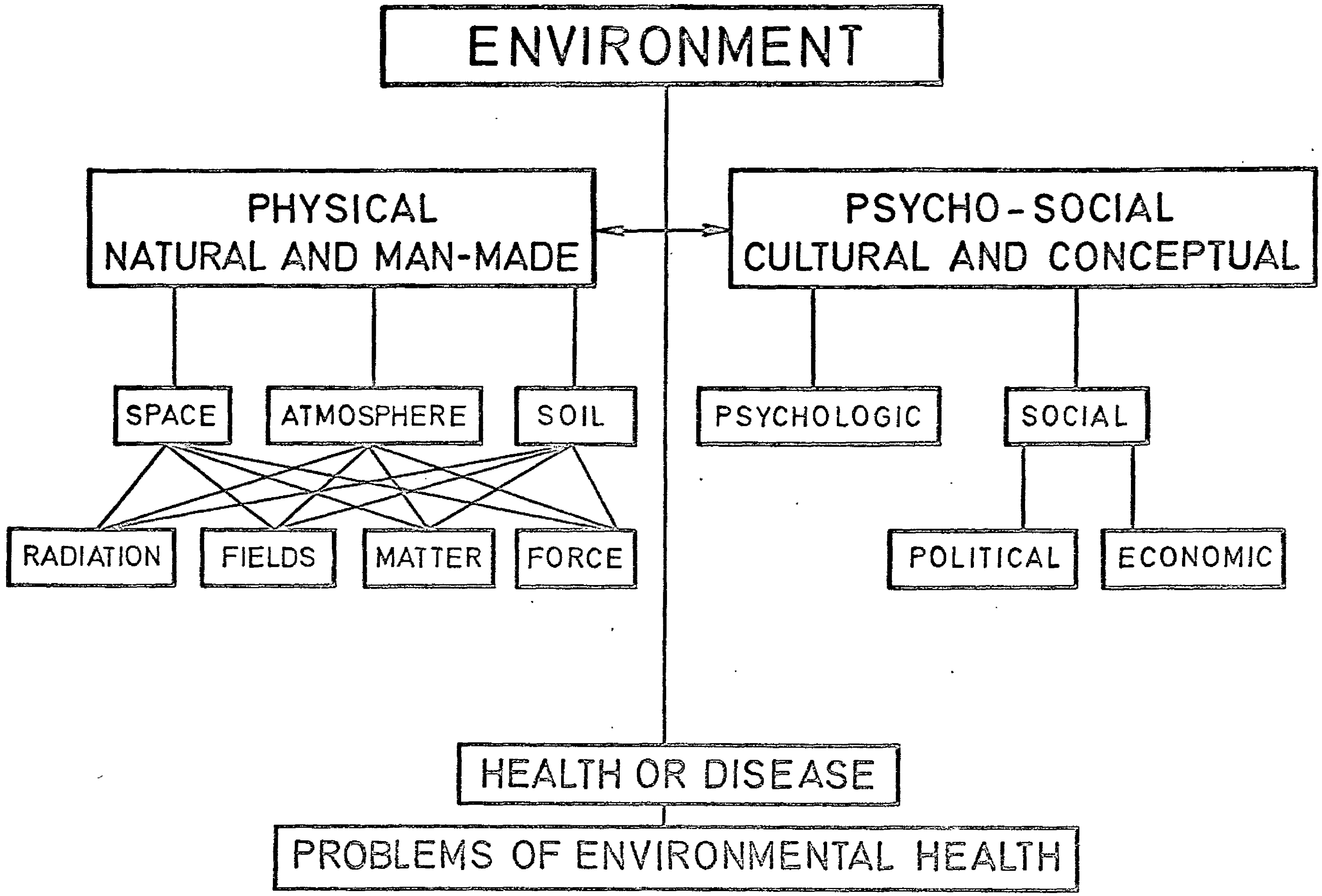

ENVIRONMENT
PHYSICAL
NATURAL AND MAN-MADE
PSYCHO-SOCIAL
CULTURAL AND CONCEPTUAL
SPACE
ATMOSPHERE
SOIL
PSYCHOLOGIC
SOCIAL
RADIATION
FIELDS
MATTER
FORCE
POLITICAL
ECONOMIC
HEALTH OR DISEASE
PROBLEMS OF ENVIRONMENTAL HEALTH

Figure 1.1.

While the more dramatic responses have attracted greater attention and as a consequence are better understood, this understanding often exposes minor deficiencies in the complete picture. For example, by studying man's reactions to the various components of his climatic environment, it should be possible to engineer conditions to give a satisfactory atmosphere for a particular level of activity. This is not so, many people find conditioned buildings very depressing and some even develop "hay-fever" or other allergies when exposed to such unnatural environments. Is there something apparently insignificant missing or is there something, perhaps mildly toxic, being added during the conditioning process?

Within the Ministry of Defence there are a variety of situations where people have to work in artificial environments. Measurement of the usual climatic parameters, air temperature, relative humidity, air movement, rate of change of air and gas composition in the work space would indicate a satisfactory condition but the inhabitants will still report that they find the atmosphere depressing. The reason could lie in the psycho-social side of Figure 1.1. The atmosphere might be "claustrophobic" possibly because of a restricted view of the outside world and working continually in artificial light, or, some workers could have a "hate the boss" complex and so on, but the reported symptoms are too prevalent to be entirely pyschological in origin. An explanation must be sought elsewhere in the physical environment.

To elucidate the feelings of depression mentioned above, the following observations have been noted many times by people working in this laboratory at the Institute of Aviation Medicine. Here there are facilities for synthesising climatic eonditions in a number of rooms. Temperature, humidity and air-movement are controllable and measurable within fine limits, considerably closer than commercial air conditioning systems. While a lot of experiments are carried out on human subjects under extreme conditions, many are performed within comfortable limits. Where people are being subjected to a series of environments or a variety of clothing assemblies in a particular environment by no means stressful, but of an hour or more duration, it is common to find that the subject will report for the first exposure armed with the latest scientific literature. Here is the golden opportunity to catch up with Journals which have been piling up. By the next day, or the one after, the journals will have been replaced by a novel with an interesting story only to be replaced subsequently by a magazine because the plot was becoming too involved. The less motivated will already have sought solace in sleep. Experienced subjects are well aware of the symptoms but still find them difficult to combat. The inexperienced will describe their successive periods of confinement as tedious or boring and might become depressing if the time scale was extended.

Having been intrigued by these observations and because of a common interest in this subject shared with other branches of the

Ministry of Defence an opportunity was sought to study the phenomenon further.

Over the past ten years there has been an increase in the study of the biological effects of air ions and to a lesser extent other "electrical" phenomena of the atmosphere, reported extensively in the Journal of the International Society of Biometeorology.

Tromp (1968) has reviewed in very broad terms the work going on in this field which he has chosen to call Electrobiometeorology. The three important electrical parameters of the meteorological environment which have received most attention are: the effects of natural ionisation of the atmosphere, the potential gradient (i.e. the electrostatic fields of the atmosphere) and electromagnetic waves, particularly those with a very long wavelength of about 6-100km and frequency of 3-50kHz. So far other parameters such as electric conductivity of the air or air-earth current have not been studied in relation to biological material.

It will be seen from Figure 1.2. which is a further dissection of Pogrund's Physical Environment (Figure 1.1.) where, according to Tromp, the main research areas are and where this present work fits into the field of electrobiometeorology. Certain constituents of the environment would seem to have very little bearing on the present investigation of the symptoms mentioned above and may be dismissed in a few words.

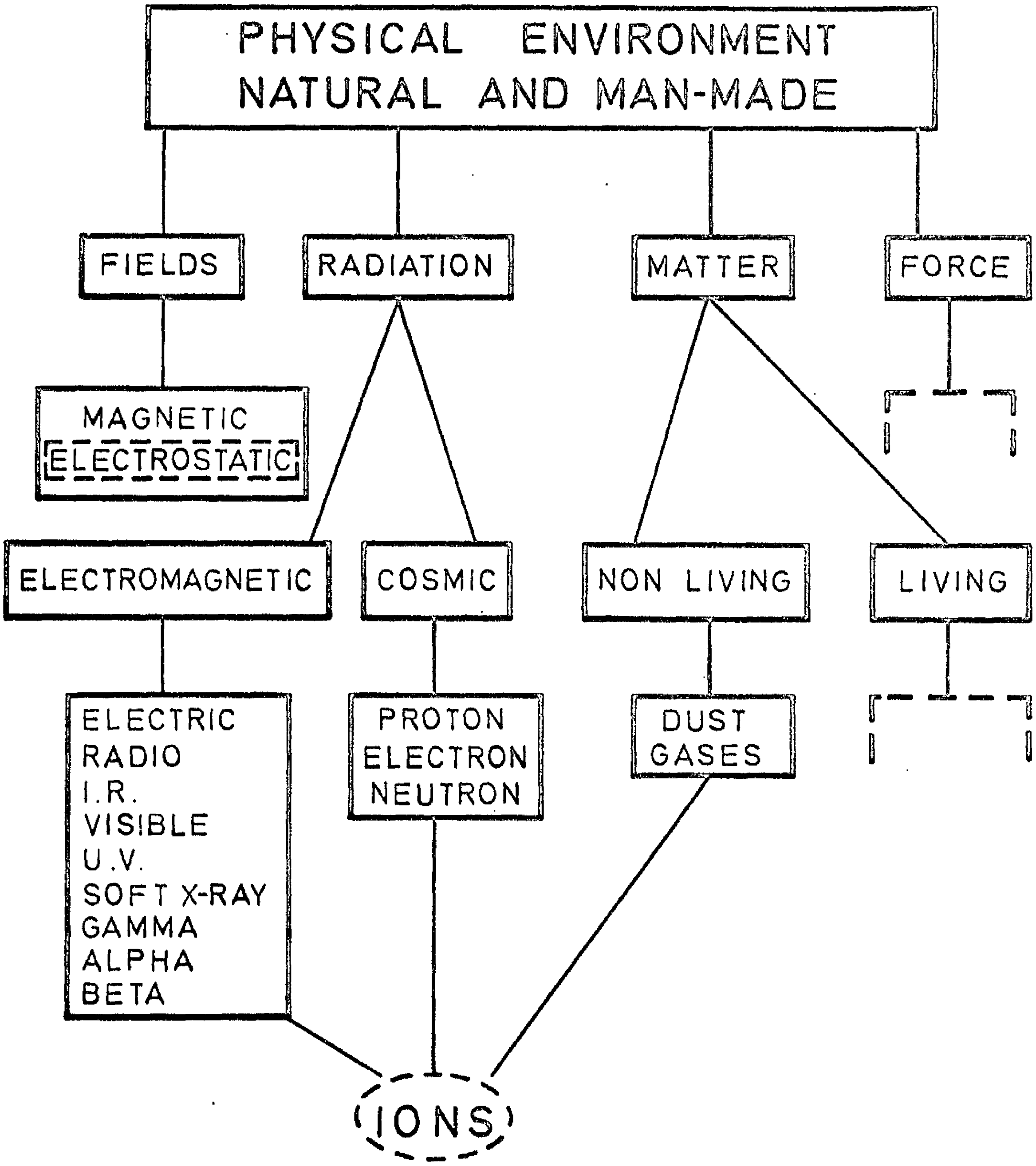

PHYSICAL ENVIRONMENT
NATURAL AND MAN-MADE
FIELDS
RADIATION
MATTER
FORCE
MAGNETIC
ELECTROSTATIC
ELECTROMAGNETIC
COSMIC
NON LIVING
LIVING
ELECTRIC
RADIO
I.R.
VISIBLE
U.V.
SOFT X-RAY
GAMMA
ALPHA
BETA
PROTON
ELECTRON
NEUTRON
DUST
GASES
IONS

Figure 1.2.

For example, there is no denying that there are many forces (vibration, noise, decompression) which cause physiological effects, mainly uncomfortable, but apart from probably atmospheric pressure they are irrelevant to the present discourse.

The effects of magnetic fields loom large in some peoples lives, Eden and Carrington (1967) note that there are people who believe sleep to be impossible unless their bed is orientated along the North - South axis of the earth. Charles Dickens and Dr. Marie Stopes both held this view although the latter did not mind whether her head or feet pointed North.

Dr. Stopes' most remarkable claim in the field of orientation was that she could locate the source of the "sense of north" in her own body. 'It is in my spine that I magnetate the north' she wrote, 'between my shoulder blades and hips. I used to have this sense so intensely that I could be blind-folded in a fog on a desolate moor, twisted round a great number of times, and could at once point to the exact North. This was tested by geologists with a compass ....' With due respect to this eminent lady and her unusual gift it is more likely that the subjective sensations under the present scrutiny are caused by electrostatic fields rather than magnetic ones.

When this study was first mooted it was thought that air ions probably held the clue to the puzzle, but as a better understanding of the physics of the atmosphere was gained it was realised that the effects of electrostatic fields and air ions are almost inextricably linked. Searching the literature produced almost nothing in the way of experimental evidence to support my view but it did reveal a number of authors who shared it, Wehner (1962) and Bach (1964) especially. Tromp (1968) has since reviewed the subject but all the work which he cites was performed either on botanical specimens or on insects. He concluded that the observations support the view that fluctuations in the natural potential gradient may affect the living organism but whether it was the electric field per se or its effect on the ion density which was the real cause could not be established.

Andersen (1965) using dummy heads has shown that the presence of electric fields in the environment reduces the uptake of light gas ions and changes the proportional content of positive and negative ions.

Although the original intention was an investigation of the part played by small ions on the spontaneous activity of rats, the work was extended to explore the effects of electrostatic fields of various strength and direction, to try to differentiate between these closely related components.

Returning to Figure 1.2. and the components of the environment not already dealt with, cosmic and electromagnetic radiations provide the necessary energy to charge non-living particulate matter in the atmosphere to produce ions. A great deal of work has already been recorded on the biological effects of natural levels of ions and artificially generated ions on the many systems of the animal body as well as other biological material; these will be reviewed in a later chapter. Artificially generated ions have usually been employed in massive concentration and as a consequence of the difficulties involved often the reported findings have not been confirmed by other workers in this field. There are many reasons which may account for this, bad original reporting, difficulties of measuring and controlling the environment and often side contaminants from the ion producing equipment. To overcome some of these difficulties and tackle the original problem of our conditioning system it was decided to look at ion free environments; the reason for this will be dealt with in the introduction to Part 2. The basic cause of the drowsiness experienced might be because of a lack of ions in the atmosphere rather than too many of a particular sign. The great emphasis in the past has been to incriminate positive ions as being the depressing ones and laud negative ones as beneficial; it could be that both within certain limits are necessary trace elements of our environment without which our well-being is depressed.

In the artificial environment we try to create closely controlled climatic conditions and are successful but dis-regard entirely the "electrical climate". The remaining chapters in this section are devoted to looking first at the constituents of the natural environment, then to analyse the methods of producing artificial conditions for experimental purposes, and finally to summarise some of the extensive work which has been carried out to try to understand how air ions and electrostatic fields affect biological material or why they should be important.

CHAPTER 2

ATMOSPHERIC ELECTRICITY

ATMOSPHERIC ELECTRICITY

HISTORY

The effects of electrical storms have been striking terror into animals including man from the earliest times. According to Wood (1969), allusions to lightning are to be found in the old Greek legend of Prometheus who stole fire from the Gods and gave it to man. Chalmers (1957) surmises that man may have obtained his first fire by the action of lightning on dry wood in the forest. He goes on to trace the development of the theories which established that thunder and lightning were manifestations of electricity in the air.

The earliest reference is to Wall (1708) who observed in his laboratory, cracklings and a flash between amber and a finger held a small distance away. He remarked that "it seems in some degree to represent thunder and lightning". Winkler (1746) compared the electric spark to the lightning discharge in more detail and went on to suggest some very modern theories on the origin of the electricity in the air.

Benjamin Franklin's (1750 and 1752) attempts to collect electricity from thunder clouds and his work on lightning conductors are known to most schoolboys. At the same time working in France d'Alibard (1752) succeeded in obtaining sparks from a well insulated iron rod, forty feet high, to an earthed wire. The sparks obtained by Franklin and d'Alibard were only very small and although they proved the presence of electricity in thunder clouds it was left to De Romas (1753), who like Franklin used a kite, to prove the similarity between a lightning flash and an electric spark. He obtained a spark three metres long and 0·03 metres in diameter with "more noise than a pistol shot".

Lemonnier (1752) copying his contemporaries noticed that dust particles were attracted to his electrified iron wire and concluded that there was a diurnal variation, but because of poor instruments it was left to Beccaria (1775) to prove this. Beccaria also confirmed the earlier finding of Franklin that there was, generally but not always, a change of polarity when thunder clouds were approaching. He used the concept of two signs of electricity and showed that under fair weather conditions his collector had a positive charge, while during thunderstorm conditions it would sometimes be positive but more usually negative.

Subsequently most of the great names in physics have made some contribution in this field, Volta, Peltier and Lord Kelvin to mention a few.

Coulomb (1795) among the pioneer experimenters was the first to realise that air is a conductor of electricity. In particular he noted that the charge on an electrified body could leak away into the air. He thought that an air or dust particle could receive by collision a charge which would then cause it to be repelled. This view remained extant until Elster and Geitel (1899) and Wilson (1900) almost simultaneously discovered ions.

Langevin (1905) discovered large ions and Pollack (1915) amongst others has described intermediate ones. Many workers have since observed that ions are continually disappearing by combination with ions of opposite sign or are converted to a different size by coalescing with uncharged particles. These are the so-called Condensation Nuclei on which Aitken (1880) found condensation of moisture when the air became saturated.

If ions are continuously being changed and destroyed then there must be some source of re-generation. The most obvious source would be the natural radioactivity of the earth which would mean that the conductivity of the air would decrease with height from the ground. Measurements by Hess (1911) and Kolhörster (1913) have shown that in fact, there is a marked increase of conductivity with altitude, which means that the source is extra-terrestrial. Cosmic rays are a very potent source of ions at all heights in the atmosphere while less penetrating solar rays are responsible for the greater numbers at the higher altitudes. This does not imply that the radioactivity of the soil and atmosphere is un-important in the production of ions, their relative roles will be discussed later.

ION MOBILITY

Before dealing with the characteristics of ions one term must be defined because on it depends the whole classification and differentiation of ions.

In a given electric field a charged particle will move with a certain velocity depending upon the properties of the particle. The drift velocity ($m.sec^{-1}$) acquired by an ion in an electric field of unit potential ($1\ volt.m^{-1}$) is called the ion mobility.

If a particle with an electric charge, i.e. an ion, is situated in an electric field then it will experience a force upon it which should make it acquire a continually increasing velocity - it is being accelerated - instead of a steady velocity which is implied by the definition. However, this overlooks the incessant buffeting which the ion experiences with surrounding air molecules nullifying some or all of the momentum generated since the last impact. There will, therefore, be an average speed of travel for the ion in the direction of the potential gradient; the greater the mean free path of the ion, the higher is the mobility.

Chalmers (1957) tries to clarify the idea by considering the ion as a small particle moving in a viscous fluid; with a constant force on the particle it acquires a steady velocity when the viscous force retarding is equal to the accelerating force.

SMALL AIR IONS

In air a gas molecule is ionised when some external radiation supplies sufficient energy to detach an electron, whereupon the positively charged part and the electron rapidly attach themselves to one or more uncharged molecules to form what is called an ion pair. Schonland (1953) describes the ions as "normal", "small" or "fast", and when found in the atmosphere have mobilities about $1{\cdot}5 \times 10^{-2}$ m.sec^{-1}(1·5 cm/sec) in a field of gradient 1×10^{-2} volt.m^{-1} (1v/cm), while Chalmers (1957) adopts the more usual and generally accepted description calling them simply "small" ions and putting the limits of mobility between 1×10^{-4} and 2×10^{-4} m.sec^{-1} in a field of 1v.m^{-1}.

Caswell (1968) who also works within the Ministry of Defence at the Admiralty Atmospheric Electricity Department is a little perturbed by the rather careless use of the term "small ion", which is often used to refer to a charged particulate relatively smaller than some others, namely large ions. He has suggested changing to Robinson and Dirnfeld's (1963) terminology, Table 2.1. calling true small ions primary ions. Then particulates of all sizes which become attached to primary ions would therefore be referred to as secondary ions. The secondary ions could then be referred to as small, intermediate or large but for precise work even so mobilities are a better indication of the consituent ions than any verbal descriptions.

Ion Class	Denomination	Radius r $m.10^{-10}$	Mobility k $m^2.V.^{-1}\ sec.^{-1}$
Primary	Small ions	$r < 6.6$	$k > 1x10^{-4}$
Secondary	Medium small ions	$6.6 - r - 78$	$1x10^{-4} - k - 1 x 10^{-6}$
	Medium large ions	$78 - r - 250$	$1 x 10^{-6} - k - 1 x 10^{-7}$
	Langevin	$250 - r - 570$	$1 x 10^{-6} - k - 2.5 x 10^{-8}$
	Very large ions	$r > 570$	$2.5 x 10^{-8} > k$

Table 2.1. from Robinson and Dirnfeld (1963)

What Caswell is seeking to underline by changing the nomenclature is to draw particular attention to one of the basic differences in properties between small and large ions. Quite apart from their mobilities, there is an important physical difference between large and small ions, which can be expressed by stating that the essence of the small ion is its charge, neutralise this and the group of molecules become detached, no trace of the ion's existence remains. On the other hand when a large ion loses its charge, it reverts to an uncharged aggregate of molecules which is easily detectable and will accept quite readily another charge of either sign.

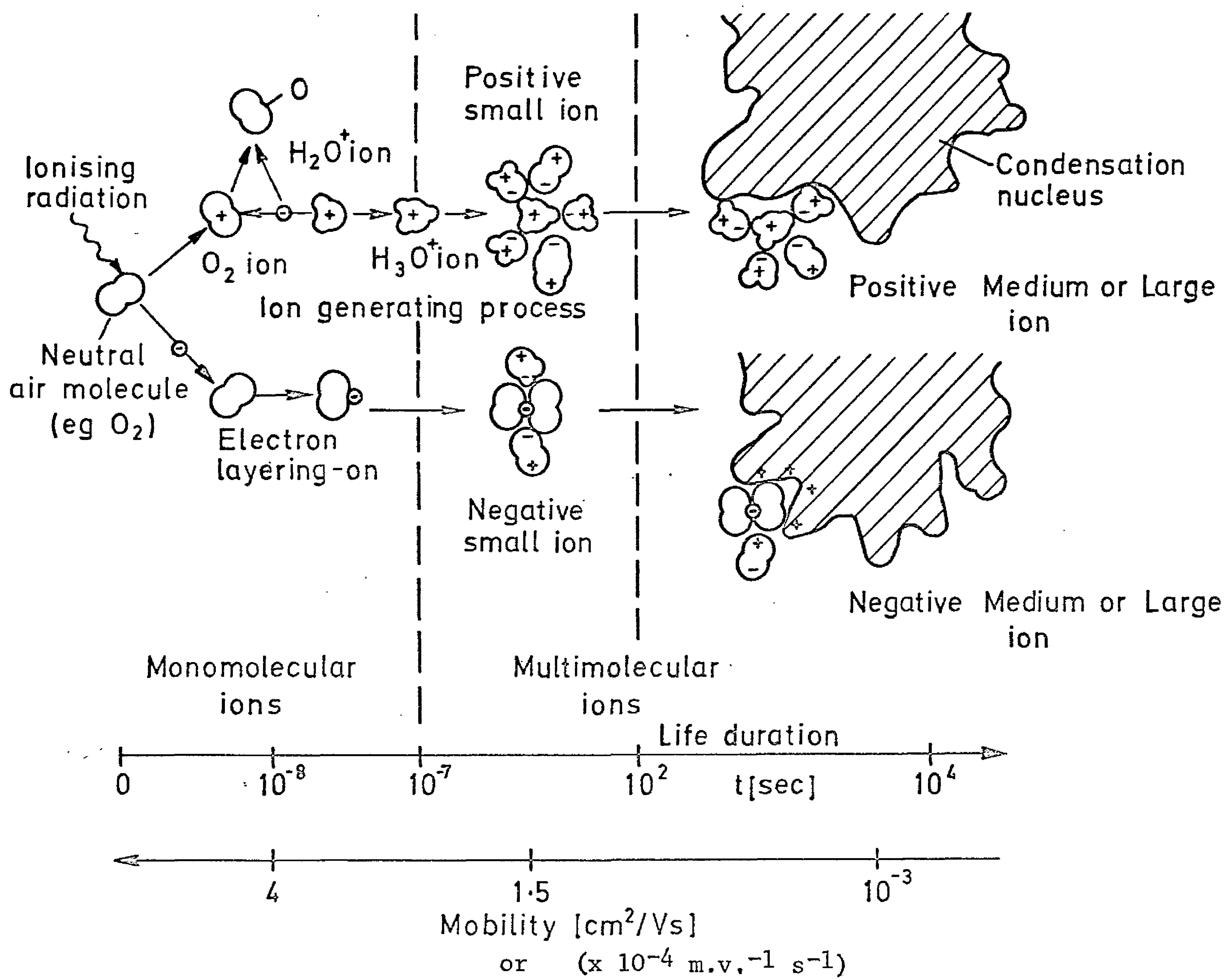
Eichmeier (1968) has tried to analyse the structure of small, naturally occurring air ions further. Assuming monomolecular ions and using the kinetic gas theory he finds that the known mobility of small natural ions is too small. On this basis he concludes that small ions are molecular clusters which are formed by polarisable air molecules grouped round the central ionised one. He still had a number of questions about the ion structure the answers to which can be summarised as follows. Small ions under atmospheric conditions are generally mixtures of molecules, the ionised nucleus can be $H_3O + (H_2O)n$, O_2^+, O_2^-, NO_2^+, NO_2^-, NO^+ or NO^- on to which a limited number of other air molecules (mainly water but also oxygen, nitrogen or carbon dioxide) layer themselves for short periods, a change in the actual layering-on molecules taking place continually. The number of layered-on molecules is less on the negative ion than on the positive. This accounts for the often quoted statement that negative ions are relatively faster than the equivalent positive one from an ion pair.

LARGE IONS

It is known, and to be expected from the above considerations with regards to the layering-on energy of molecules, that the larger charge carriers are not formed by progressive snow-balling of molecules on to small ions, but by the attachment of small ions to already present (uncharged) particles suspended in the air. Figure 2.1. shows the processes of formation and probable structure of the small and large atmospheric ions according to Eichmeier (1968). The time scale shows the order of magnitude of ion lifetimes and the mobility abscissa the order of magnitude of ion mobilities.

Large ions were originally discovered by Langevin and are commonly referred to by that name. Their mobility range is between 3×10^{-8} and $8 \times 10^{-7}\ m^2.v^{-1}.sec^{-1}$ (3×10^{-4} and $8 \times 10^{-3}\ cm^2/v.sec$) but Chalmers (1957) states that it is sufficiently accurate to take the average mobility of the large ions to be $\frac{1}{500}$ of that of the average small ions.

Whereas the small ions are not much larger than molecules the large ones are of considerable size and comparable to the nuclei on which Aitken (1880) found condensation of moisture when the air became saturated.



O
H_2O^+ ion
Positive small ion
Ionising radiation
Condensation nucleus
O_2 ion
H_3O^+ ion
Positive Medium or Large ion
Ion generating process
Neutral air molecule (eg O_2)
Electron layering-on
Negative small ion
Negative Medium or Large ion
Monomolecular ions
Multimolecular ions
Life duration
0
10^{-8}
10^{-7}
10^{2}
t[sec]
10^{4}
4
1·5
10^{-3}
Mobility [cm^2/Vs]
or ($\times 10^{-4}$ m.v.$^{-1}$ s^{-1})

Figure 2.1.

CONDENSATION or AITKEN NUCLEI

When he first discovered them Aitken considered these particles to be of such substances as evaporated sea water or soluble constituents of industrial smoke. Chalmers is careful to point out that condensation of water does not take place on coarser smoke or dust particles, but only on nuclei or large ions. He is insistent that the nuclei consist of substances soluble in water; in some cases, at least, the nuclei are hygroscopic, and the condensation may take place when the relative humidity is less than 100%.

There is a growing tendency, Eichmeier (1964) and Siksna (1961), to adopt a change in nomenclature for these particles and to call them kernels as first suggested by Chalmers to avoid confusion with atomic nuclei.

MEDIUM or INTERMEDIATE IONS

These were first described by Pollak (1915), but Chalmers appears a little sceptical of the limits of mobility suggested by some authors preferring to think of a continuous spectrum through from small to large. However, Schonland (1953) puts limits on their mobility (between 2×10^{-5} and $1 \times 10^{-6}\ m^{2}.v^{-1}.\ sec^{-1}$) but qualifies this by saying that they are only found in special meteorological conditions, such as low humidity, in association with molecular clusters of industrial origin probably oxides of sulphur or sulphuric acid. Further reference to this low humidity weather phenomenon and its biological significance will be made in a later chapter.

ION PRODUCTION

There are three principle agencies responsible for the ionisation occurring in the lower atmospheres; radiation from the radioactive substances in the earth, radiation from the radioactive substances and gases present in the air, and cosmic rays.

EARTH RADIOACTIVE EFFECT

Elements such as uranium and thorium are found extensively distributed in the earth's crust. The surface layers therefore emit α, β, and γ-rays into the air, and the local ion levels will depend greatly on the surface and geological conditions.

The effect of α rays is negligible since they are capable of penetrating only very thin layers of either soil or air. Any ions produced will be confined to the earth-air boundary layer of a few centimetres. β - rays can penetrate a bit further, arriving from a greater depth in the soil they are responsible for most of the ions found in the layer of air up to about 10 m. To the atmospheric physicist the γ-rays are the most important, their powers of penetration are far greater, therefore they can come from greater depths which means there is more material available for their production.

They can also penetrate further into the atmosphere and are still effective at a range of 1 km from the surface. The radioactive content of sea-water is very small in comparison with that of soil and rocks so the earth radioactive effect over the oceans is negligible.

AIR RADIOACTIVE EFFECT

Emanations such as radon and thoron are contained in the atmosphere as decay products of radium and thorium within the earth. They escape from the earth's crust by diffusion, natural thermal convection and as a result of a decrease in the atmospheric pressure. The greater portion of the ionisation produced is due to α-rays from the emanation since there is no absorbing layer between the disintegrating atom and the air. The radioactive gases and their products are fairly evenly distributed by atmospheric turbulence through the lower air. The air-radiation effect varies according to locality and falls off very rapidly with height also like the earth-radiation effect over the sea it is negligible.

COSMIC RAYS

Until 1911 it was thought that the ionisation inside a closed vessel was due entirely to emanations from the walls and radioactive matter of the earth and outside air. It was therefore concluded that the ionisation would decrease with altitude. Hess in 1911 and Kolhorster in 1913 tested this theory using balloons and found that it was true up to a height of about 1 km but then it began to increase.

This led Hess to postulate "cosmic" radiation which has a penetrating power considerably greater than the γ-rays from radioactive bodies and travels downward to the earth's surface undergoing a certain absorption on the way. Cosmic rays therefore produce ions at all levels from the ionosphere to the earth.

IONISING POWER

To summarise the effects of the three ionising agencies it is convenient to use the term ionising power, "q", to represent the number of ion pairs produced per c.c. of air per second in air at N.T.P. Thus $q = xI$ where I is one ion-pair/cc/sec.

According to Schonland,

$$q = q_e + q_a + q_c \qquad \text{where}$$

				over land	over sea
q_e	=	ionising power of earth	=	3·5I	0
q_a	=	ionising power of air	=	2 I	0
q_c	=	ionisation due to cosmic rays	=	1·9I	1·9I
q		....	=	7·4I	1·9I

These figures summarise the relative importance of the three natural means by which small air ions are generated. The values quoted are measured in free air near the earth's surface and are therefore of biological significance.

More recently Robinson and Dirnfeld (1963) have quoted figures of 4·0 I for q_e, 4·6 I for q_a and 1·8 I for q_c. The large disparity between the quoted values of q_a probably lies in the height that they were measured. Schonland does stipulate that his figure applies to a location at sea-level measured one metre above the ground surface. At this height q_a and q_e will be subject to considerable fluctuations due to local conditions and later in his book Schonland does use a value of 11 I for q in some of his calculations.

OTHER SOURCES OF NATURAL IONS

Before moving on there are two further sources of ions which must be mentioned. Parts of the broad spectrum of electromagnetic waves emanating from the sun, especially ultra-violet rays, produce relatively intense ionization but this is confined to much higher levels of the atmosphere. The direct effect at ground level is insignificant (Hansell 1961) but indirect results influence us via the weather.

The second minor way in which ions are produced is of very local significance only, it is known as the Lenard or waterfall effect. Lenard found that when a fine spray of water is produced so that the droplets fall through a constant positive potential gradient the charges on the droplet orientate themselves in such a way that in colliding with themselves or the ground the positive charge is retained and the negative one is passed into the air.

The air near waterfalls and fountains has a freshness, even up-wind, which is attributed by some people to this increase in negative ion content. Several other workers have found that the separation also occurs when water drops are broken up by air currents such as the very large vertical currents in thunder-clouds, resulting in positively charged water droplets and negatively charged air within the cloud.

DESTRUCTION OF IONS

There are three ways in which a small ion is lost in the atmosphere, if it is assumed that large ions of multiple charge do not exist naturally. It may recombine with a small ion of the opposite sign and revert to a collection of separate air molecules. By combining with a condensation nucleus it can become a large ion or by neutralising the opposite charge on a large ion they revert to an uncharged nucleus and a group of neutral air molecules.

Large ions cease to exist as such by combination with a small ion or large ion of the opposite charge.

AVERAGE LIFE OF A SMALL ION

The life span of small ions depends mainly upon the concentration of condensation nuclei in the air. Where atmospheric pollution is high for example at Kew in Central London the average life is short whereas in mid-ocean it is relatively long. Chalmers calculates the average life from the formula

$q = \beta n$ where q = number of ion pairs/cc/sec
β = dissipation coefficient
($\frac{1}{\beta}$ = average life)
n = no. of a particular type of ion

TABLE 2.2.

Area	q	n	$\frac{1}{\beta}$
High pollution	11 I	200	20 secs
Low pollution	11 I	550	50 secs
Mid-ocean	2 I	600	300 secs

Table 2.2. summarises the interaction of ion production and availability of condensation nuclei. From this it is apparent that there is an inverse relationship between small ion content and condensation nuclei content, the more polluted the atmosphere the lower the small ion count and higher the large ion content.

NATURAL LEVELS OF IONS

It has been found that the great majority of naturally occurring ions carry only one charge either positive or negative. Over land areas large ones considerably outnumber the small ones often in the ratio 10:1. The normal numerical range of small ions of each sign is from 300 to 1,000 per cubic centimetre in the air over land and 300 to 700 per cubic centimetre over the sea, whereas the large ions number from 1,000 to 80,000 per cubic centimetre over land but only about 200 over the sea.

In view of their comparative freedom from capture over the sea, it is surprising to find that the number of small ions over land areas differs very little from the count in mid-ocean, this can be explained by a decrease in the rate of production over the sea as well as a decrease in the rate of destruction.

CONDUCTIVITY OF THE AIR

Coulomb (1795) appears to have been the first to notice the conductivity of the air, in particular the leakage through the air of the charge from an electrified body. It was left to others to show how this was brought about. The leakage is achieved by the charged body attracting ions of opposite charge to itself and repelling ions of the other sign. Many laboratory experiments have been performed to investigate ionic conduction using artificially produced ions but the results confirm that natural conductivity of air is almost entirely due to small ions. The actual value of mobility depends upon humidity, pressure, presence of nuclei and age of ions. Near large towns where the nuclei and large ion counts are extremely high the conductivity of the air is influenced by large ion participation; about 15% of its value being derived from this source (Schonland).

The ionising effect of cosmic radiation increases with altitude and as one would expect from the increase in small ions produced and the reduction in the number of available condensation nuclei, the conductivity of the air increases. At a height of 18 km the conductivity is about 100 times the usual value at ground level. This was confirmed in 1935 using the United States army balloon Explorer II which also recorded that ionisation of the air increased by roughly

500 ion pairs per km.

SPACE CHARGE & POTENTIAL GRADIENT

If we imagine a line of force originating on each positive charge and dropping vertically to earth the density of lines of force across any area parallel to the earth gives a measure of the potential. A comparison with the number across any other parallel area of equivalent size is a measure of the potential gradient between the two regions. If there is a difference in the density of the lines of force there must be charges present on which the extra lines of force have commenced or on which the missing lines have ended. Thus a change of potential gradient with height involves space charges.

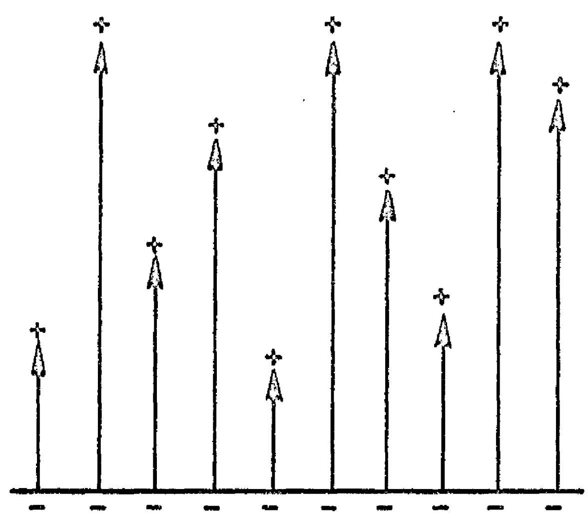


Figure 2.2. Lines of force in the earth's normal potential gradient.

Figure 2.2. shows the lines of force and the charges at their ends in a typical case of a positive potential gradient which decreases with height above the earth. This is an oversimplification because in the atmosphere not only are there positive charges but negative ones, all of which are in a very dynamic state. Any excess of ions of one sign represents the space-chage. Therefore, to find out whether lines of force end within any given volume, it would be necessary to measure the number of lines entering the volume over its entire boundary. To obtain a complete picture of the distribution of charge in the atmosphere it would be necessary to monitor all points simultaneously.

The idea of the electrical potential at a point was first introduced by Lord Kelvin. The definition of the potential difference between two points is the mechanical work (in joules) per unit charge necessary to move a small positive charge from one point to another. For practical purposes the earth (a conductor) is regarded as zero potential and all other potentials are measured relative to it although it is known that the earth does carry a surface negative charge. By convention the downward direction is adopted as the positive direction for potential gradient in the atmosphere.

According to Schonland the average value of the fine weather potential gradient is about $100\,\mathrm{v.m}^{-1}$; the corresponding value for the average charge density is $2{\cdot}7 \times 10^{-4}$ e,s.u. squ. $\mathrm{cm.}^{-1}$ or 0·0009 coulomb $\mathrm{sq.km.}^{-1}$

VARIATIONS OF POTENTIAL GRADIENT & SPACE CHARGE

In the immediately preceeding consideration of the various electrical constituents of the atmosphere it is assumed that the portion of ground is flat and far removed from projections such as trees and building which would disturb the distribution of charge and concentrate lines of force at certain points.

There is a decrease of potential gradient with altitude and it has been estimated that at a height of 18 km the field has fallen to less than $\frac{1}{100}$ of its value at ground level. This diminution of potential gradient with height indicates that a free positive charge practically equal to the negative charge on the surface of the earth, resides within the lower 18 km of the atmosphere.

As well as variations vertically from the earth the potential gradient over land areas varies considerably with local conditions, but in fine weather conditions its sign is positive over the earth's surface. The mean value at Kew is $317\,v.m^{-1}$ while at Davos in Switzerland it is only $64\,v.m^{-1}$. Over the oceans a value of $126\,v.m^{-1}$ has been found with little geographical variation.

Schonland concludes that the potential gradient observed on land is not a quantity of much fundamental significance its value depending primarily upon local conditions of atmospheric conductivity. He, of course, is an atmospheric physicist but it is just such parochial variations which might be important to the biologist. The considerable local changes which occur before and during thunderstorms may be the cause of symptoms which enable sensitive people to forecast the ensuing storm.

AIR-EARTH CURRENT

In the ordinary fine-weather conditions positive ions are driven earthward while negative ones are repelled; the motion of these ions constitutes a downward directed conduction current. The current passing through $1 \times 10^{-4}\ m^2$ of a horizontal plane is very nearly 2×10^{-16} amps. From measurements all over the globe this current changes much less than does the potential gradient and is less affected by purely local conditions. Its importance has been neglected by atmospheric physicists and completely ignored by biologists as already mentioned (Tromp 1968).

DISCUSSION

In reviewing the various electrical parameters it has been carried out in a broad uncomplicated manner from the atmospheric physicists view point where he is concerned with large scale manifestations affecting weather. Obviously, as has been mentioned in passing, over land there are many complicating factors: for example, the effect of large contours, even small projections, such as trees and most significant the effects of man's "civilised" ways all have local influences. By an unfortunate choice of building material or by siting a building over earth rich in radioactive material, unnatural local levels of ions may be produced. To quote a specific instance, this was the coincidence which happened to the Atmospheric Physics Department at the University of Uppsala (Siksna 1963).

Over a number of years great difficulty was experienced in obtaining satisfactory insulation of the very sensitive electrometers in use. By a close investigation it was shown that the reason for the effect was the very high concentration of radon permeating the builing from the basement. Measurement of the content of radon showed that it was between 10 and 30 times greater than is normally found at other than exceptional places. The direct consequence was that the small ion count was 3 to 10 times higher inside the building than outside. Down in the transformer room in the basement the small ion counts reached nearly 20,000 per cc of each sign on one occasion, while the large ion count was 1550 positive and only 350 negative per c.c. Siksna wonders what the long term biological effects of such high levels of small ions might be and also what the health hazards are with concentrations of radon often at the tolerance limit. Bach (1967) has investigated health aspects of the radio-activity of the soil but this will be discussed in a later chapter.

There is a diurnal variation in ion levels when measured over land, the minimum occurring early in the morning between six and eight a.m. coincidental with an increase in the relative humidity and number of condensation nuclei. The maximum occurs during the night usually before four a.m. with a secondary peak about two p.m. and subsidiary trough about nine p.m. These fluctuations can only be demonstrated in fine weather conditions with very light winds. As soon as fluctuating weather conditions are superimposed the picture changes markedly and small regional conditions are the only important ones biologically.

The best documented of these regional climatic phenomena are the characteristic warm dry winds which are found in certain places and all of which have local names. There have been many suggestions as to why they produce quite dramatic effects on some people, while very similar climatic conditions elsewhere have none. Similarly there are some people who can sense impending thunderstorms but not every storm. Thunderstorms are heralded by fluctuations in pressure, temperature, wind and reversals of potential gradient, a mixture of climatic and electrical changes. Not all thunderstorms show all of these changes, it is possible to have thunder without a reversal of the potential gradient, perhaps these are the ones which are missed. In thunderclouds there is usually an excess of positively charged rain and negatively charged air

(Lenard effect) but identical conditions prevail in ordinary rain, perhaps the intensity is different. There is a third type of rain, showery or squall rain which has a preponderance of negatively charged droplets with positively charged air. However, this is an area where very little work has been carried out by the physicists and Chalmers hastens to point this out, perhaps there is a sufficiently great change in the potential of the air to be sensed or perhaps the air-earth current flowing in the opposite direction is the stimulus. So far I have found no mention in the literature of the reversal of the air-earth current having any significance physically or biologically. Perhaps the air-earth current flowing through our bodies is not quite as important as it once was when our ancestors literally had their feet on the ground. Dr. Stopes (1956) thinks otherwise, expressing her opinion as follows; 'the soft foam rubber mattress is an example of a modern "advance" to be avoided by all who value their health. It is pernicious. Do not use any rubber mattress, and do not have rubber-tyred wheels upon your bedstead. Why? Because rubber is an insulator, and cuts you off from electric currents of the earth with which you should be in contact. Many, sadly many people are insulating themselves incessantly. Rubber-soled shoes all day, and then rubber covering to their floors, small rubber wheels on their beds - alas, poor things, they are being devitalised. No wonder millions at the end of the day feel limp and exhausted .....'

CHAPTER 3

ARTIFICIAL PHYSICAL ENVIRONMENT

ARTIFICIAL PHYSICAL ENVIRONMENT

INTRODUCTION

Dr. Stopes makes the point very forcibly about insulating ourselves from earth and its possible effects on physical well-being. With the advent of man-made fibres and controlled environment, by walking about in a room with low humidity very large static charges may be built up on a person. The nature and sign of the charge will be discussed later when the triboelectric series is considered, but these charges may be sufficiently high to affect the ion concentrations within the room and will certainly influence the ionic content of the air being breathed (Andersen 1965). A person in a field-free room who is at zero potential will be able to inhale ions of both polarity, if he is now charged positively he will attract negative ions and repel positive ones. With a moderate charge the negative ions will be attracted into the air in the vicinity of the person and be available for inhalation, but if the charge is very high then the ions will quench themselves on the person and not be available for breathing. Thus, if one believes that the modus operandi for ions is via the respiratory tract then too high a charge is just as bad as none at all for influencing the ionic content of the surrounding air. In carrying out this type of investigation in the laboratory, instruments for generating artificially air ions of both types are required. Instruments to monitor the ions produced and potential gradients are also required, these will be reviewed in this chapter.

ION GENERATORS

Since ions were discovered at the turn of the century many people have been using them as therapeutic agents. Various types of generators have been constructed with apparent success to the inventor but other investigators have had little or no response from their patients, even though they have been using what would appear to be the same equipment. This perplexing situation stimulated Nagy (1961), of the Westinghouse Electrical Corporation in the United States who no doubt had a vested commercial interest, into an analysis of the various methods of artificial ion generation. A similar review was carried out by three Russians, Baranova, Bulatov and Vasil'yev (1957) but they were rather parochial in their outlook, however the paper is valuable in that it does summarise the vast amount of work which had been done in Russia up until 1957.

CHARGE SEPARATION

This type of generator relies on the Lenard or waterfall principle already mentioned. The Russians call them hydro-dynamic aero-ion generators because their machines use water jets but water is not a pre-requisite of this method. Under certain circumstances when fine dust particles are blown through metal air conditioning ducts momentary contact is sufficient to dislodge an electron to the wall with a resultant charged particle.

The ultimate preponderant sign of ion will depend upon the type of dust, duct material and traces of adsorbed gases or impurities on the particles. Nagy suggests that the ions reported in the Fohn winds of the Alps and Chinook of North America are probably produced by charge separation of the rapidly moving dust in a dry atmosphere. Although he was unable to find any data as to the number of electrons attached to each particle, the work of Israel on dust and Lenard on waterfalls suggests to him that each aerosol particle is likely to have attached to itself a number of charges.

The first hydro-dynamic aero-ion generator was made in Germany. Water under very high pressure was forced through a fine nozzle charged either positively or negatively with respect to earth, with the result that the water was atomized and electrically charged. The charged aerosol was directed on to the patient by a fan.

A second type of hydro-dynamic generator which has the advantage of not requiring a potential on the nozzle has been extensively used in Russia. It tries to emulate the Lenard effect of thunderclouds. Water under very high pressure is sprayed into hemispherical bowls or rotating drums causing the air to be negatively charged, this is blown towards the patient and the waste water drains from the bottom of the bowl or cylinder. There are many variants of this principle see Baranova, et al. (1957), it is attractive for clinic use since there is no high potential involved and no complicating electrostatic field, however the number of ions produced is limited, although the proportion of negative is high. Generators of this type are often referred to as ballo-electric generators rather than hydro-dynamic generators especially in the Russian literature.

THERMIONIC EMISSION

Metals and other materials will emit electrons when heated to high temperatures, the number so emitted depends upon the temperature and thermionic emission characteristics of the material. By combination with particulates or gas molecules (especially oxygen) of the air, ions will be created. The number of ions produced from common heating elements such as nichrome and platinum is small, however if certain salts are placed on these hot elements, the emission of ions can be increased. Barium, calcium and magnesium oxides all have this property.

Dessauer working in Germany pioneered the early work on biological effects of air ions in the 1920's and 1930's. He used the thermionic method of ion generation in his experiments with purified magnesium oxide compressed into rods and heated to a temperature of 900-1,000°C by platinum elements to produce ions. Electrons would be liberated by both the platinum and the magnesium oxide however, as the air was blown over the element to remove the ions, sub-microscopic particles of MgO were also dislodged from the compressed block. Dessauer considered magnesium oxide to be a physiological material safe enough to breathe, however later workers have shown that platinum and iridium ions were the principle ones inhaled (Pavlik 1967). Very high ion counts have been claimed, in the order of 1 - 10 million ions per c.c. with a high negative content. These figures no doubt are for total ion counts because counting equipment at this time was very primitive. The proportion of small ions was thought at that time to be high but because of the high concentrations of electrons in the vicinity of the generator it is now considered that what appeared to be small ions were large ions with multiple charges. It is also significant that the Russian workers who claim high quantities of small ions from their generators were actually making the measurements only 10 to 15 centimetres from the device.

Earlier it was stated that metallic elements when heated to high temperatures emit electrons but Martin (1952) and Sikena (1952) have shown that positive ions can be generated by impurities in the air striking hot filaments. The effect can be demonstrated by blowing smoke over hot nichrome wires and measuring the positive ion current under the two conditions.

Perhaps the first major contribution to ion research in the United States was made by the Wesix Electric Heater Company when they tried to find out why some electric heaters were making people uncomfortable. The conclusion which Beckett came to was that electric heaters inherently produce positive ions, generated by the incandescent materials.

CORONA DISCHARGE

At one time the corona discharge method of producing ions was the most widely accepted but because of adverse by-products it was superceded and is only just regaining its popularity. Considering the high voltages involved it is surprising that it was so extensively used, but where a treatment room can be set aside in a clinic exclusively for ion-therapy the discharge points can be mounted well away from the patients. Corona discharge has been extensively used in the ionisation and precipitation of dust from the air industrially, so commercial equipment was readily available; another reason for its apparent popularity.

Generally an electric potential is applied between two electrodes one of which is usually a wire or series of wires, of very small diameter or a series of needles. The very high electrical field surrounding the needle tips produces large numbers of negative and positive ions. If the needle is negatively polarized any positive ions are readily collected and the negative ones repelled to the opposite electrode. The high potential gradient in the space between causes more than one charge to be deposited on dust particles etc. which results in abnormally high small ion counts. Thus, an experimenter working in a dusty atmosphere may believe he had a large number of intermediate or small ions which in truth are large ions with multiple charges. Nagy concludes that since most of the work on air ions has been conducted in atmospheres of varying dust concentrations this effect could account for the many inconsistancies encountered.

The reason that the corona discharge method went out of favour was that the early generators produced ozone and various oxides of nitrogen as noxious by-products. The early dischargers were usually mounted in the ceiling, well away from patients, so that very high potentials were employed to give high counts of 1×10^6 ions/cc of unipolar ions near the patient. As well as high concentrations of unwanted gases the large field strength was also regarded as a possible health hazard.

Radio-active materials became more readily available about this time and appeared at first sight to be ideally suited to the production of air ions. As research tools isotope generators probably are the most convenient, but always in the background of pure research there has lurked the electrical appliance manufacturers, who have stimulated much work in the United States. The Wesix Electrical Company produced not only the best commercially available ion counter but re-awakened interest in the corona discharge method of ion generation (synonymous with the Russian Electro-effluvial aero ion generation) by manufacturing instruments which produced very low concentrations of contaminants. The instruments although they may still have a relatively high voltage (up to 10 kv) are comparatively safe and may be used near patients.

RADIOACTIVE EMISSION

Various radioactive materials have been suggested and used in the production of air ions although in Russia, work has been concentrated mainly on Radium. Alpha emitters are the most efficient ion generators because their action is confined to a small volume surrounding the substance. Nagy quotes as an example, one alpha particle from polonium 210 is capable of producing about 150,000 ion pairs. Also because the electron affinity of oxygen molecules is greater than nitrogen ones, a proponderance of negatively charged oxygen is produced. In the absence of a potential gradient there is a very rapid recombination of the ions producing neutral atoms. With a properly designed housing for the radioactive substance, a regulated air flow and a suitable voltage gradient, positive ions will be removed and mainly negative ions emitted. However, the process of ion formation by this method is by attachment and the number of charges on a particle will certainly be less than in a corona discharge where the attendant field is high.

Radioactive materials have some disadvantages. Polonium has a half-life of only 138 days and must be specially prepared and covered with thin layers of gold or other foil to prevent the escape of radio-active material into the air. Radium D with a half-life of 22 years is more suitable but very great care in shielding is necessary. Verigo working in Leningrad has used minute quantities and claims that beta and gamma radiations are only three times normal and radon materially the same.

Recently tritium with a half-life of $12\frac{1}{2}$ years dissolved in zirconium has been introduced as an ion generator. It is a soft beta emitter of low energy, Siksna (1959), so that most of the ion production takes place very close to the zirconium surface. Again by polarising the element to one sign, ions of the opposite with a high proportion of single charges may be produced almost exclusively.

ULTRAVIOLET RADIATION

A fifth type of aeroion generator is based on the ionising capability of short-wave ultraviolet rays produced by a mercury-quartz lamp. There is not sufficient energy present to ionize ozygen or nitrogen molecules directly but electrons are liberated from dust particles or nearby metal objects and produce ions by attachment. Ozone, formed by dissociation of oxygen if the wave-length is short enough, may be a complicating side effect, but by suitable choice of surrounding metal the wave-length need not be too short to produce ions.

Since only electrons are ejected from the metal surfaces, only negative ions will be produced. The quantity of negative ions produced is not nearly as high as with some of the other forms of generator and it has the added drawback that patients must protect their eyes against the ultra-violet light.

DISCUSSION

Each of the ion generators described has its advantages and shortcomings, but just how natural are the emanating ions? The obsession over the years has been to produce devices capable of at least 1×10^6 ions per cc. with a very low coefficient of unipolarity. This is defined as the ratio of positive ions to negative, thus the higher the coefficient the higher the positive content. The normal environment has a coefficient of 1·2 and in the Russian literature a coefficient of zero means that the air is unipolarly charged negative.

To satisfy the obsession of high counts the corona discharge method fell into disrepute in favour of the radioactive types but just recently small corona instruments with no noxious gas by-products have been reintroduced. These two types of generator have been the most commonly used and according to Tammet, et al. (1968) their advantages are so obvious that other types of air ionizers are only experimental attempts to find new solutions. Electro-aerosols, they exclude from this generalisation since they are used for medicinal purposes other than disseminating ions.

Of the two types of generator the ions produced by the radio-active sources are probably more "natural" because even the modern corona instruments will produce many multi-charged ions, especially when the air is heavily contaminated with dust. Medium and large ions with several charges will be received in the counter and registered as small ions perhaps physiologically the same thing happens. Since according to Schonland medium ions are produced only under certain atmospheric conditions it may be that some workers have by accident chanced to produce these conditions unwittingly in their experimental rooms whereas others have not. This could account for the variable results reported in the literature and for the reluctance of some medical investigators to accept ion therapy. It would appear that basic information must be obtained in a controlled dust-free atmosphere similar to the so-called white rooms. In such rooms nearly all particles above 0·2 microns are removed from the air, those which remain would accept probably only one charge no matter what the method of generation.

ION COUNTERS

One difficulty with all of the ion counters in common use is that, since they sample the air by an aspiration method, they disturb the environment which they monitor. Tammet et al. (1968) mention a test-plate method which makes it possible to measure the flux density of air ions which they say characterises the effect of air ions on the surface. This seems to be a device for use with artificial generators which can be used to measure the space charge at some distance from the generator, probably the area to be occupied by a patient or test subject. They give no details except two formulae, one for the calculation of air ion flux density and the other relates flux density to concentration of air ions. However, they go on to describe the aspiration methods as more adaptable and precise.

EBERT COUNTER

Figure 3.1. illustrates the basic cylindrical aspiration condenser ion counter designed by Ebert in 1901. His was slightly more primitive in that it only had the central collecting electrode, the deflecting voltage being applied to the case of the instrument, and the electrometer was not the sophisticated electronic instrument we know today.

From this counter have evolved present-day forms where in some the electrometer signal is recorded as a current, giving a continuous indication of the ion level, or as in the alternative version, accumulates the charge over a small time interval and displays the amplified output as a voltage, at the end of the time interval the electrometer is earthed and the collecting process restarts. With this type of collector very short term fluctuations are not recorded, dips caused by large multicharged particles cause transient voltage fluctuation often not noticed in the recorded tracing.

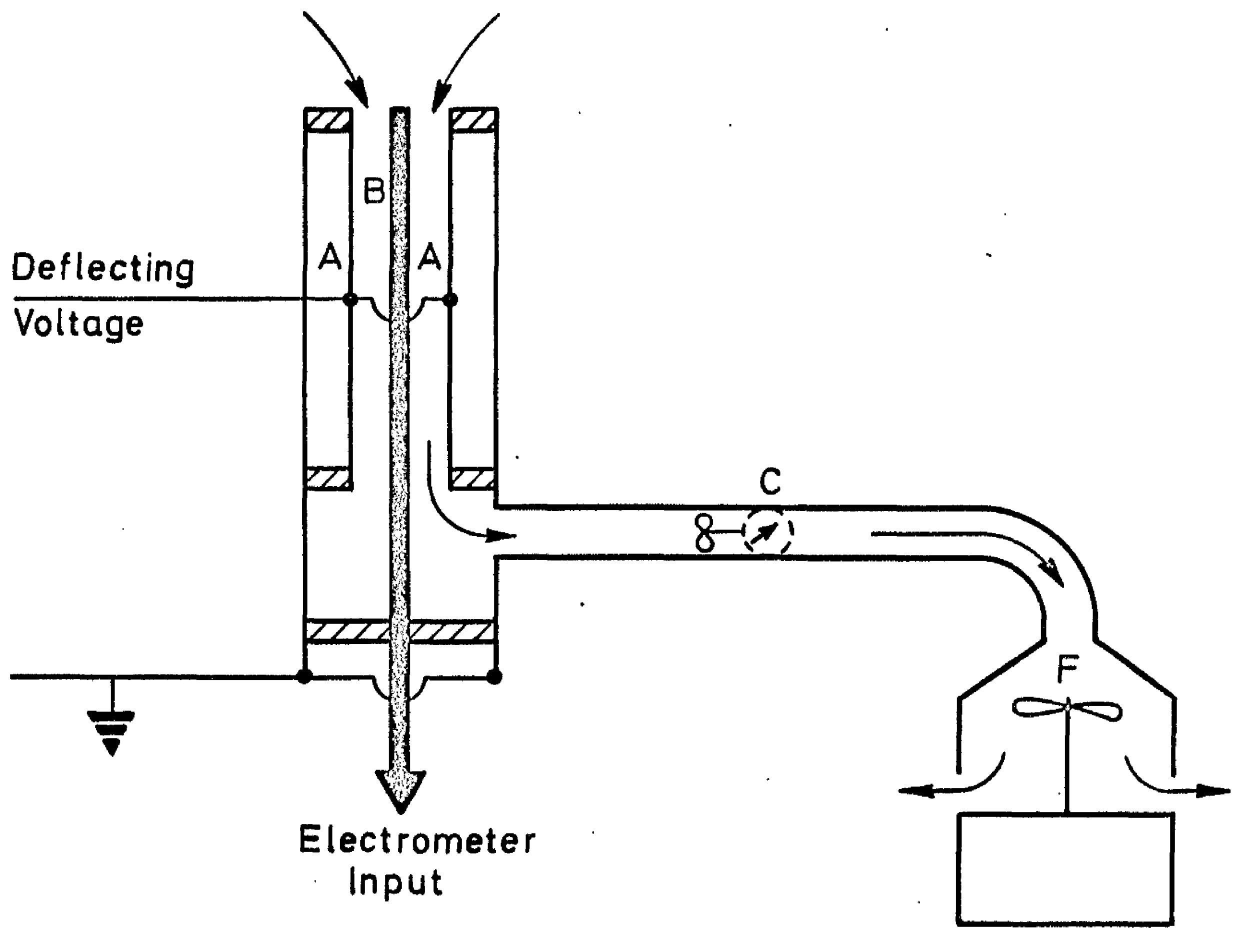


Figure 3.1. Improved Ebert Ion Counter.

Recently new types of ion counters have been developed but always on the Ebert Principle mainly to overcome faults in the elementary form. Figure 3.2a. shows the essential parts of the Ebert counter with a voltage which might be as high as 1000 v applied to the outer cylinder. Hock & Schmeer (1959) calculated that errors up to 25% were possible because of the stray electric fields on the outside. They showed experimentally that as V is increased n(the number of ions counted) increases initially but then decreases. Figure 3.2b. shows the curve obtained (b) with their simple counter whereas curve (a) illustrates the calculated response if no stray currents prevail. Small ions are being "side-tracked" from the counting electrode in greater numbers than the number of large ions attracted by the now higher deflecting voltage. By adopting the form indicated in Figure 3.2c. not only is the outer electrode at earth potential but also the inner electrode is recessed and shielded against end effects. Depending upon the ion concentration actually present the curve obtained is displaced between the curves indicated a^{1} and a^{11} in Figure 3.2b. The counter illustrated in Figure 3.1. was designed about the same time and it has the deflecting voltage electrode inside the body of the instrument which is earthed.

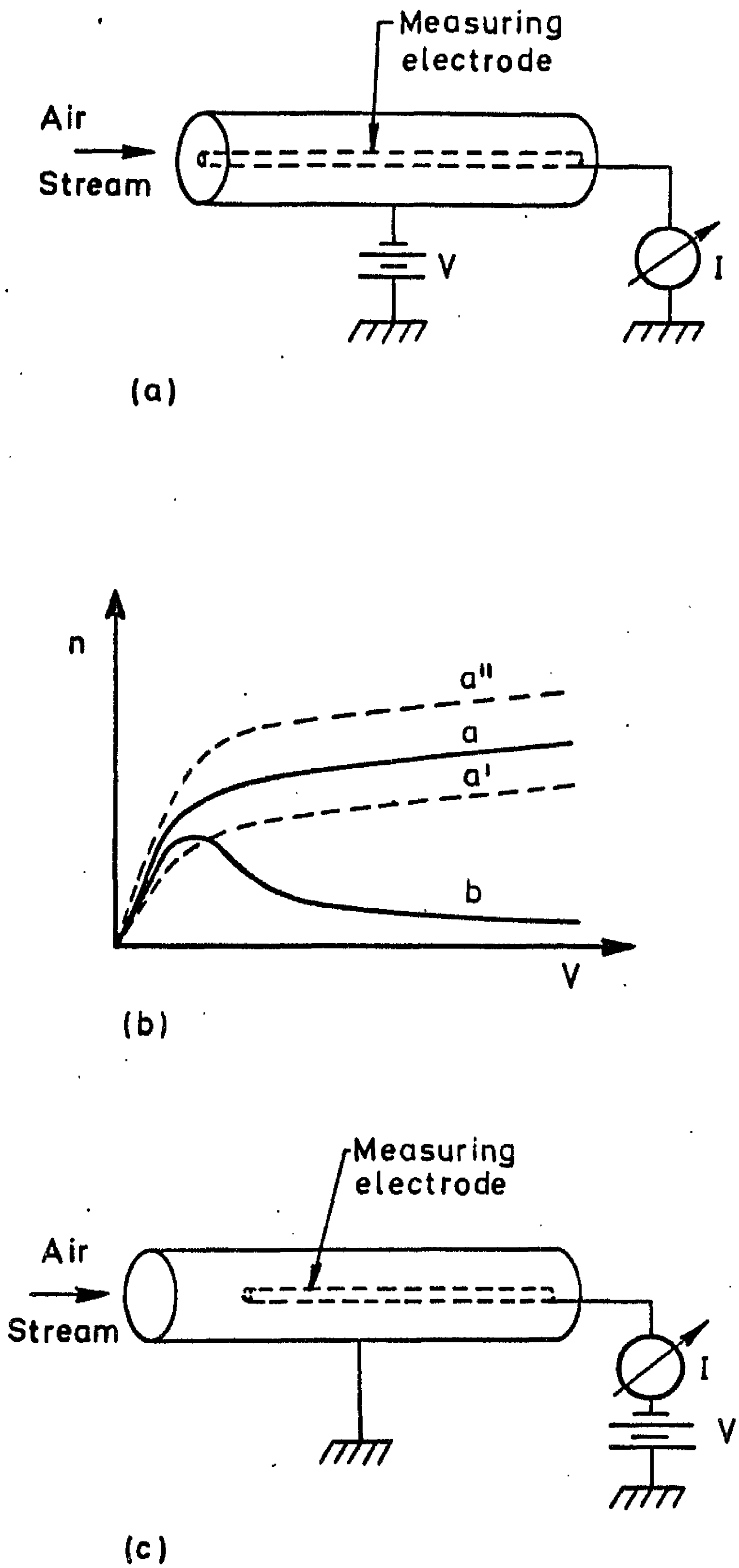

Measuring electrode
Air
Stream
V
I
(a)
n
a"
a
a'
b
V
(b)
Measuring electrode
Air
Stream
I
V
(c)

Figure 3.2.

The hatched areas are P.T.F.E. insulating material. Not illustrated is a heating element which is wrapped round the outside of the deflecting cylinder. Hoch (1961) had found that humidity could affect the insulators especially if the device was used out-doors: to prevent this a simple low-wattage heater was incorporated.

Collectors can be constructed to suit particular measuring problems, but certain design parameters are common to all types. The internal surfaces must be clean and polished to minimize air turbulence otherwise the sensitivity will be impared. Similarly the air velocity must be sufficient to provide a minimum ion current but not high enough to cause turbulence. As already illustrated the polarizing plate must be electrically shielded from the space being sampled and also the collecting surface must be similarly shielded and well insulated. The size and shape will depend upon the ion mobility range to be measured, and to a lesser extent the air velocity and polarizing potential; the more versatile the machine, the larger it becomes. Usually if only large ions are to be measured, a small ion trap is necessary in series. Beckett (1961) says the practical design limit is a collector which will provide an ion current of 10^5 ions/sec with a sensitivity of 20 ion/cc, this is good enough for measuring ions in room air, where the normal density is between 500 and 1,000 small ions/cc of each polarity. Unfortunately the Philco Model ICF6. counter available in this laboratory of similar design to that illustrated in Figure 3.1. does not meet this specification of Beckett and is therefore limited in value when the ion counts fall below 500 ion/cc.

Technical improvements of the Ebert collector (sometimes also called the Zelény collector) were started at Uppsala University by Norinder and Siksna (1949), and carried on by Eichmeier at the Institute for Technical Electronics in Munich. Since 1959 there has been a very close association between these two establishments with the result that since 1968 Eichmeier has published a series of papers (Eichmeier, 1968, 1969 a and b) dealing with the physics of small ions, how to measure them, a critique of the apparatus: also a heavy ion counter and condensation nuclei counter. The results of his work in terms of commercially available instruments are not yet complete but technical information is very fully supplied in the literature.

WESIX COUNTER

Eichmeier deals also with the parallel plate condenser ion counter which relies on the same principles as the classical Ebert type but which has a number of parallel plates of alternating potential. This enables the physical dimensions of the elements to be kept to a reasonable size especially when large ions are to be counted. Originally this type was developed at Stanford University in conjunction with the Wesix Electric Heater Company and is therefore known as the Wesiz Ion Counter.

The Wesix Model IV has a set of four collecting plates interspaced between five polarizing plates (Figure 3.3.) The collecting plates are set on pedestal insulators of polystyrene which are housed specially to prevent their surface being charged by the air friction. The insulator compartment is also heated to counteract humidity effects. The body of the instrument acts as a guard shield against stray electric fields and the same design parameters apply to this type equally as to the concentric capacitor type.

In both types calibration of the air velocity over the collector is a critical feature of the instrument. The ideal concentric type would be as illustrated in Figure 3.1. where the fan F could be varied and the change in air flow monitored by an anemometer C. A similar arrangement for periodic calibration of the blower is necessary with all aspiration systems.

One shortcoming of the aspiration condenser system which has always been recognised is that when set to collect small ions a number of medium and even large ions will be trapped. Figure 3.4a. illustrates this. The collecting electrode is A, and B is the deflecting one. With a certain potential applied to B all ions of a mobility greater than kg indicated by BC will be collected. But so will ions, M, of lower mobility if they enter the counter near enough electrode A. If the ions of lower mobility are in much greater numbers than the fast ones the error could be significant but unknown unless the slow ion count is also registered. Ideally what is required is an ion

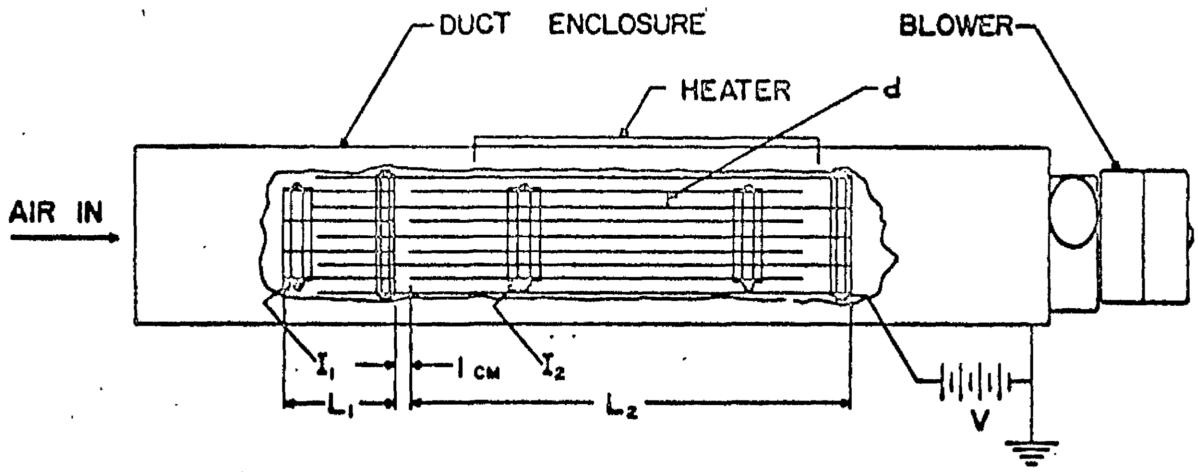


FIGURE 3.3. The Wesix Parallel Plate Counter

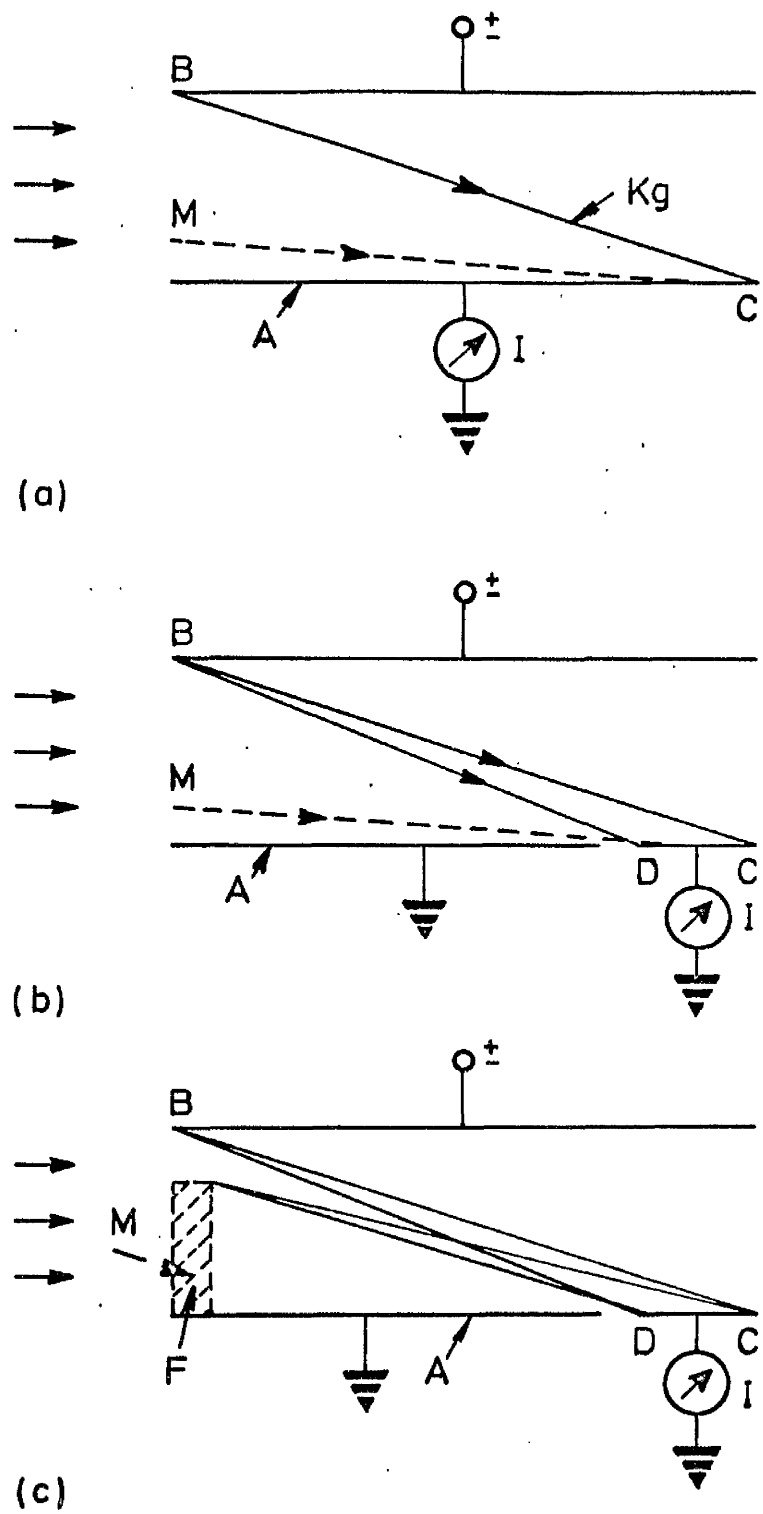


Figure 3.4.

spectrometer. Eichmeier (1969) has carried out a mathematic appraisal of the problem, calculating limit mobilities and re-solving power of different plane aspiration condenser systems. In Figure 3.4b he has split the measuring electrode A into an earthed part and a measuring part DC. Ions within a specific mobility band can be tuned on to DC but stray ones, M, will still be recorded. By putting an ion-trap F in the air stream the ions recorded on DC will have an even more specific mobility range indicated by the four lines arriving on DC, Figure 3.4c.

The schematic diagram Figure 3.3. of the Wesix Counter is an extension of the Wesix Model IV and is in fact two counters, small ions are counted by portion L_1, and slower ions on portion L_2. This is a first step towards an ion spectrometer, but since the air-flow through the instrument is fixed information is restricted to two bands of mobility of one sign of ion at any particular time.

Siksna and Lindsay (1959) have drawn attention to the effect of space charge inside the ion collection especially when the ion density is high. The effect is only marked when small ions are being counted in the presence of large quantities of large ions because the deflecting voltage required is very low. However, if small and small medium ions are the biologically active ones then these are of primary importance in experimentation. Since a great deal of work on the effects of air ions has been carried out using very high quantities of artifically produced ions under varying circumstances, one wonders how reliable the quoted ion counts are.

SCHMEER ION COUNTER

This portable ion counter was built in a very compact form to monitor small ions and its mobility range in restricted to small ions. It consists of nineteen small cylindrical condensers coupled in parallel through which air is aspirated in the normal way. It is mentioned here because it was the first attempt to build a compact battery operated small ion counter for field work. When reference is made to a Schmeer type counter in the literature the author is stating that his apparatus has a number of condensers in parallel and it is specifically for measuring small ions.

SUMMARY

To sum up the state of the art, there is as yet no ion spectrometer capable of a quick scan of the existing ion levels in a room. The Wesix Model V of the existing counters is capable of producing information on a range of mobilities of one polarity over a short time scale. This counter is used in conjunction with a Beckman Model V micro-microammeter to give an overall accuracy of about 12%; somewhat better than the 25% accuracy of Hock & Schmeer's cylindrical Ebert type, although later developments probably have the same accuracy as the Wesix. So much depends upon the quality of the electronics as well as the aspiration system.

The response time is also a function of the electronics, according to Beckett (1961) a typical value of response speed for a vibrating reed type of instrument is 4 seconds at 3×10^{-13} amp range. A mobility spectrum can be built up in steps of several minutes each by altering the deflecting voltage, the precise time for each step depending upon the speed of response of the micro-microammeter. One disadvantage of this arrangement although it gives a continuous trace of the mobility distribution it requires a high speed recorder which produces a large quantity of chart paper if used for any length of time. For long-term experiments the Philco counter produces a voltage reading roughly every two minutes, conservative on recording paper but very inadequate in other respects (see Part 2).

Accuracy will vary from instrument to instrument depending upon the accuracy of construction especially in the parallel plate type and how well the aspiration system maintains its original calibration; most commercial units do not have an anemometer incorporated.

Electric fields built up between the counter and its surroundings will affect the distribution of ions, as will the airflow through the instrument. Ion counting although a great deal more refined than in the mechanical eletrometer days of the 1930's, still leaves a great deal to be desired, perhaps the theoretical analyses of Eichmeier will become physical realities.

ELECTRIC FIELDS

As well as the electrio field generated by the ion counter, an ion generator when used in a confined space will create its own electric field. Any occupant of the room when moving about will also generate on his person a charge, the magnitude of which will depend upon the climatic conditions prevailing, how well the person is earthed and the variety of clothing. We are all becoming familiar with the crackling of items of clothing as we undress or the effect of walking about on new synthetic material carpets and then brushing against some well earthed metal object. If the atmosphere is particularly dry quite large sparks may be produced, the result of a discharge from an accrued potential of several thousand volts. Ths polarity of the charge is of no consequence in producing a spark, but it does influence the surrounding ions. A few people respond so strongly that they are forced to notice that they cannot tolerate some types of material. The time may come, according to Hansell (1961) when clothing and room surface materials will be graded and labelled according to their position in the triboelectric series. Many investigators have prepared lists of solid substances arranged in such an order that when any two substances in the list are rubbed together the substance higher assumes a positive charge. Table 3.1. gives the electrostatic or triboelectric series devised by Lehmicke (1949)

Positive End

Glass

Human hair

Nylon yarn

Nylon polymer

Wool

Silk

Viscose rayon

Cotton

Paper

Ramie

Steel

Rubber

Acetate rayon

Orlon acrylic fibre

Saran

Polythene

Negative End

Table 3.1. ELECTROSTATIC SERIES ACCORDING TO LEHMICKE

Hansell feels that one solution requires action on the part of the manufacturers of clothing and room covering material to correct for unusually large electrical charging effects, either by control of their composition, or by application of corrective finishes. Dupont has a material called Baymal which always tends to assume a positive charge; this could be incorporated with predominantly negatively charged fibres in order to cancel or reverse this effect. But according to Froger (1961) negatively charged fibres, especially P.V.C., have a therapeutic value.

Although the voltages may be high the energy levels are very low. Rogers (1967) gives some values of energies involved in discharging helicopters and the possible physical effects if this is achieved through a person. While painful, in his experience, reactions can be controlled up to energy levels of 0·5 joules. For energies in excess of 1·0 joule it is expected that limbs might be thrown clear of contact points and in excess of 2·0 joules persons may be thrown clear bodily. He also points out that if voltages become high enough certain dielectrics, skin included, break down with a resultant lowering of the resistance path to earth. Normal skin resistance is in the order of $50\,k\Omega$ whereas body resistance is only $500\,\Omega$, thus peak currents could be increased a hundredfold. Hazard to life and limb from a build up of "static" on clothing of such magnitude is not likely, but it can be disturbing. Several authors suspect that charge may have a direct biological effect, but more usually it is considered to act by influencing the availability of ions as will be seen in the next chapter. For those practising ion therapy to prevent excess build-up of charge the most direct solution, according to Kranz and Rich (1961), is to earth the subject and avoid synthetic clothing such as nylon, dacron and rayon, but cotton is acceptable. Where the surface conductivity is high the accrued charge will be limited, the importance of moisture content of the fabric in increasing the conductivity has long been recognised, Hayek and Chromey (1950). They documented some work done earlier by Slater (1924, 1925) who found that the conductivity of cotton was over one thousand times greater at 60% relative humidity than at 20% although the moisture content rose only 5%. Herein lies the basic difference between natural fibres and synthetic, the first are much more wettable than the latter.

CHAPTER 4

THE BIOLOGICAL EFFECTS OF GASEOUS IONS AND ELECTROSTATIC FIELDS

THE BIOLOGICAL EFFECTS OF GASEOUS IONS AND ELECTROSTATIC FIELDS

INTRODUCTION

In a recent exposition on the biological significance of atmospheric ions, A.P.Krueger (1968) introduces the subject in the following manner.

> "Frequently medical progress is characterised by a series of evolutionary stages; first, some fortuitous observation that application of an agent - usually in crude form - ameliorates some disorder; next, a protracted period of empirical trial in a variety of conditions followed by recognition and/or isolation of the active ingredient. Then a further period for the performance of laboratory and clinical tests to elucidate the mechanisms responsible for its action, and finally, the formulation of a set of principles for the use of the agent. Medicine traditionally embraces this time honoured sequence, and understandably it exercises great caution in approving and adopting any new therapeutic tool".

Kreuger would like to think that the development of air ion therapy is now into the third stage, especially in a number of European countries. In some other nations, especially the

United States, despite the efforts of some enthusiasts the whole subject has been viewed by the medical profession with suspicion and misunderstanding. Even in some countries where ion therapy is practiced there are many sceptics.

In the following review of the literature it would be very easy to be critical and sceptical because generally few details are given of how well the more usual environmental parameters were controlled or measured. This is especially so in view of the effect of air movement found in the third experimental series (Part 2) of the present investigation. Since in all forms of ion generators air must be blown over the ionizing head, and generally the experimental material is very close to this, effects may be the result of a different air flow rather than what it contains. Could it be that the bistable results found by Knoll et al. (1961) and the many unconfirmed findings are due to climatic differences rather than ions? With this proviso the literature has been reviewed always trying to keep an open mind.

At the Fifth International Biometeorological Congress at Montreaux 1969, there was a plenary session set aside for a discussion on Climatotherapy in mountainous regions. There were seven leading exponents from a number of European countries who introduced the session with a brief resume of their particular clinic's speciality.

The first speaker, Prof. H. Jungmann of Germany, outlined the parameters of climatotherapy at altitude and enumerated five known factors from which beneficial results were derived. The five factors are, air temperature, PH_2O, PO_2, U-V radiation and lack of air pollution. It was quickly noticed, and frequently suggested, by its devotees in the ensuing discussion that a sixth parameter, namely the electric content of the air was missing from the list, and should be added. However, none of the representatives of the established mountain clinics present on the platform, was convinced enough of the beneficial action of air ions to have thought of using ion therapy.

From the time that ions were first discovered at the turn of the century, until Dessauer published his book on inhalation therapy in 1931, the work on air ions was confined mainly to physicists and climatologists. The work of Dessauer in Germany, and that of Tchijevsky (1938) published a little later in the U.S.S.R., marked the beginning of this new era.

Dessauer put his subjects, including himself, into a small room with heavy concentrations of negative or positive ions. He noted that the subjects felt more comfortable and exhilarated when the atmosphere was negative, but when exposed to positive ions they were cross and irritable and suffered from dry throats, headaches and nausea. The Russians claim prior discovery to the premise that negative ions are beneficial to human health and advantageous in the treatment of certain diseases. Vasil'yev attributes this to a hygenist (Skvortsov) and a climatologist (Sokolov). Strength was added to the premise when it was noted that negative ions often predominated in localities long known as climatological health resorts. This led Tchijevsky to construct a special apparatus to produce negative ions which he used for laboratory experiments and later for treating patients. He became organizer and director of a Russian Institute specializing in this field and his publications have spanned more than thirty years, culminating in a book, "Aeroionization in the National Economy". It was not until 1950 that negative ionization became a special, permanent undertaking of the U.S.S.R. Academy of Sciences. Now there are five main research centres, including the Pavlov Institute of Physiology, where work on this subject is a speciality.

In 1958, Dr. Kornblueh one of the leading American authorities in this subject, visited Russia and found that the medical schools taught the physical and medical aspects of ionization as part of the curriculum, also there were about a hundred hospitals using ionization equipment for the treatment of a number of diseases. The diseases for which the Russians indicate negative ion therapy and where they claim successful application include:

peptic ulcers with no tendency to haemorrhage; pulmonary tuberculosis; bronchial asthma; acute and chronic catarrhs; some neuro-dermitoses; slow-healing wounds; avitaminoses; certain arthritic and rheumatic conditions; some forms of hypertension and certain psychoneuroses. The outstanding feature of the treatment is the large quantity of negative ions administered. Patients must be placed very near the generators where the ion counts are in the order of $1 \cdot 5 \times 10^6$ ions/cc and they are subjected to this for periods ranging from 15 to 30 minutes on twenty to twenty-five consecutive days.

It was not until late in the 1940's that American research workers became seriously interested in this subject. Perhaps the first major contribution stemmed from Wesley Hicks and J. Beckett, president and chief engineer of the Wesix Electric Heater Company, who were anxious to find a satisfactory answer to why certain electric heaters made some people feel uncomfortable. Before the war two prominent research workers in the climatic physiology sphere, Herrington (1935) and Yaglou (1935) both became interested and published rather inconclusive results of their laboratory studies with ions. However, they were disturbed by the war, and have unfortunately never returned to ion research.

While the electric appliance manufacturers in America have always been generous with financial and technical help in stimulating research at certain University Hospitals, the Armed Services have also contributed, especially the United States Navy. Since the advent of atomic submarines with submerged operating capabilities of long periods of time, the effects of ionization on men and materials has become very important. Considerable work of a fundamental nature has been carried out for the U.S.Navy by Professor A.P.Krueger and his co-workers at the University of California. He and Dr. J.L. Worden are now the leading authorities on the fundamental aspects of the actions of air ions, while Dr. Kornblueh is the doyen in the clinical field, outside the Russian block countries.

Due to the war, the work in Western Europe was severely disrupted; Dessaur was forced to move to Switzerland and his research effort petered out. Bach (1967) working in Denmark because of personal circumstances became interested in the effects of air ions and from 1950 until 1961 he worked in comparative isolation establishing that negative ion therapy was beneficial to asthma - his asthma, which he contracted about 1950. He is a professional electrical engineer so his training was a great help in his early researches, but it was only in 1961 when he attended the International Conference of Ionization of the Air that he realised the full scope of the physiological importance of ions. Since then his research efforts have been taken over by the Hygene Institute at Aarhus University. Bach (1967) is unique in his approach to the subject of Ion Therapy by tackling the problem, not as an ameliorative exercise, but from the preventive aspect. He distinguishes between the two by calling them Active and Passive Techniques.

PASSIVE TECHNIQUE

Not being a physician Bach had to rely on others for the conducting of some of his experiments. Two female asthmatics had been obtaining relief using Bach's negative ion generator, but it was noticed that the effectiveness of the treatment seemed to depend on where it was administered. In one case there was a noted difference between two rooms in the same house and in the other case treatment in the patient's home was completely useless, whereas it had been giving good results before. The conclusion arrived at was that, in the rooms where no alleviation of symptoms was obtained, the negative ions were being quickly destroyed.

Dust immediately came under suspicion because the lady who had had negative results with the ion generator in her own home, had noticed that when visiting a friend's house her attacks disappeared. On testing there was no difference in the behaviour of the dust samples from both houses and the signs of the electric charges on the two were identical. However, the experiments carried out with the dust demonstrated the great difference to be found between surfaces of different materials against which it was blown. Bach had just discovered the significance of the triboelectric series. He used wool as his reference, not a good choice. since it is too high in the series, and rubbed the various surfaces in the room with it, then measured the charge collected. Surfaces which charged the wool positive he associated with adverse effects on subjective feelings of many asthmatics. The premise here being, that if the wool became negative, so would any dust blown across the surface rubbed by the wool, and it was better to have negatively charged dust than positive. This is only true if the dust happens to occupy the same place as wool in the triboelectric series. Later on it was realised that the magnitude of the charge was also important, but Bach was now experimenting with surface treatments which would reduce the tendency for materials to charge domestic dust. He suggests that it is for the manufacturers of the materials to incorporate something which will establish electrical conductivity within the material as homogeneously as possible.

PASSIVE TECHNIQUE IN ANIMAL HUSBANDRY

Bach (1967) tells how a Danish farmer noticed over a long period that there was a marked difference in conditions between two of his poultry houses despite the fact that they were the same size and built almost identically. Out of 20,000 chickens, considerably more died in one house than in the other. The only difference in the construction of the two houses was that in the bad one the roof was lined with masonite sheets, smooth side down, and in the other house it was underdrawn with boards.

The farmer also noticed that when thundery weather threatened the death-rate increased, so he suspected the air-electric charge as a contributory factor. Radio-active radiation was measured in both houses, but the levels were identical, however the electric field strengths differed markedly. Subsequently, field measurement was carried out frequently.

The field conditions which depend upon the dust conditions were governed by the age of the chickens. When they were small the dust consisted mainly of particles from the litter, which was usually negatively charged, but as the chickens grew the dust from the feathers predominated and it was positively charged. The incidence of positively charged particles was always much higher in the masonite clad building. Inside the buildings the dust was deposited in an even layer in the boarded roofed building, whereas in the other the dust had agglomerated. Outside there was ample evidence of dust on the roof around the ventilators of the first house, but nothing on the roof of the bad building. Antistatic treatment reduced the mortality rates in the two houses to the same level.

Hearing of Bach's success with the poultry, the Agricultural High School sought his help with a problem they had with some pigs, tail-biting. The tail-biting occurred with different frequency in three sties of practically the same type. The maximum field strengths measured in the three sties were 3500 $v.m^{-1}$, 700 $v.m^{-1}$ and 100 $v.m^{-1}$ and the incidence of tail-biting was highest in the first and least in the latter. The problem was resolved once again by the application of anti-static agents.

An atmospheric physicist would be much more familiar with the equipment used by Bach in the type of investigations just described. These took a long time and used skills which are those of a research scientist rather than a practicing physician, which would exclude this technique from the armoury of the ordinary doctor. From Bach's work there would seem to be some asthmatics who derive benefit from the investigation of their electric climate; what is still unknown is which other forms of allergy and diseases could be treated similarly.

Prevention is only one aspect of the role of air-ions, as already indicated in the introduction. There is a wealth of evidence to suggest that it may have a part to play in clinical medicine.

EFFECT OF AIR IONS ON MICRO-ORGANISMS

Tchijevski (1938) and his colleagues in their early studies were the first to demonstrate the effects of air ions on bacteria. They showed that the growth rate of several types of coccal bacteria was inhibited by both negative and positive ions (5×10^4 - 5×10^6 ions/cc) when cultured on agar plates.

the negative being much more inhibitory than the positive. Tests on the natural microflora of the air in enclosed spaces or on artificially created bacterial aerosols showed that similar ion densities rapidly reduced the viable cell counts of air samples.

These results have been extended by a number of observers in America who because of communication difficulties were probably unaware of the extent of Tchijevski's work. The amount of data accumulated over the past thirty-five years has been reviewed by Krueger (1968) and he claims unanimous agreement that unipolar ionized atmospheres of either charge exhibit a moderate inhibitory effect when colonial growth of bacteria or fungi on agar surfaces is measured. When vegetative cells are exposed in aerosol form both types of ions increase the exponential decay rate and negative ions also have a bactericidal action, Phillips (1964). It is almost certain that Tchijevski used a corona discharge generator for producing his ions. Phillips certainly did; he used a Philco RG-4 at its maximum setting for all his experiments in a small chamber, so it is not surprising that both polarities had an effect. He showed that the fan of the generator did increase the physical destruction rate in a control experiment, but what this did not expose was the effect of the 9kv. potential and the contaminants produced by the discharge.

However, not all gaseous ion action on micro-organisms is lethal in character. Krueger mentions some work by Zacharias who noticed that the efficiency of nitrogen fixing Azobacter vinelandii was materially increased by the replacement of non-ionized, with positively ionised nitrogen.

EFFECT ON PLANTS AND INSECTS

Hansell (1961) in his post-conference summary commented on the lack of papers dealing with the use of ions in horticulture and ventures to suggest that ions must be as important to vegetables as they are to animals. He uses as an example mushrooms which have often exhibited baffling seasonal variations in production which may well be explained by fluctuations of air ions amongst a host of other variables.

If little work was being carried out at that time, the influence of electrical effects had been suspected for a long time. Krueger quotes several workers in the latter half of the eighteenth century who severally noticed effects which were summarized by one of them (Beccaria) as follows:-

"It appears manifest that nature makes extensive use of atmospheric electricity for promoting vegetation".

Also in the nineteenth century a few years before ions were demonstrated, Lemstrom reported that an electrical discharge from metallic points placed above cereal seedlings produced a detectable stimulation of growth.

During the first half of the twentieth century the only work of significance seems to have been by Blackman (1923 & 1924) and his colleagues who conducted a carefully controlled study of the growth of the coleoptiles of individual barley seedlings exposed to an electrical discharge in the absence of light. After determining the growth rate for an hour prior to treatment it was compared to the rate during and after a five hour exposure to the discharge. An increase in the rate of growth was observed with both polarities of charge but it was significantly greater with positive, and it continued for several hours after cessation of the discharge. Blackman and his co-workers considered that the observed response was a result of the passage of current ($0{\cdot}5 \times 10^{-10}$ amp from a point discharge) through the coleoptile and that air ions were used simply as the conducting medium. They eventually extended their studies to field crops of oats, wheat and barley; of 18 satisfactory experiments, 14 showed increases in crop yield. The continued benefit from a treatment with ions could also be explained by extra nitrates being available from the fixation of atmospheric nitrogen by the corona discharge.

Krueger (1966) and his associates at the University of California have since 1960 carried out experiments on barley, oats and lettuce growing in pollutant-free air under very strict atmospheric conditions and accurately defined nutrient solutions. Their experiments have demonstrated that high concentrations of both negative and positive artificial ions accelerate certain physiological functions of plant cells through stimulation of known metabolic mechanisms. Air ion depletion produced a significant reduction in growth of Hordeum vulgaris seedlings as measured by integral elongation, fresh weight and dry weight. Similar effects have been found by several authors, Blackman and Krueger included, if the plants are grown within grounded wire cages (Faraday cages).

To test Blackman's hypothesis that the current through the plant was the important feature and not ions, Krueger (1964) again used Hordeum vugaris seedlings grown under his very rigorous conditions. Concentrations of O_2^+ or O_2^- averaging $1{\cdot}8 \times 10^4/cm^3$ in oxygen enriched air accelerated growth rate while a like number of CO_2^+ or CO_2^- in CO_2 enriched non-ionized air had no effect.

At this point Krueger found that CO_2 ions in the presence of CO_2 enriched air had toxic effects but CO_2 ions of either polarity in normal air acted as a stimulus to growth, results which he is at a loss to explain as yet. Since one of the features of a small ion is the free exchange of layered-on molecules in the ion with the surrounding gas (Eichmeier 1968) it is difficult to see how Krueger can be so sure of this concentrations and little wonder he became baffled.

Work on insects is very scant and because of this there is no corroboration of evidence. The moulting rate of aphids is stimulated by an increase density of negative ions or a drastic reduction of positive. Variations in the electrical field with no attendant elevation of ions also acts as a stimulant or depressant depending upon the field strength. Krueger's (1956) school tested the effects of air ions on the growth rate and moulting of silk work larvae (Bombyx mori L.). This activity is very dependant upon a hormone produced in the prothoracic glands whose primary function is to stimulate the biosynthesis of cytochrome C and possibly other cytochrome components.

The following effects were noted 1.) a marked increase in the rate of larval growth, 2.) increased biosynthesis of cytochrome C oxidase, 3.) earlier onset of spinning, 4.) an increase in weight of cocoons and development of heavier silk layers. Krueger mentions, but puts little emphasis on his findingsthat by increasing the air temperature of his controls from 24°C to 26°C spinning started on the 38th day as against the 46th; this was three days earlier than by ion action.

In all of these experiments with insects quoted, the changes were statistically significant and readily reproduced.

Krueger's apparent rambling willy-nilly through the plant and animal kingdoms is not as haphazard as it might seem. He is seeking to establish a theory of the action of air ions which involves the enzyme cytochrome C or close relatives, and in the next section his experiments are extended into the higher realms of animal evolution.

AIR ION ACTION ON MAMMALS AND MAN.

As in the case of ion-induced changes in plants their influence on vertebrates was postulated by Beccaria and independantly by l'Abbé Bertholon in the middle of the eighteenth century, but it was not until the second decade of the twentieth century that serious work began in Germany and Russia. The paths pursued by the various research efforts are naturally diverse and now, almost half a century later one can generalise by saying, that in Russia experimental studies have taken second place to the application of ions for therapeutic purposes, while in America and some European countries, although ions are used for therapy the dosage is very much less than used by the Russians, and the whole subject has been approached with much more caution and a great deal of scepticism. Basic research has gone along hand in hand with clinical application, the bulk of the research emanating from the Krueger school and to a lesser degree from Worden (1953 & 1954) and his colleagues, Kornbleuh and his associates have used ion-therapy extensively in a variety of clinical conditions.

MODE OF ENTRY

Various mechanisms which logically could be expected to play a part in the biological activity of gaseous ions were analysed by Tchijevsky in the light of existing experimental data. Krueger (1968) states that it is generally agreed that both skin and the respiratory tract are ion receptors but the latter is the more important. The same could be said about these organs being receptors for protein macromolecules which produce allergy reactions similar to some of the reported effects of air ions. Tchijevsky claims direct action through the skin of ions on nerve receptors which produce functional changes in internal organs. Recently McDonald et al. (1965) claim to have substantiated this finding with experiments in which anaesthetised rats were subjected to negative and positive ions but prevented from breathing either. Under these circumstances the heart-rate was unaffected by negative, but slightly retarded by positive, an effect opposite to what they found when the ions were breathed.

Tchijevsky considers that 78% of the ions of various sizes inhaled reach the alveoli where the action may take place. However, this view is disputed by the evidence produced by a number of workers and no one has really stated with any conviction the fate of ions in the respiratory tract. Skorobagatova claims that small ions are completely absorbed by the lining of the naso-pharynx and heavy ion concentrations increased. Surely some of the small ions are utilized to produce the large ions during the humidification of the inspirate and are not, therefore, completely absorbed. The fate of the heavy ions as they pass down the trachea depends very much on the species of animal used, Nagy (1961) however, believes that only intermediate ions can remain in the lungs during respiration and that large particles would be caught in the upper respiratory tract. The most recent work of all is that of Schaefer (1969) who, experimenting with dogs, has shown that when large quantities of ions are used a considerable percentage of small ones can be recovered from the finest ramifi-cations of the bronchial tree. Unfortunately full details of Schaefer's work have not yet been published.

Pavlik (1967) has calculated the existence of a central electrostatic filter in the upper respiratory tract by determining the bioelectrical potential of the mucous membranes. He believes that this filter actively removes some of the small ions during mouth breathing; his analysis did not extend to other mobilities. Another factor which has been investigated by Andersen (1965) is the important one of ambient electrical fields. His results indicate that the presence of electrical fields reduces the oral intake of small ions. This would underline the importance of knowing what sort of charges are being built up on our exterior. Our ancestors with their feet on the ground would have in fair weather conditions a positive charge of only 200 V on their heads when standing, while we with rubber soled shoes and modern fibres in our clothing are responsible for generating several thousand volts of either sign capable of repelling the ions or attracting them with such force that they are not available for breathing.

One other natural feature of our micro-environment which Andersen's models overlook is the normal convective currents of air sweeping upwards over our bodies. From the initial work carried out on nude erect subjects the vertical air current in the nose region can be as much as 0·5 m/sec, Cox et al (1969) and Lewis et al (1969). Lewis's main concern is the role this current of air plays in transporting micro-organisms from the clothing to the respiratory tract, their preliminary findings have shown that the micro-environment contains significantly more micro-organisms 30 - 400% than does the ambient air. Obviously the clothing and the charges generated theron will become important as this study extends but already Lewis has formed the hypothesis that this mechanism provides the link between some skin diseases such as eczema in children and asthma which often follows the eruption.

MODE OF ACTION

If one grants that mixtures of ions reach the alveolar area, many unanswered questions remain regarding the mechanisms which enable them to bring about physiological changes. According to the Tchijevsky school the possible chain of events may include the following:- light ions might penetrate the alveolar barrier and reach the blood directly; or, the oxygen ion fraction of medium and heavy ions penetrates into the blood while the condensation nucleus part remains in the alveolus; or, upon impact on the alveolar wall the ion regardless of size, affects the blood cells and capillaries by electrostatic induction. The alveolar area then acts as a double electrical layer so that the blood component acquires the same sign of charge as the incoming ion. Krueger states that much of the Russian work has led them to conclude that molecular ions of oxygen enter the bloodstream and are therefore free to pass to and act at any part of the body. Vasilyev (1960) has however stressed the action of air ions on the endings of the pulmonary afferent nerve fibres with resultant alteration in the functional state of the central nervous system and through it the peripheral organs. He quotes much evidence from experiments by himself and fellow Russians (Baranova et al 1957) which supports the existence of a complementary action by neural and humoral mechanisms.

KRUEGER'S THEORY.

It was mentioned earlier about the Krueger school (1965) being involved with the enzyme cytochrome C and its relevance to the action of ions. During the past twelve years studies have been going on testing the effects of gaseous ions on rabbits, mice, rats, guinea pigs and monkeys, as well as on plants and micro-organisms. The observations have led Krueger (1966 ' 1968) and his colleagues to evlove the 5 - HT (5-hydr. -oxytryptamine or serotonin) theory of air ion action.

Following exposure to high concentrations of positive ions the tracheal mucosa became vasoconstricted, the posterior wall on examination through a tracheotomy aperture was contracted and the mucus escalator was slowed. Negative ionised air reversed these effects. Subsequently it was shown that CO_2 must be present in positively ionised air to generate the characteristic effects while O_2^- ions are responsible for their reversal. All the physiological effects of positive ions on the trachea could be duplicated by the intravenous injection of the powerful neurohormone 5-hydroxytryptamine and reversed with negative ion treatment.

This led to the theory that positive ions bring about a local accumulation of 5-HT and that negative ions accelerate the rate at which 5-HT is oxidised. Supporting evidence for this theory has gradually been built up using such tools as reserpine, a drug which causes tissue depletion of 5-HT, and a great deal of biochemical analyses of invivo and invitro material.

SIZE OF STIMULUS

The air at sea level contains some $2{\cdot}7 \times 10^{19}$ molecules per cc. A total of 2,700 positive and negative ions per cc. would represent a relatively high natural density which means that only one ion is present in 10^{16} molecules of air. This deceptively large ratio led Prof. F.B. Loeb of the University of California at Berkeley to report to the air conditioning industry in 1934 that it would "seem ridiculous in the extreme" to expect biological effects from any agent existing in such homeopathic dilutions. This argument has often been used to prove that any effect of ions is absurd, but Krueger (1968) opposing it, quotes two examples where biological systems are capable of responding to minute stimuli. His first is that the human retina is sensitive to a single quantum of light and the second is that the male silk worm can react to the sex attractant pheromone of the female in concentrations less than 200 molecules per cc. of air. Kingdon (1960) has calculated that a single small ion has chemical and electrostatic energies about 6eV or 10^{-11} erg. Since it is possible for a human respiring in an artificially ionized atmosphere to inhale as many as 5×10^8 ions with each breath, he may inspire approximately 3×10^9 eV, which is still only 5×10^{-3} erg.

Krueger concludes his discussion on this subject with the following analogy. The situation seems comparable to that confronting the bumble bee whose flight, although proven by theory to be an aerodynamic impossibility, is yet a fact of life. Thus there is something wrong with both theoretical structures - one which dooms the bumble bee to an earth bound existence and the other which utilizes a very weak logical ploy to establish the biological insignificance of air ions.

DISCUSSION OF PHYSIOLOGICAL EFFECTS

Air ions seem capable of evoking a wide range of response, for example, Krueger claims to have found an increase in growth rate of barley seedlings of 60% and Silverman and Kornblueth (1957) obtained a 2% - 10% change in the alpha frequency in the electro encephalogram. Variations in the findings of different workers are not surprising in view of the large variations in ion generating and counting equipment used. In many cases reproducible outputs were not possible from day to day. However, this persistent inability of workers to reproduce the effects shown by others is disturbing. Andersen (1969) gave a communication at the Fifth Interternational Biometeorological Congress in which he challenged the now almost classic experiment of

Krueger and Smith (1958 & 1962) in which they demonstrated the effects of negative and positive ions on ciliary rate and mucus flow. He concluded that what they had shown could be due to a lack of control of climatic parameters, especially temperature and humidity.

Species differences and subjective individual variation must also play a part. The administration of any active agent or placebo to a person will result in one of three things, a positive reaction, no reaction at all or a negative response. So with the administration of ions it is not surprising to find conflicting indications but these conflicts cannot immediately be used as evidence to detract from the biological value of ions. There is certainly plenty of ammunition for the detractors. For example, simple visual reaction time in man may be increased or decreased by either sign of ion quite unpredictably (Knoll 1961). Both positive and negative ions act as a stimulus to plant growth but in the case of mice positive ions raise the blood levels of 5-HT significantly and negative ones lower the level. Sometimes a response is produced by one sign and not by the other or sudden changes in natural levels stimulate a reaction. As already mentioned Krueger became confused when he used CO_2 enriched air, obtaining toxic effects when least expected.

Krueger (1968) sums up the situation by saying that it would be to the advantage of the biologist and clinician if they had at their disposal exact information about the composition of the small ions employed in their work. This could usefully be extended to cover not only small ions but a knowledge of the full spectrum of ions. Because of the influences temperature and humidity may exert on small ion concentrations these should be controlled if possible, but at least monitored. Some data (Baranova et al. 1957 and Knoll 1961) indicate the existence of a dose-related response, Krueger et al (1965) found this also in their barley seedling experiments and so did Bachman et al (1966) dealing with air ion effects on the activity rate of rats. More fastidious attention is needed to these details in the conduct of experiments and in the reporting.

In short, there is a mound of literature claiming to demonstrate the effects of air ions on plants and animals, much of which is uncorroborated by workers in other laboratories, a few of whom have reported the fact. Since people are reluctant to publish negative results one wonders if the mound would now be a mountain if all the unsuccessful ion experiments had been reported.

There is still confusion as to whether small ions do or do not get into the alveoli and if they do, how they act. Krueger's serotonin theory is attractive in that the respiratory tract abounds in mast cells which produce histamine and in certain species, serotonin. These cells could provide the necessary biological amplifier as they do in allergy reactions if they are sensitive to ions, but so far no one has suggested this. Could it be that the ions simply charge the macromolecules responsible for producing specific antigens and prevent them from being caught harmlessly in the upper respiratory tract when carrying one sign whereas the opposite charge ensures their precipitation. The large molecules could also be charged in the air by the Lenard effect under the appropriate conditions, and also by being swept up over the clothing by natural convective currents (Lewis et al 1969) as well as bellows action of the clothes.

CHAPTER 5

AEROIONTHERAPY

CLINICAL INDICATIONS

Baranove et al (1957) state that since the most favourable effects on the functional performance of the body are produced by negatively charged ions only these are used for medical purposes. As well as the sign being important so also is the dosage in therapeutic action; too small a dose produces no noticeable effect while an excess may result in an adverse response similar to the effects produced by positive ions. Therapeutic doses have little effect on healthy organisms with well adjusted functional performances of the nervous system and internal organs. The greater deviation from normal the more likely are negative ions to be effective; they claim this is especially true when patients are suffering from nervous or allergic complaints where the ions have a desensitizing and sedative effect.

What these general statements are leading up to, is the now fashionable theory that negative ions have a "normalizing" effect. To substantiate this view the Russian clinicians claim that they are equally effective in treating pathological bradycardia and tachycardia. The similarity between the ionisation couch and the psychiatrist's couch may suggest that in many cases normalisation is mere tranquillisation.

The results obtained by Krueger in his many laboratory studies, which led to his serotonin theory, would fit in with this description as well, where the effect of the negative ions is to accelerate the oxidation of 5-HT. This neuro-hormone is known to be present in some of the disorders where ion therapy has proved beneficial.

It has been suggested by Bulatov that the medical dose should be expressed as the actual number of ions received by the patient during one aeroion exposure session. To do this the subjects respiratory rate and volume must be known also the ion concentration at the patient's head. The first two variables must be monitored during the actual treatment and its duration terminated accordingly, periods of treatment usually last from 5 to 30 minutes in which time the patient may receive up to 200 billion ions.

HAYFEVER AND ASTHMA

After a course of aeroion treatment by Bulatov a complete stoppage of asthmatic attacks was achieved in 55% of his patients, and it was effective from six months to ten years. Of the remainder only 10% received no medical benefit, but he claims an improvement in their general well-being. The therapeutic effect is much more marked in the groups where the bronchial asthma is the result of a sensitivity to some allergen. A smaller effect is observed in groups of patients with a history of toxic infection of the respiratory tract as a result of pneumonia or bronchitis. It is perhaps relevant that many cases of asthma have a psychosomatic underlay.

According to Faybushevich, there are asthmatics whose attacks increase after the first treatment by hydro-aerion therapy, but these are people with a long history of bronchial asthma and suffering from a pronounced recurrence of emphysema.

In a series of rather tentative experiments Kornblueh (1958) obtained results in which about 63% of his patients suffering from hay-fever experienced relief, sometimes only very temporarily, but these were exploratory studies using minute amounts of ions compared to the Russian therapeutic doses, and no "cures" were obtained.

Wehner (1969) has been practising electroaerosol therapy rather than ion therapy and claims about the same percentage of response. What he does underline is the magnitude of the problem of respiratory ailments existing in the United States where there is great reluctance to adopt either form of therapy.

"Statistics from the Department of Health show that there are more than 10 million emphysematous patients in the U.S. More than 1 million employees are collecting social security benefits totalling almost 68 million monthly because of total disability due to this complaint. In addition an estimated 6 to 10 million suffer from bronchial asthma causing partial or total disability. These staggering figures represent not only a tragic amount of human suffering but also a significant burden to the national economy. Air pollution, once considered a professional hazard of miners and others chronically exposed to dust, has become a national problem".

In spite of the fact that several researchers have reported reasonable success in their treatment of asthma with negative ions, this apparent success has been criticized as being due to insufficient controls and to psychologically suggestive effects of the treatment. In order to determine the possible effect of air ions of both sign on spastic respiratory attacks Palti et al (1966) undertook some work on infants below the age of one year who were suffering from asthmatic (spastic) bronchitis, specifically to eliminate any psychological factors. Here is a summary of their findings:-

<u>Negative Ions</u>

1. Shorter duration of the spastic attack as compared with duration of the attack in children receiving the conventional therapeutic treatment.
2. Reduction of tachypnea in cases of spastic bronchitis and bronchopneumonia.
3. Termination of spastic attacks induced by positive ionization.
4. The effect of negative ions on respiratory spasticity usually becomes obvious about 8 hours after the beginning of the ionization.
5. When the negative ionization is stopped, a moderate rebound of spasticity and tachypnea was noticed in several cases.

Positive Ions

1. Induce spastic attacks in normal infants.
2. Cancel the therapeutic effects of negative ions on patients with spastic bronchitis.
3. Cause tachypnea in infants.
4. On the average, the effects of these ions on respiratory spasticity becomes evident about 10 hours after the beginning of ionization.

These clinical investigations started auspiciously using double-blind technique but unfortunately, no attempt was made to control or monitor the usual climatic parameters and again the ion generator was placed only 0·1m from the babies' heads. The air movement over the patients must have been quite unnatural and the electrostatic field effect on dust etc. in the air must have been marked.

Hypertension

The action of negative ions on patients with hypertension are characterised by the Russian authors as hypotensive, moderately sedative and soporific. In the early stages of the disease with successive treatments there is a lowering of the blood pressure to normal levels, but in the nephrogenic stage of the disease treatment should be approached with caution because sometimes ions are contra-indicated. For all who receive this treatment the results show only temporary improvements; after a period of several months the disease returns.

OZAENA

Grobshtein (see Baranova et al) claims to have successfully treated ozaena with negative ions; he has shown a restoration of the secretory function of the mucosa of the nose and throat and a disappearance of malodour and scabs. Head pains cease and the patient's general condition is improved. Unfortunately again the improvement is short-lived and repeated therapy is necessary but the treatment is as successful as any other tried so far.

POST OPERATIVE TREATMENT

In 1958, the Northeastern Hospital in Philadelphia extended negative air ion treatment to all post operative patients (David 1960). The hypothesis was that negative ions would be beneficial in relieving post-operative pain. During the first eight months 138 patients were exposed on the first and second days after surgery. It is claimed that in 57% of the cases pain was partially or completely relieved.

WOUNDS AND ULCERS.

In the treatment of prolonged non-healing wounds and ulcers of amputation stumps (according to Landsman, quoted by Baranove 1957) under the influence of aeroion therapy granulation became brighter, cleaner and more plethoric, and in the cases where the secretion had an odour, it soon vanished. Within the circle of the wound epithelia appeared round the rim, the size gradually diminished, then the granulation became dry and scabbed over. Cytological examination of the exudate from the wound showed that under the influence of negative ions there was a notable increase in the concentration of polyblasts, a decrease or elimination of micro-flora, and an increase in phagocytic activity.

The therapy consisted of directing a stream of ionized air on to the area of the wound or ulcer, for local influence, and also on to the patient's face, for general effect by inhalation. The general treatment was carried out first for a period of 15 minutes after which a further 15 minute period of local application was made. The full course ran to between 15 and 20 applications at daily intervals. Post-operative therapy was carried out in the same way, the course consisted of 8 to 10 applications.

TREATMENT OF BURNS

The results and procedure enunciated by Russian workers in the last section are almost identical to the findings of David et al. (1960) in their treatment of burns. It was quite by chance that a patient suffering from severe burns was brought into a room in which an ion generator was working. The fact that he did not go into shock or require narcotics when the physicians examined him, led to an investigation of what might have contributed to this unusual state. The search narrowed down to the room in which the patient was initially placed with its negative ion atmosphere. Because of inadequate controls only subjective results are given, but the indications are that

1.) exposure of burn patients to negative ionisation produced no adverse effects,
2.) it produces relief to complete cessation of pain following the first or second treatment and eliminates in many cases the need for narcotics or sedatives,
3.) a drying out effect accompanies ionization and reduces loss of exudate, reduces the number of local infections and promotes the formation of eschars,
4.) the deodorizing quality reduces an objectionable factor associated with many extensive burns,
5.) healing is much faster with less scarring.

The Russian workers investigating other disorders report that in a number of cases the medical application of aeroions has not progressed beyond the stage of clinical laboratory research and verification, but promising results are indicated in relation to the following diseases:-

a. Severe chronic catarrh, pharyngitis, laryngitis, severe and chronic bronchitis.

b. Ulcerous diseases not haemorrhagic during prevalent neurotic occurrances.

c. Various allergic diseases including migraine.

d. Neuroses of different aetiologies.

e. On practically all healthy people negative ions are beneficial for an over-tired and over-strained cerebral cortex.

SUMMARY

The Russian workers hasten to add that quite often negative ion therapy is not a substitute for other forms of therapy and no "cures" are claimed, but is a very useful complementary tool in many cases, especially in the treatment of hypertension.

After seventeen years of practising negative ion therapy in his burn-unit, Kornblueh (1969) is still uncertain of the mode of action but he genuinely believes that it is beneficial and the outstanding feature is the great reduction in the malodour in the wards. Although widely practised, especially in Russia, ion therapy would seem to be of most aid in disorders which often have a psychosomatic basis.

PART 2

CHAPTER 6

INTRODUCTION AND GENERAL METHOD

INTRODUCTION AND GENERAL METHOD

As already stated in the introduction to Part I there were certain subjective sensations by experienced observers and responses by unaccustomed subjects noticed time and time again when working in artificial environments, which indicated that the conditions although comfortable climatically, were in some way unsatisfactory. In what way the climate was different from normal was not quite clear but from snippets of conversation and passing references, air ions were frequently mentioned as having an effect and atmospheric electricity also featured in discussions about the natural climatic environment.

We are all familiar with certain individuals who seem to be able to predict thundery weather from their sensations rather than any meteorological skill, also those who suffer from headaches and arthritic or rheumatic pain during disturbed weather. Is it just a combination of climatic circumstance, temperature combined with high relative humidity, unstable pressure, the calm before the storm or does the atmospheric electricity have a contribution ? The answer might lie in an interaction of both. Humidity and air movement will affect the rate of ion destruction; radio-active emmanation from the ground is modified by atmospheric pressure and the reversal of the air earth potential gradient, resulting in a change of ion generation and flow patterns.

The tales associated with the "Winds of Ill Repute" are numerous from various parts of the world, but no such phenomenon seems to occur in this country. These hot, dry winds such as the Santa Ana of Southern California, the Chinook of Canada, Sirocco and Xlokk of Mediterranean, the Chamsin of the Arab countries, the Sharav of the Old Testament, the Foehn of Switzerland, Southern Germany, Austria and Tyrol, the Mistral of France and the Argentine Zonda are notorious for causing depression, discomfort, headaches, irritability and the exacerbation of respiratory ailments (Danon & Sulman 1969). Crime rates and suicides are often increased and it is not uncommon to find courts being lenient when sentencing for offences committed during this period. Moos (1963, 1964) has shown that there is an increase in both death rate and birth rate associated with Foehn type weather and also that traffic accident rates are increased in the period immediately preceeding Foehn weather in the city of Zurich (Switzerland). The special features of this type of weather are a rapid rise in temperature and a decrease in relative humidity, but these climatic factors are not the cause of the symptoms produced because sensitive people feel well enough at other times and places where similar temperatures and humidities are recorded, e.g. at Eilath in Israel and in Arizona (Robinson & Dirnfeld 1963). They found one other significant feature; the symptoms are produced anything up to ten hours before the hot dry wind arrives so that the effect is caused by something moving ahead of the wind. Again some change in atmospheric electricity is indicated which they showed in the case of the Chamsin to be an increase in the medium/large ion content at the expense of small ions and also a marked change in the $\frac{N^+}{N^-}$ ratio with a preponderance of N^+. Robinson and Dirnfeld call this effect the "electrical" Chamsin.

There is another side to this coin, some places have a reputedly bracing atmosphere which can be accounted for in a number of ways. According to work already quoted there is a good correlation between these resorts and the negative ion content of the air. Waterfalls and fountains have a freshness about them which can be explained by the Lenard effect producing negative ions and the same mechanism probably accounts for the bracing air of the seaside although ultra-violet radiation contributes at times and the wind blowing in over the open sea has a low condensation nuclei count which prevents destruction of the small ions already present. Mountains can also be bracing but here it is probably because of the remoteness from industrial contamination that the full spectrum of small ions is available and the air is cleaner. Pine forests also have a freshness which manufacturers of cleaning fluids are quick to copy but the clear air is supposed to contain higher than normal quantities of negative ions which are probably produced by corona discharge at the needle tips, especially when the air is dry. In all of these instances except the mountain condition, could the same bracing effect not be explained simply in terms of temperature, humidity and air movement? The air round a waterfall, the wind blowing in over the sea and through a forest must be cooled by evaporation as well as the surface over which it is blowing. However, there is a body of opinion quick to suggest that air ions have a place in the natural environment, the presence or absence of which affects our well-being.

Little was it realised when this study was commenced that our observations were very similar to those which had stimulated Hicks & Beckett in America some twenty years earlier to sponsor research at various centres which continues today. Also it was probably the same effects which prompted both Yaglou (1935) and Herrington et al. (1935) to devote some time to this subject. Both of these scientists were at that time very actively engaged in the field of climatic physiology using techniques and equipment which were the antecedents of our present climatic chambers. Herrington's work in climatic physiology with his colleagues Winslow & Gagge at the John B. Pierce Laboratory of Hygiene was leading them to the concept of Partitional Calorimetry for the study of the body's mechanisms for heat exchange with its environment. Yaglou's interest was in the study of physical efficiency related to industrial hygiene and since both were climatologists they were generally concerned about the effects of climate in its widest sense upon human reactions.

The observations of depression and lethargy are not confined entirely to climatic chambers, since this section of the Institute of Aviation Medicine has been consulted on several occasions about working environments, where a great deal of trouble has been taken to engineer the conditions for comfort, and where the results have been disappointing. Eichmeier (1969) has also investigated similar symptoms reported by people working in underground studios of the West German Broadcasting Corporation in Bonn. He was able to make limited measurements of the ion content of the air, as well as the usual parameters which were well within the comfort limits, but the ion content was predominantly positive. From the scant literature available at the time this study commenced, it appeared that positive ions in some way were detrimental and ipso facto negative were beneficial, a situation which has in the past led to numerous experiments where large quantities of ions of both polarities have been administered to human and animal subjects in attempts to understand better what their action might be.

There was, therefore, evidence both from naturally occurring phenomena and measurements in artificial environments to suggest that the adverse symptoms which have been noted separately, were of the same origin. The cause would seem to be a marked reduction in the small ion content of the air, particularly negative ions. Change in the air-earth potential was not considered to have any direct physiological effect, only an indirect influence by affecting the polarity ratio of the available ions.

To return to the local situation, the main climatic chamber is essentially a large closed-loop, metallic conditioning duct, nine feet square in cross section, very adequately earthed. This would act as a Faraday cage maintaining the ion content of the air very low. However, this is not the case in the other rooms which are supplied with conditioning air via metal ducts in the conventional ducted-air manner so that only in part is the system earthed. The most significant common feature of the entire suite of rooms is the air movement. For adequate control of conditions the air must be moved, and as a consequence the small ion content is soon reduced (Minkh 1961). Eichmeier (1959) showed that the easiest way to increase the small ion content of a room is to seal it completely, if there is no source of heat to stimulate natural convective currents the large particulates will settle out leaving natural generation and destruction free scope. The ultimate level of ions will depend upon the cosmic ray activity and the amount of radio-active material in the walls and floor of the room. The age of the ions will also be extended because they are only moved by virtue of their charge in the prevailing electric field and the Brownian movement of the uncharged molecules of the air.

In ducted air central heating systems the air is recirculated by a fan, an excellent way of ensuring destruction of the small ion content of the air, by providing good mixing with condensation nuclei. However, under very dry conditions inadequately earthed metal ducting might act as an ion generator, the sign of the predominant ion depending upon the type of metal, but since the mobility and the diffusion coefficient of negative ions are both greater than those of their positive equivalent (Chalmers 1957) the net result is usually a preponderance of positive ionization (Davis 1963). This is in sharp contrast to the days of open fire heating where the convective currents involved ensured a goodly supply of fresh air with presumably adequate ion content.

Measurements by Shilling and Carson (1953) quoted by Chalmers (1957) indicate that there are simultaneous changes in the electrical conductivity inside and outside buildings which corresponds to similar results found by Kähler (again quoted by Chalmers 1957) for ion counts. How this comes about was not confirmed but it was thought that it occurred by infiltration of air through cracks.

If this is the mechanism then our conditioned rooms each being virtually a sealed system, would not benefit in this way. The problem now resolves itself to indicate that the effect of conditioning the air in earthed metal ducts is to reduce the ion levels or to convert the ratio to a preponderance of positive.

When the experiments were planned the initial undertaking was to investig te the effect of an ion free atmosphere on some biological indicator other than human, as far as this is possible, to achieve without resorting to excessive means to minimise cosmic penetration. A room was avilable with a crude open-ended conditioning system capable of housing a number of small laboratory animals. Although the symptoms were observed on humans, with all their complex psychological and statistical disadvantages it was thought that a more controllable situation was offered by the use of experimental animals. This offered the advantage of the ability to select uniform strain, age, sex and size of population compatable with the available space, and their physiological mechanisms are complex and sensitive enough to respond in a similar manner.

Since the predominant symptom embraces tiredness and lethargy, the animals spontaneous activity was one of the parameters chosen for study, the other was normal growth rate. Both of these were chosen since measurements could be made with the minimum of disturbance to the animals. If it was found that an ion-free atmosphere had a reproducible depressing effect then it would be time to investigate more complex physiological systems. The first task however, was to establish that spontaneous activity was measureable and reasonably consistent. As far as growth rate was concerned this was well documented for all small laboratory animals in several animal husbandry handbooks.

GENERAL METHOD

ANIMAL MATERIAL

The animals chosen for these experiments were rats because they were readily available, their size was compatable with available room space, they are easy to handle and most important, they are nocturnal. It was considered necessary to use nocturnal animals for two reasons. Since spontaneous activity was the main parameter to be measured, normal laboratory noises, especially people moving about in the experimental room during the day, would disturb the animals and could cause unnatural activity patterns. Secondly, the choice of nocturnal animals precludes the use of the fluorescent lights in the windowless experimental room, which might produce ions probably in sufficient quantity to interfere with the ion-free experiments.

EXPERIMENTAL ROOM

The room set aside for the housing of the animals was originally designed as a clothes drying room. Air is drawn from outside, passed over a bank of enclosed electric heaters and discharged into the room through four inlets (12" x 8") opening 10" above floor level at the back of the room; it exhausts through two exits high on the opposite wall. Because of the symmetrical design the room was easily divisible into two similar parts.

Figure 6.1. is a picture of the room taken from the door showing one trolley arranged for six rats on either side of the central slotted-angle and hardboard partition. The D.C. electrical supplies are on the left-hand wall and a sink in the right-hand compartment. On the wall opposite are the inlet ducts, two per section of room. Lighting of the room was by one 80 watt fluorescent tube in each side, switched on at 8 a.m. and off at 8 p.m. by a Venner time switch.

ENVIRONMENT

Twenty-five degrees centigrade was the environmental temperature generally used.. This is probably a little higher than usual for housing rats, but because the air entry ducts are situated high in the conditioning plant room ambient temperatures were usually in this order for long periods during the

Figure 6.1. Experimental Room.

the summer. Unfortunately, it was not possible to control the humidity, but it was monitored on a seven-day hygrograph which was periodically checked against an Assman psychrometer. Control of air movement was achieved by altering manually-operated dampers in the duct system. In all of the experiments relating to the first set of rats the dampers were left fully open to permit maximum flow of air. The fibre-glass filters at the duct entrance were removed in case they acted as an ion precipitator, this had the added bonus that it further enhanced the air flow to the room.

CAGES

The rats were individually housed in polypropylene cages 13" x 8" x 6" which were unperforated when purchased. The holes were made by a hot soldering-iron with a pointed bit, to allow a circulation of air. Figure 6.2. shows a modified cage. The holes are just under $\frac{1}{4}$" diameter, $\frac{1}{2}$" apart in rows 1" apart. No evidence was found of the rats having attempted to nibble the plastic round the holes. The two larger holes cut opposite each other were necessary for the activity measuring device, their size was dictated by the optical system and was found by trial and error. They were eventually big enough for a rat to get its muzzle into and would have provided endless entertainment. To foil any such attempt it was found possible to protect the plastic by bushing the hole with brass kit-bag eyelets.

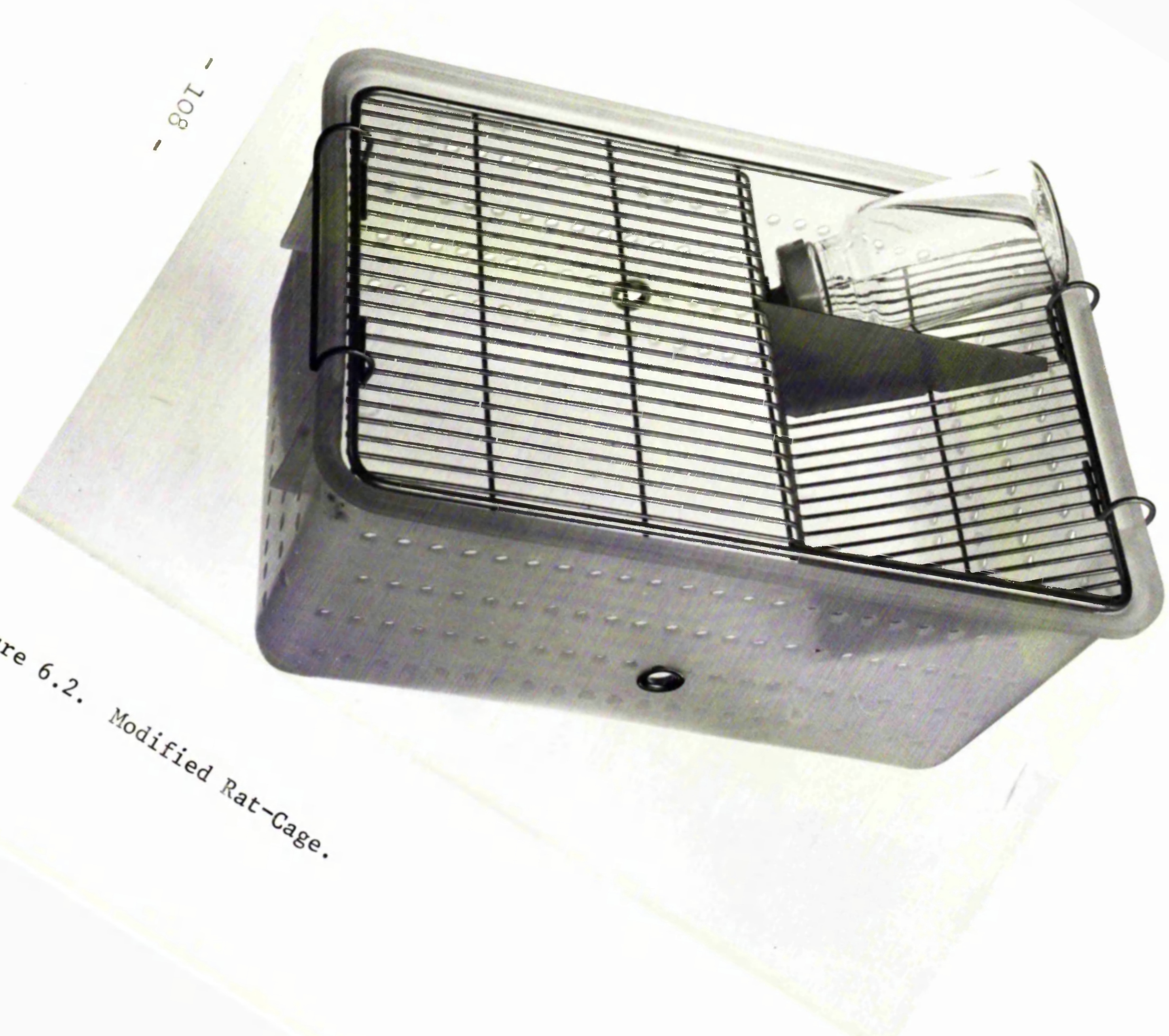


Figure 6.2. Modified Rat-Cage.

CAGE STORAGE

Metal racks were constructed from slotted-angle to contain six cages, in two tiers of three in each side of the room, as shown in Figure 6.1. The various parts of the optical system were mounted on the racks in such a way that the cages could be easily removed for cleaning and would slot into realignment when returned.

ACTIVITY MEASUREMENT

Several methods of monitoring spontaneous activity were contemplated. The simplest to construct would be to put a microswitch under the cage near one end with the cage bottom pivoted along its short axis, like a see-saw. There are several snags to this method, the main one being to set the sensitivity of the switch to take account of the change in weight of the cage as food and water were consumed, and also gross vibrations caused by other rats on the same rack, hopping. As an alternative a proximity switch of the type TL 2 GNA made by OMRON PRECISION CONTROLS (1966) could have been used, which would have eliminated these shortcomings.

Two other devices were investigated, one was made by A.B.FARAD called "ANIMEX" which gave information about activity patterns but was more suited to drug or social activity studies within colony cages. The other used an ultrasonic beam across the cage which was interrupted by the animal in the same way as the light device adopted. These last three methods would all have proved rather costly in capital equipment for twelve rats.

One final method brought to my notice, and used by Morrison (1968), which was developed by Greer (1958) was rather too sensitive for my purpose.

The following one was adopted because most of the parts were readily available from local sources, at very little cost. The basic circuit used, Figure 6.3. was the Mullard (1961) Infra-red Burglar Alarm using OCP-71 phototransistor, but there was one snag. As a burglar alarm when the beam is broken the alarm locks and is reset manually, whereas for monitoring activity it must be quickly and automatically reset. This problem resolved itself as the circuit was modified and the optical system established during development.

The nearest service equivalents for BCZ11 and the miniature relays werd obtained. By setting up the circuit as the original but with substitute components and variable resistors to positions R_c and R_b it was possible to adjust the latter to obtain the maximum effect from Trl. and the necessary current to drive the relay (19mA) Figure 6.4. shows the modified circuit.

During this procedure the light source was mounted near the phototransistor. Some suitable small lenses from the Laser Laboratory were used in extending the optical system to cope with an interposed cage. Figure 6.5. and Figure 6.6. show the eventual arrangement. Several strengths of car bulb were tried in the collimator and it was found that a 7 watt bulb, gave sufficient light to reset the circuit automatically. It was sensitive enough to

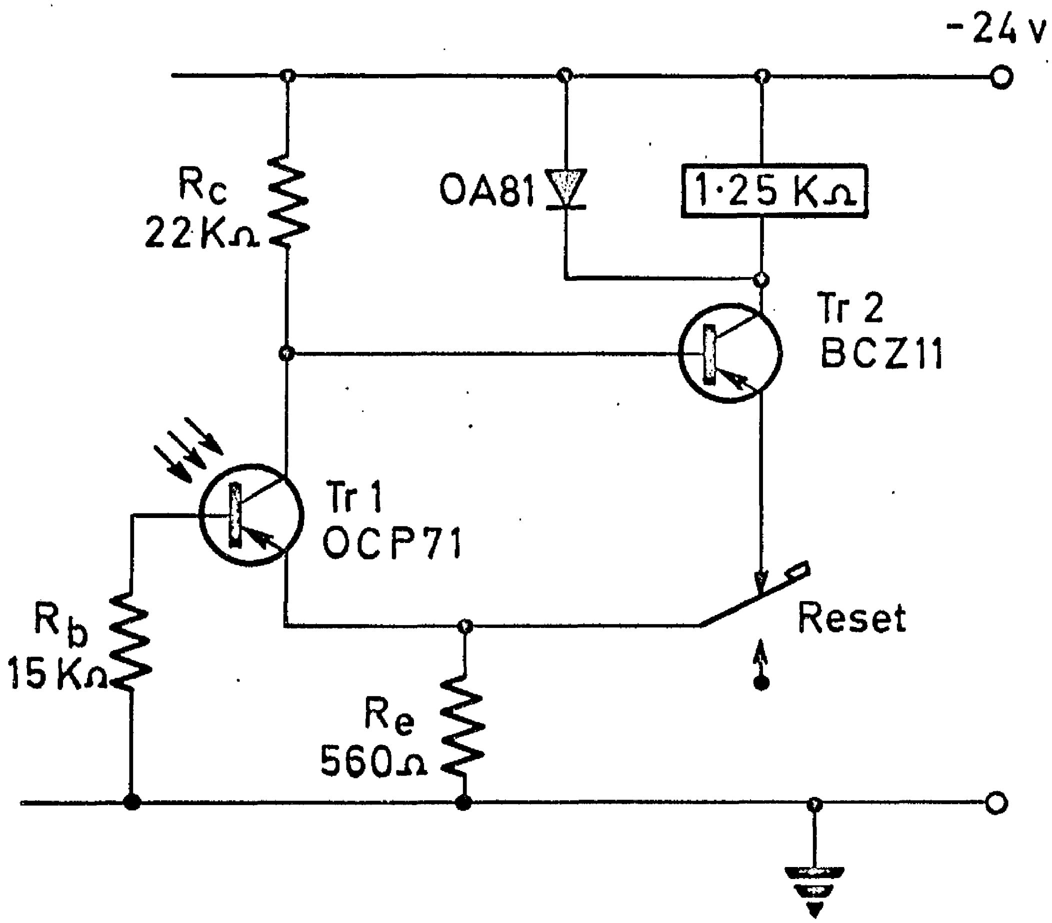


Figure 6.3. Mullard Burglar Alarm.

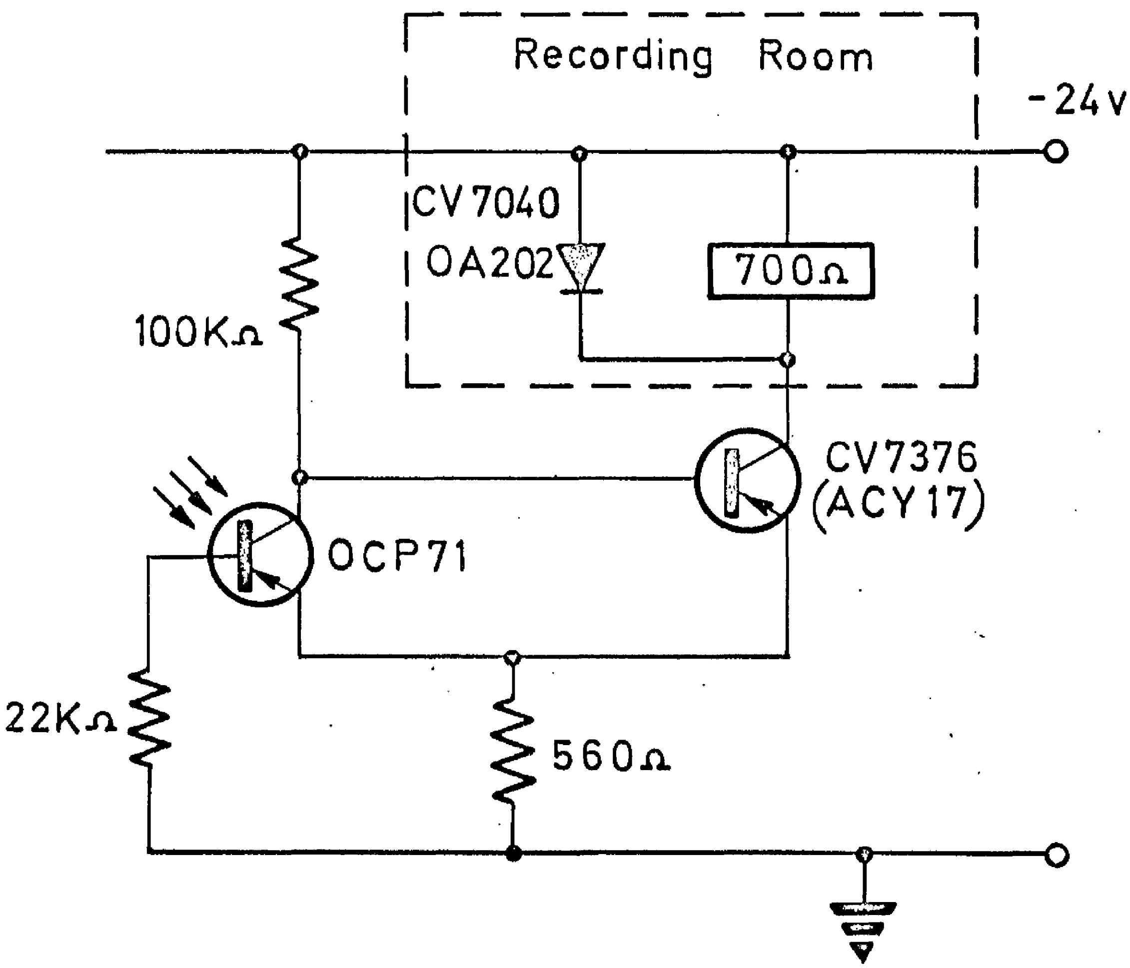


Figure 6.4. Modified Burglar Alarm.

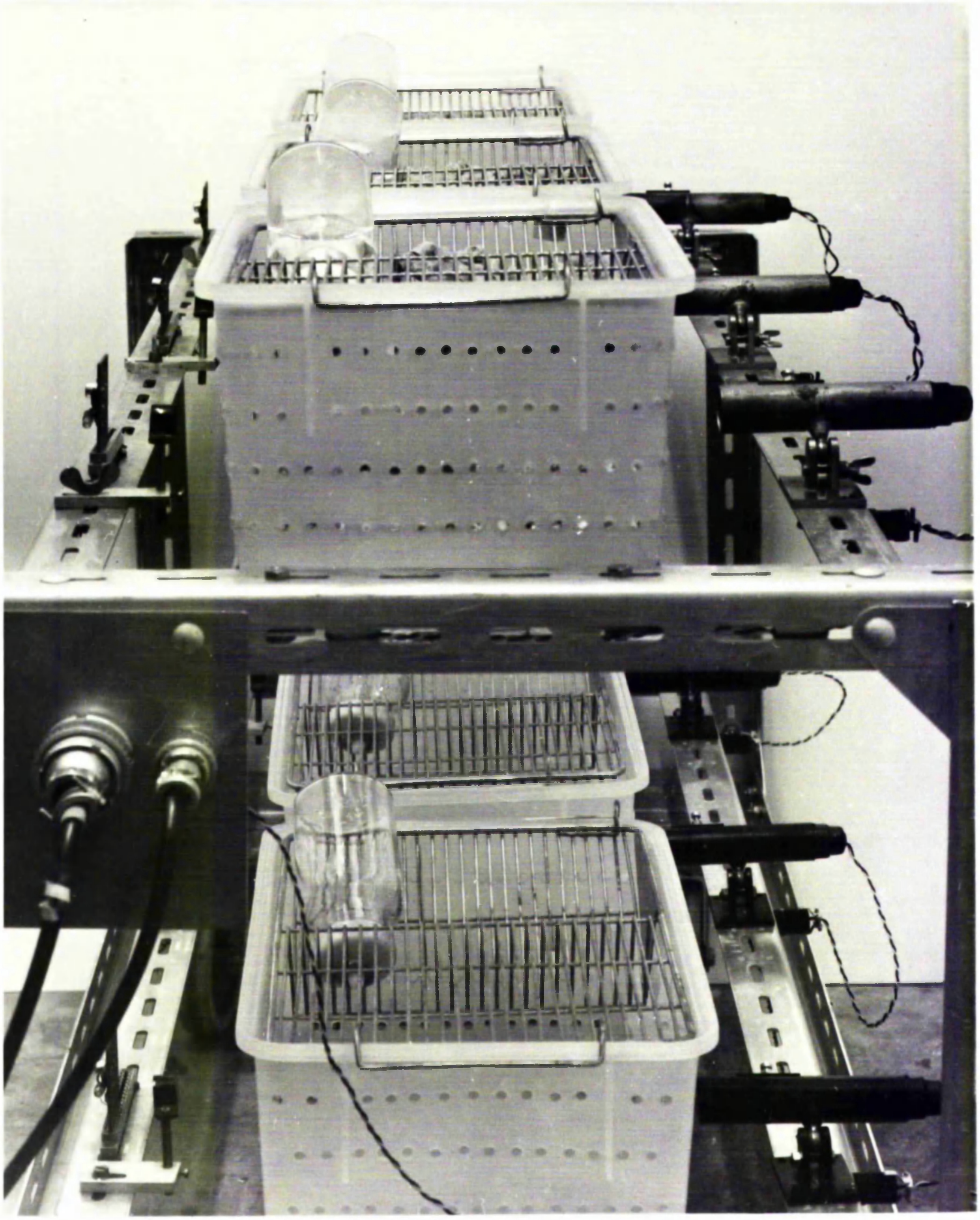


Figure 6.5. Activity Measuring System.

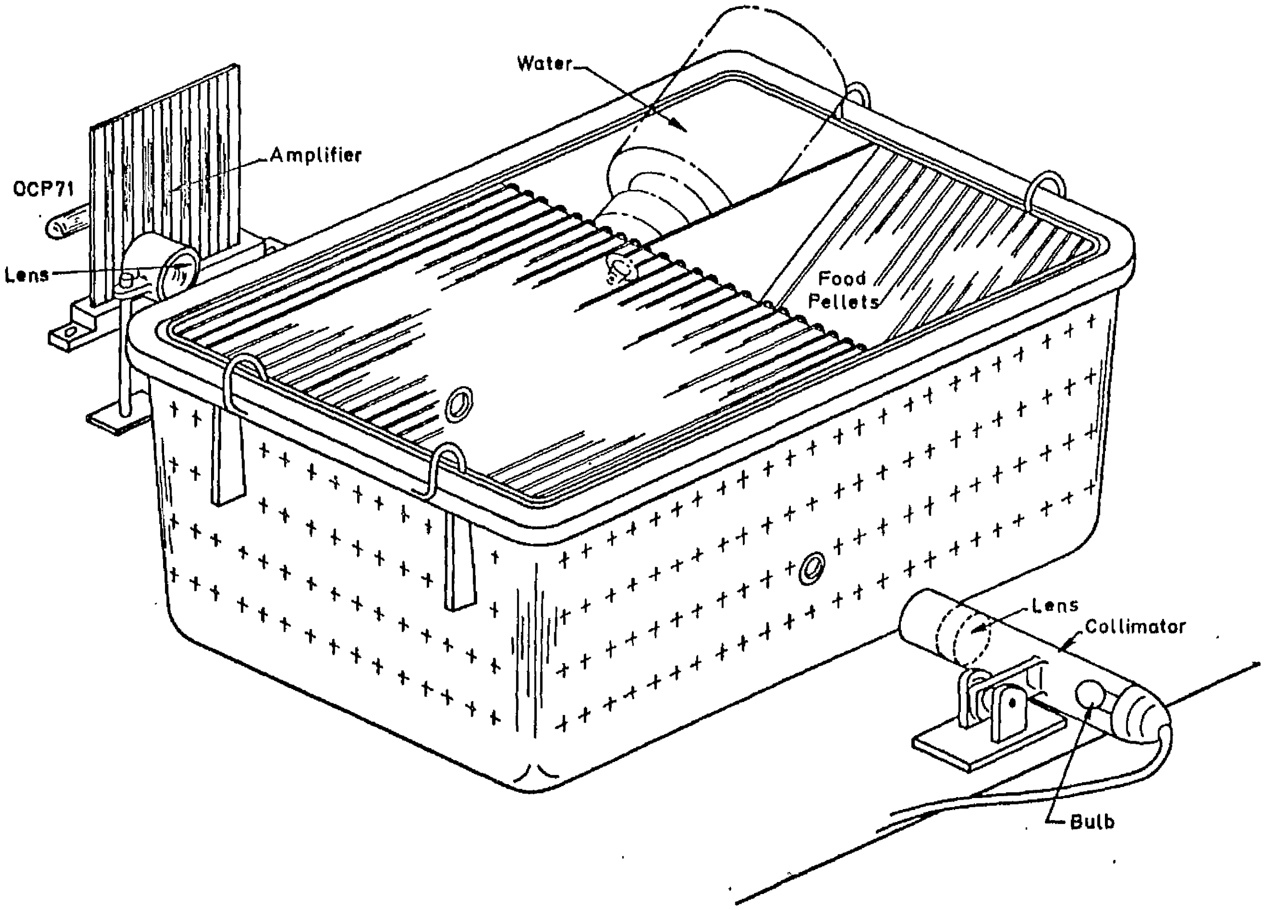


Figure 6.6. Activity Measuring System.

be able to count the fingers of a splayed-out hand when there were moved across the light beam. It has since proved an easy, uncritical circuit to build and very reliable. The light sensitive part of the circuit was mounted on the trolley and the relay part confined to a separate recording room in case the rats learned to click their own relay solenoid. In Figure 6.4. the broken line contains the part of the circuit housed remotely in the recording room. All the resistors and transistors were mounted on a small piece of "Veroboard" so that the unit was easily replaceable, see Figure 6.7. The socket part of the Veroboard was mounted in slots in the trolley rail to enable horizontal alignment with the light beam. Limited vertical adjustment was achieved by mounting OCP71 on $\frac{1}{2}$" long connecting wires (Figure 6.7.). One lens was mounted in the lamp-housing, the other fitted into a $\frac{5}{8}$" plastic cable cleat and aligned at the appropriate distance from the photo-transistor.

SETTING UP

For setting up the counter beam in the room, a separate module was constructed with a relay and indicator light to complete the recording circuit, Figure 6.8.

RECORDING

Each movement of a particular rat through a light-beam was ultimately recorded on its own digital counter in the recording

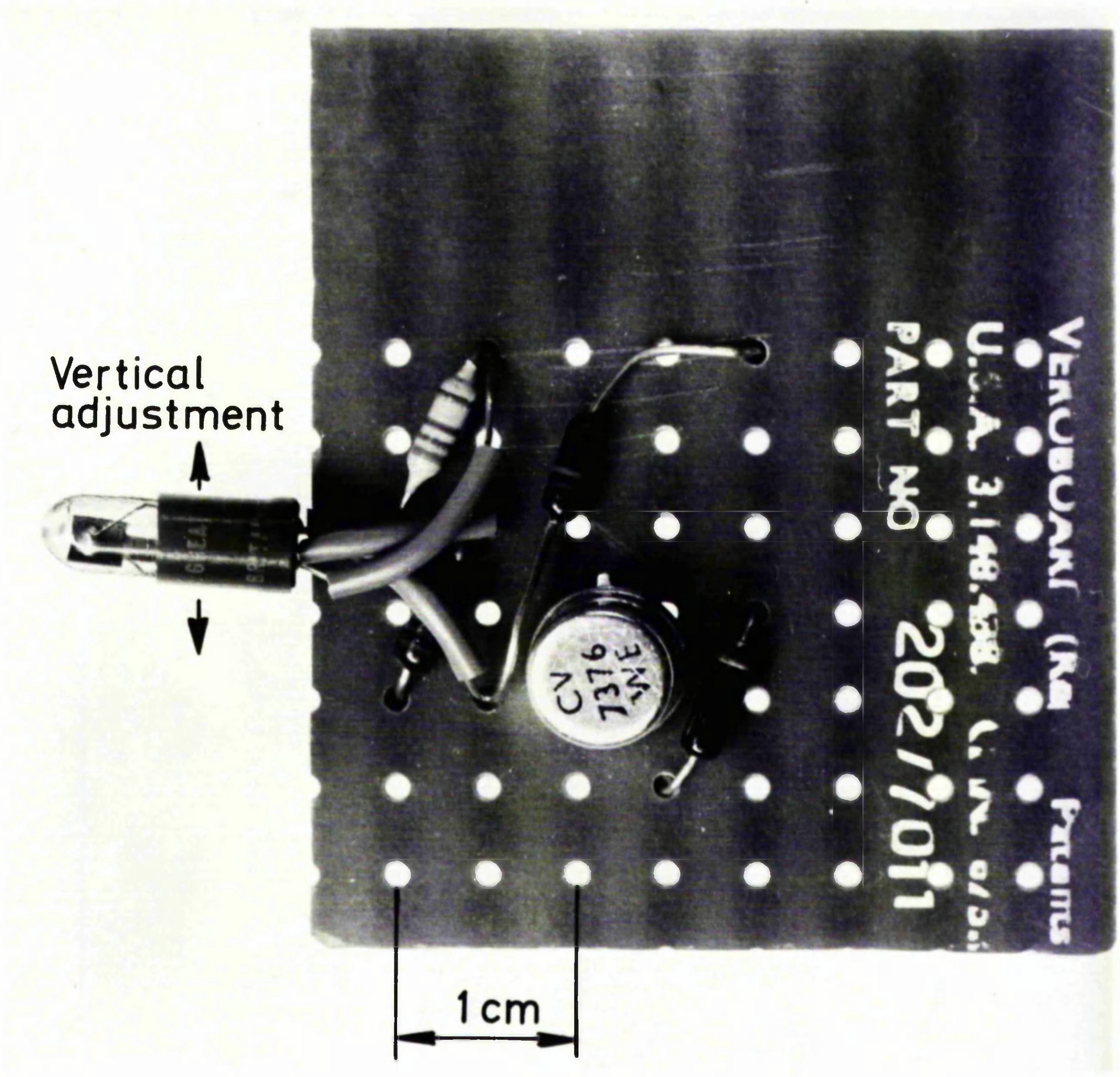


Figure 6.7. Activity Module.

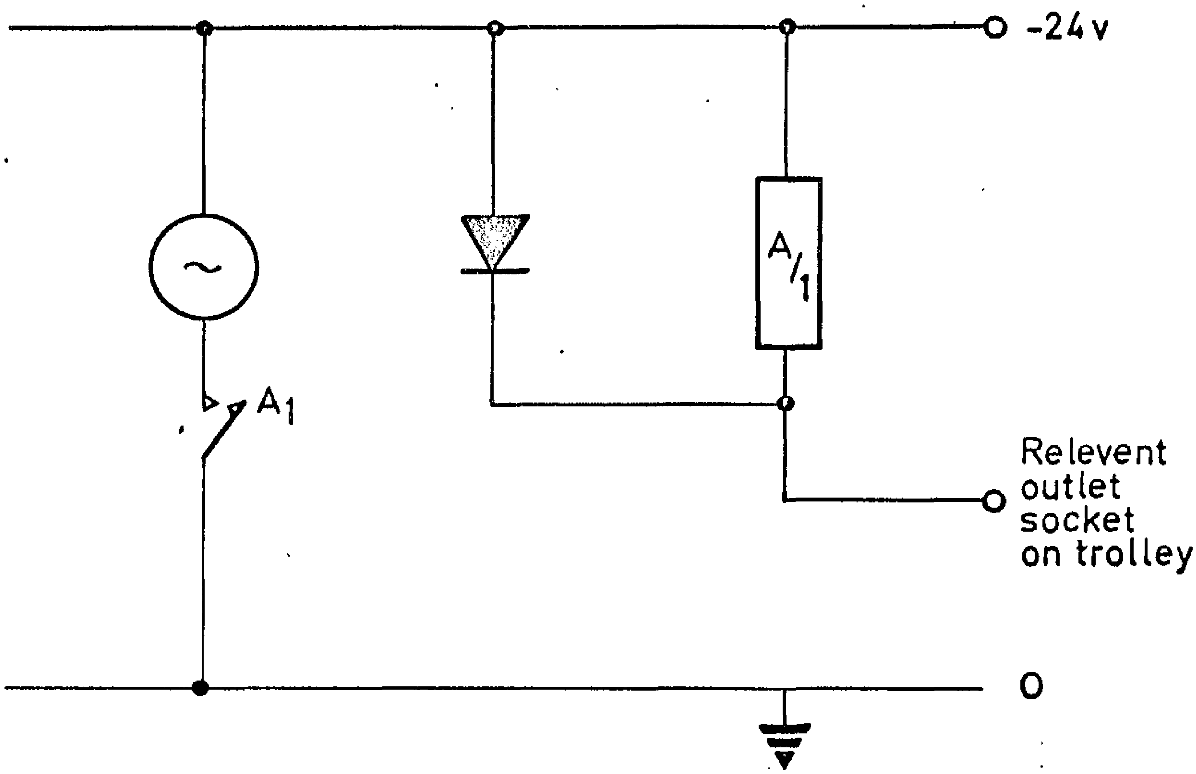


Figure 6.8. Setting-Up Module.

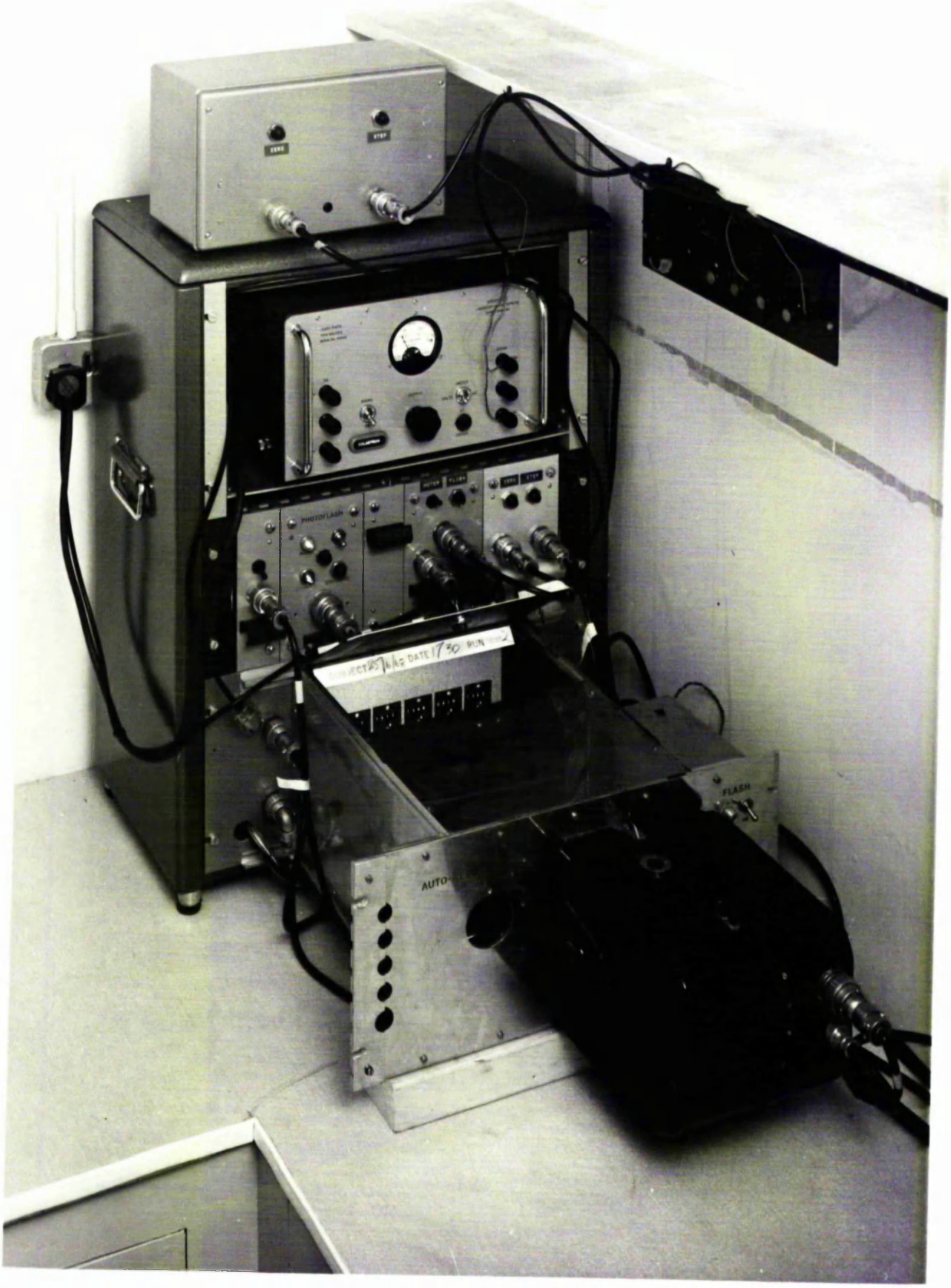


Figure 6.9. Recording Room.

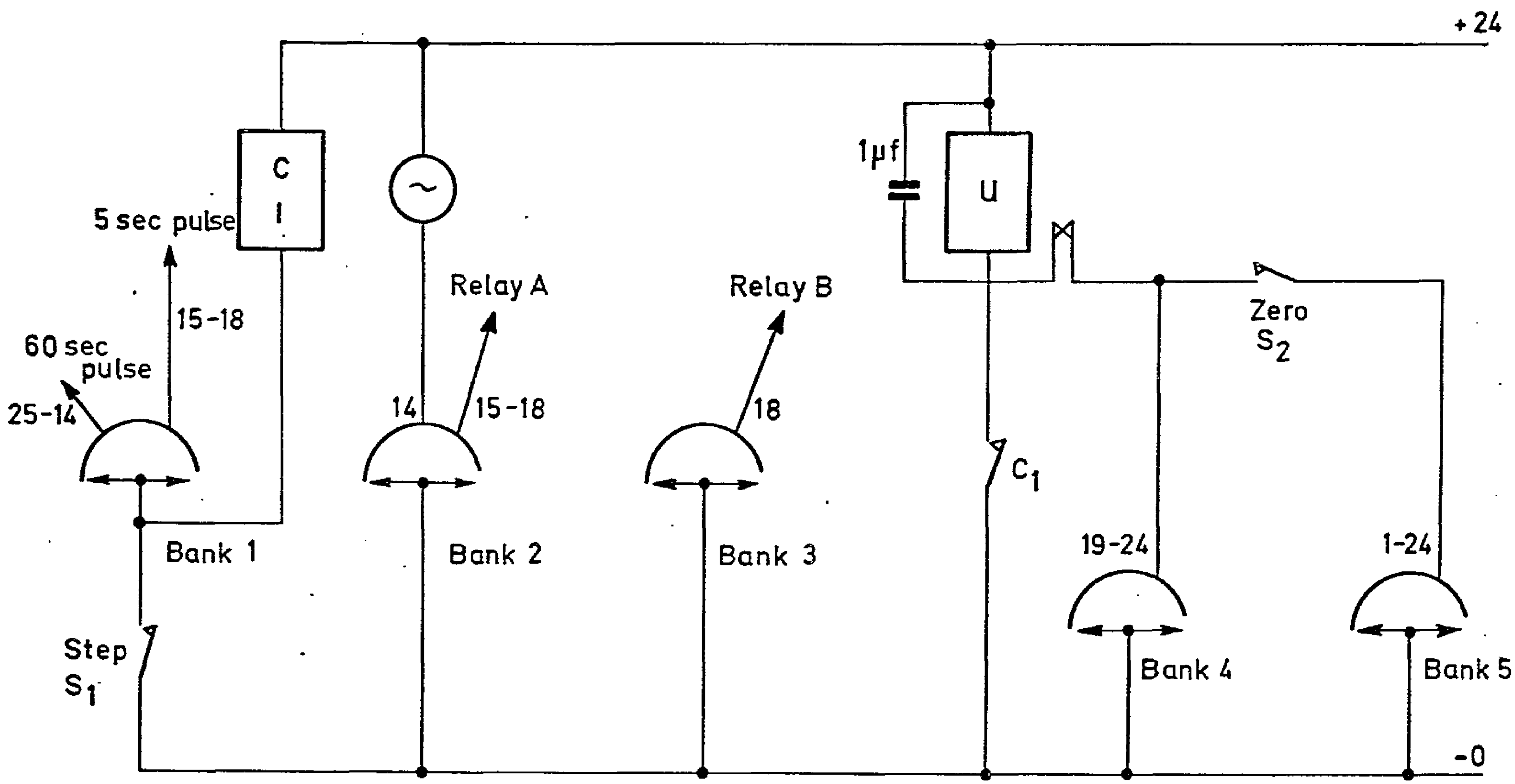


Figure 6.10. Camera Timer.

room. The counters used were Stonebridge Type ATCeZ4E and the necessary power to drive them came from a Solatron Vari-pack. To protect the counters, which were intended for intermittent use only, against the rats deciding to go to sleep in the light-beam, they were connected to the relays through a resistance-capacitor link which actuated the counter as the beam was broken. The time constant of the R-C. counter circuit was 40 milliseconds, which was the slowest part of the entire activity measuring device.

PHOTOGRAPHIC RECORDING

The information display was photographed every fifteen minutes by an automatic 35 mm camera. This photoflash camera was available in the laboratory as an in-flight system for photographing aircraft instruments. It was constructed to fit on to a standard $8\frac{3}{4}$" x 19" chassis panel, Figure 6.9. Although the camera and associated electronics would run happily for a few hours, they were not intended to be used continuously for weeks on end. The camera motor was a particularly noisy piece of equipment, so to preserve its life and maintain good relations with the other members of the staff, a simple timed switching device was built, Figure 6.10.

CAMERA TIMER

A twenty-five position Post Office uniselector is stepped initially (bank 1) by a sixty seconds pulse, when the wipers reach the fifteenth position they are then progressed by a five second pulse to give a complete cycle of fifteen minutes. Bank 2 switches on the power supplies to the photoflash and the camera motor via relay A. Bank 3 via relay B fires the photoflash and actuates the camera shutter. The fourth Bank zeros the uniselector ready for the start of a new cycle at the next sixty-second pulse. The system worked well except for the photoflash which was shy of the dark, but even with a priming light although better it still proved unreliable.

Although it made the analysis of the finished record rather inconvenient, it was more economical to store up several days exposed film for processing. The ultimate analysis involved long sessions of subtracting three digit numbers in semi-darkness. This proved very tedious and time consuming to correct lapses in sustained mental arithmetic; however it was used initially until an alternative method could be commissioned.

PUNCH-TAPE RECORDING

The choice of an alternative method of recording the animals' activity was again dictated by what was readily available. In the laboratory there was a CREED 25, seven channel punch with "Teletype" tape reader. The Creed 25 takes a 340 yd. reel of tape which can be moved through the punch, 1/10" per stamping, at the rate of twenty-eight perforations per second. With the punch operating at its maximum rate it would therefore be possible to record discreet movements for each of twelve rats of fourteen per second at the cost of an astronomical amount of tape. This/

This is an unnecessarily high rate since rats are not particularly fast moving animals, but what should the rate be?

Two methods of sampling were considered, the first was to copy the photographic method and construct a device which would add up the movements for each individual in some time interval e.g. fifteen minute totals. This way all movements within the limits of the time constant of the electronics could be recorded whether they be gross movements of the animal or higher frequency ones where the rat may just be touching the light beam rather than moving through it. However, no information about the distribution pattern within the fifteen minute period is available.

If as an alternative the sampling time is considerably shorter but only one hole is punched to record any number of movements within this period, the activity pattern with respect to time is in more detail but some counts will be missed. These counts would be generally the higher frequency ones mentioned above. This was the method chosen, with a time interval of six seconds or ten possible movements per minute; it enabled four complete days records to be contained on one reel of tape.

I am indebted to Mr. D.V. Field for designing and constructing the relay box which converted the pulse signal which the digital counters received, to the form which was punched out every six seconds. A Cambridge Instruments time clock supplied the necessary triggering pulse.

Six channels of the tape were used for rat information, the seventh was used to identify whether the holes related to rats one to six (a hole in channel 7) or seven to twelve (no hole in channel 7); Figure 6.11. illustrates this graphically.

TAPE READING

Available in the laboratory was a Teletype Type CX tape reader capable of handling one hundred characters per second which was much too fast for extracting data from short time interval sections of tape. By under-running the drive motor the reader could be slowed but the movements of the hole sensing pins became inaccurate, probably because their mechanical linkages required some minimum inertia value for proper actuation.

Since only six rats were used routinely it was easy to read the tape visually, one night's recording could be scanned and the relevant information extracted in about $1\frac{1}{2}$ hours the following morning, which was considerably faster than possible with the original photographic method. When twelve rats were used the tape was read by computer.

ION MEASUREMENT

The ion counter and generator available were both made by the Philco Company in the U.S.A. The Model ICF-6 counter which is of the Ebert concentric cylinder type was capable of measuring air ion concentrations of both polarities from 100 to 100,000 ions

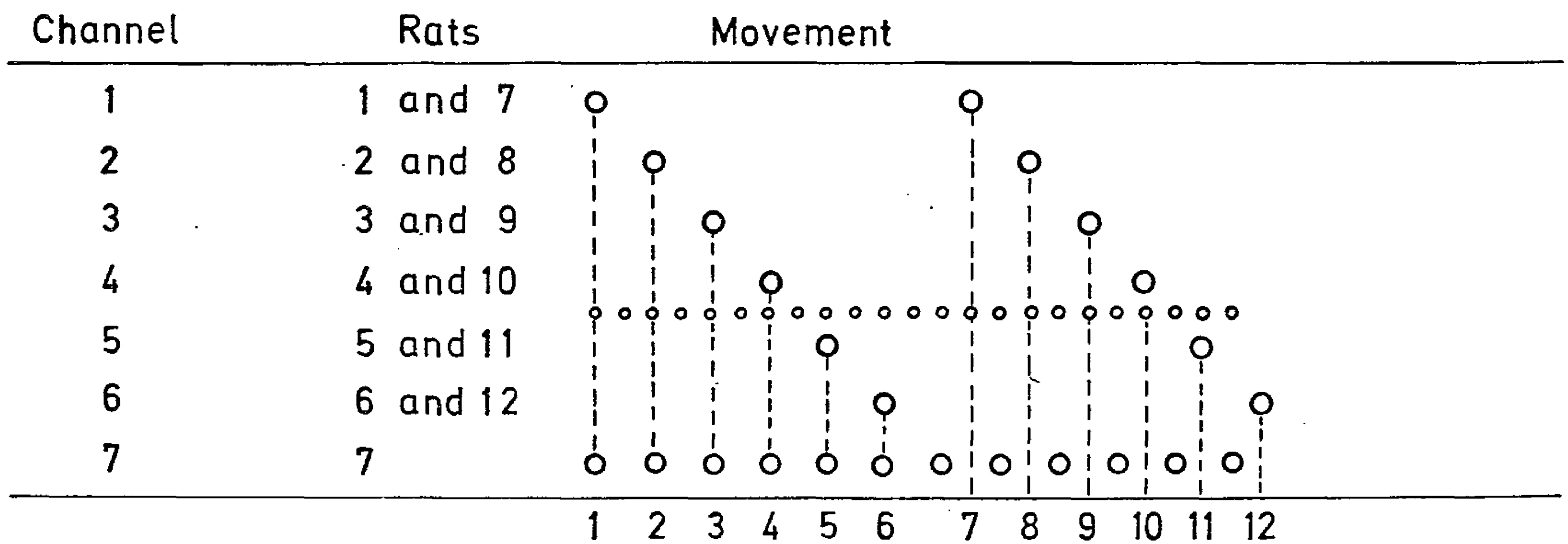


Figure 6.11. Punch-Tape Code.

per c.c., but not simultaneously. Furthermore the manufacturers claim "it can be used unattended for extended operation", this is perfectly true but the resulting information is limited to one polarity and one mobility only. An attempt was made to increase the versatility of the counter when it was left unattended.

Charge from the air ions is deposited on the central electrode which is connected to a sensitive electrometer, the amplified out-put of which is displayed on a Voltmeter on the front of the instrument or may be recorded. Every two minutes the collecting electrode is automatically grounded for 15 seconds, then the sequence recommences. The deflecting voltage is supplied from batteries and is set manually either positive or negative between 0 and 300 v depending upon the mobility of ions to be measured. Making use of the grounding solenoid supply and dispensing with the polarity switch a simple programmer similar to the camera timer, was constructed which automatically reversed the D.C. deflecting potential after every five counting cycles. This was changed to ten counts because of the characteristics of the sensing capacitor (becoming "soaked") or residual capacitance in the electrometer which required four cycles of the new polarity ions to purge itself of the old. By this modification it was possible to monitor both polarities of ions serially but the deflecting potential still required setting by hand.

Another severe limitation of the instrument is that the output has a five position sensitivity switch which means anticipating the correct range when setting-up for a prolonged recording.

Because of these limitations the instrument was used for spot checks on the natural environment and also for setting-up and monitoring preset ion levels in the later experiments. The out-put was recorded on a single channel potentiometric recorder.

ION GENERATION

Ions were produced by a Philco RG-4 generator which is of the corona discharge type. The instrument is in two parts, the first consists of a mains operated power pack capable of producing potentials of either polarity, variable up to 9kV with extremely low current. The other part is the corona tip which is a very sharp needle projecting $\frac{3}{4}$" from a heavy-duty, aerodynamically shaped ceramic insulator over which the air is blown by an ordinary fixed speed electric fan. Heavy duty insulated cable carried the high electrostatic voltage to the corona point.

ELECTROSTATIC FIELD GENERATOR

Since the ion generator is capable of producing a variable voltage to a limit of 9kV it was used to apply the necessary potential difference across the cages in the electrostatic experiments. The applied potential was monitored by a simple electrostatic voltmeter but no attempt was made to plot the field patterns produced.

ANIMAL HUSBANDRY.

Bedding Material

As stated earlier in the method the rats were individually caged. To absorb their excreta a layer of wood shavings was scattered on the floor of the cage. The animals arrangedthis to suit their mood, sometimes piling it up so that it interrupted the light beam, with the loss of that night's information. Generally they slept curled up in the corner of the cage under the food hopper, presumably they felt more secure here as it was the most nest-like part available. They also learnt to keep this area relatively unsoiled.

Cleaning, Weighing

The cages were regularly cleaned out twice weekly; on Friday afternoon and Tuesday afternoon. A litre beaker was held in the cage and when the rats were young they were coaxed into it but after a few months they would enter the beaker without prompting. Confined in this way weighing, which was carried out every Tuesday, was very easy. Weights were recorded to the nearest gramme.

Food

Water and food in the form of rat pellets (Diet PRM, supplied by Allington Farm, Porton) were allowed ad libitum with an extra tit-bit of apple or carrot immediately after cleaning. It was noticed that generally the rats would have some food as soon as they were replaced in their clean cage while waiting for their tit-bit. They soon learnt to anticipate this extra and would become very excited.

FIRST EXPERIMENTAL SERIES

AIM

The object of the initial experiment was to establish the form of the rats spontaneous activity pattern and prove the method which had been devised for monitoring it. At the same time the ion counter was used to compare conditions inside and outside the experimental room.

METHOD

Six young rats were used, three in each part of the room, individually caged on the top tier of the racks (already illustrated). There was a period of about three weeks from the time the animals were housed until the activity measurements commenced, during which time the animals became familiar with the twelve hour light - twelve hour dark cycle, and the cleaning routine.

After the first two weighings the positions of the rats were slightly rearranged so that the total weight of rats in the left hand compartment was equal to that in the right hand. The rats were nominally the same age and since both groups started with the same gross weight any effect of a difference in treatment should be readily apparent from a difference in growth rate.

The number of times an animal passed through the light beam across its cage was recorded on its individual digital counter. Using the photographic method already described, the counters were photographed every fifteen minutes over several days.

CHAPTER 7

FIRST EXPERIMENTAL SERIES

PROOF OF METHOD

Nine consecutive days records were obtained with only one break of three hours duration one afternoon for routine cleaning and weighing of the animals, also to change the film cassette in the recording camera. A second period of five continuous days was monitored but with the light-dark cycle reversed.

RESULTS

Figure 7.1. is an example of one rat's 24-hour activity pattern. Starting at midnight each vertical line represents the number of interruptions of the light beam in the preceding fifteen minutes. During the day all the animals had long periods of inactivity interspersed with very short bursts of activity. Sometimes the number of counts in one fifteen minute period would be as large as any during the dark part of the cycle, but it would be an isolated incident followed by a period of non-activity.

From the fifteen minute activity totals extracted from the film, the hourly sums were obtained for each animal and each group. The mean (nine days) hourly totals for the two groups of rats are illustrated in Figures 7.2. and 3. Commencing at midnight the blocks of hourly activity are continued through one complete on-off light cycle; the second series of blocks one to eight, being simply a repeat of the first eight. The diurnal pattern of activity is clearly demonstrated confirming that the laboratory rat is indeed nocturnal.

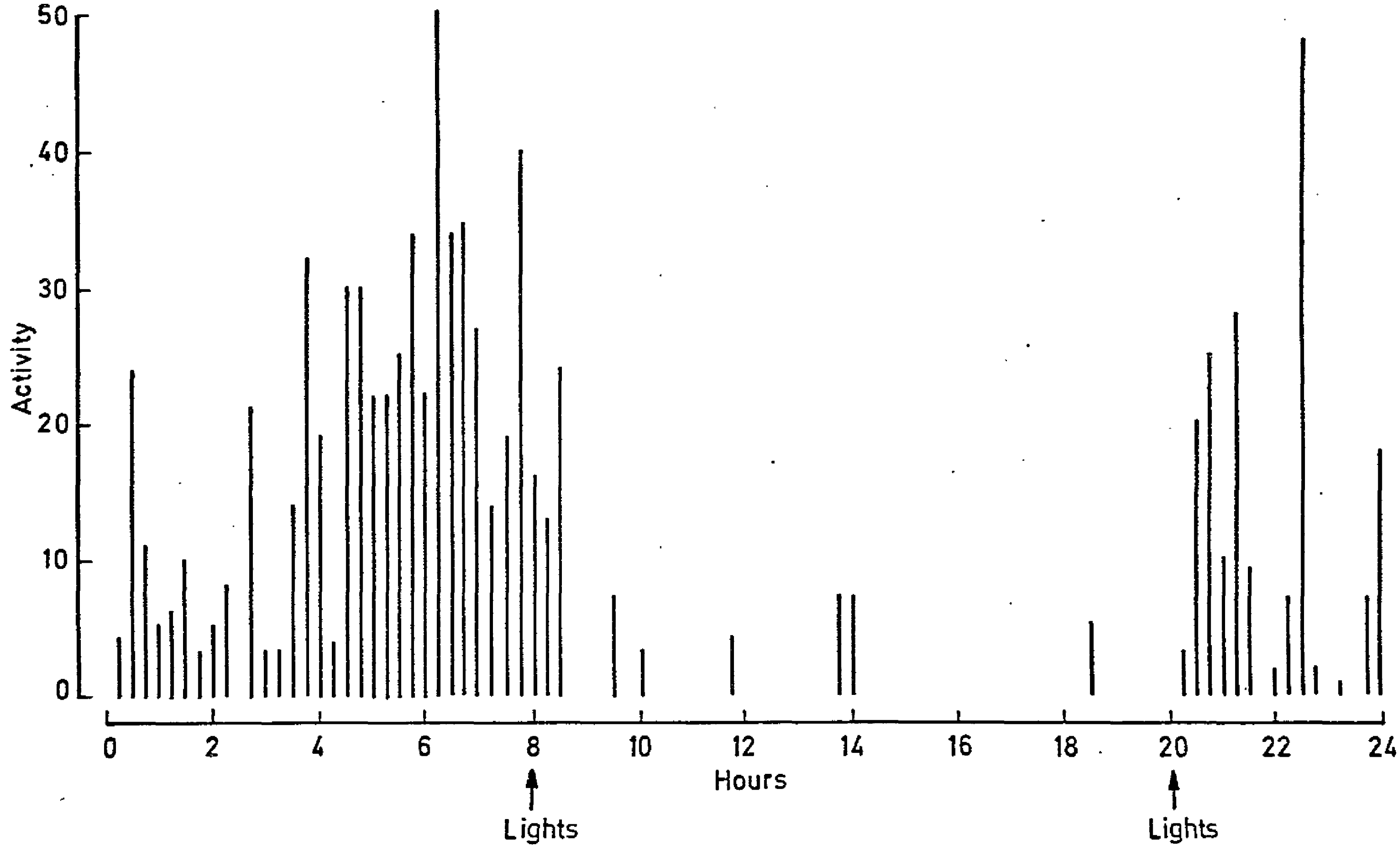


Figure 7.1. 24 Hour Activity Pattern.

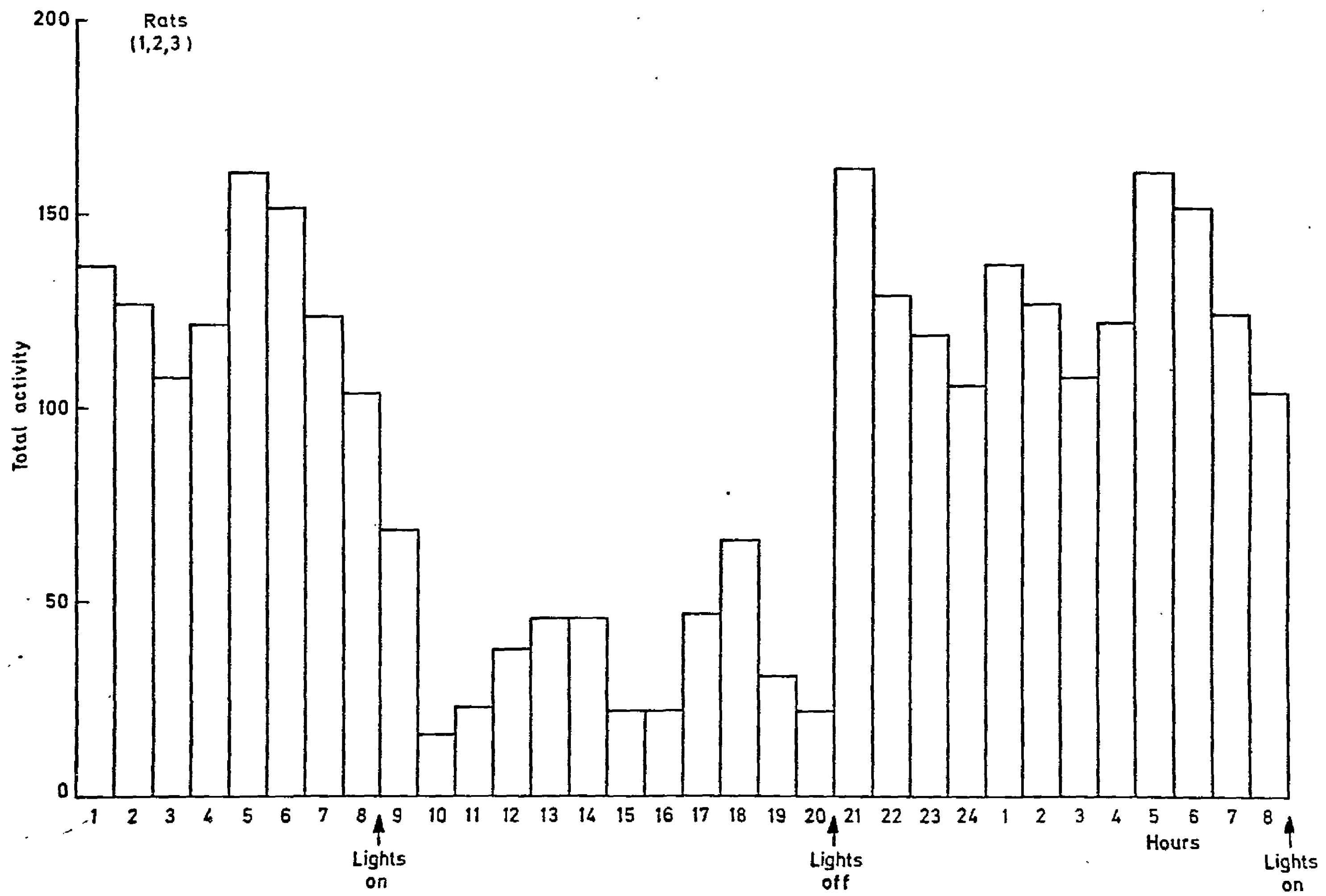

Rats
(1,2,3)
200
150
100
50
0
Total activity
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8
Hours
Lights
on
Lights
off
Lights
on

Figure 7.2.

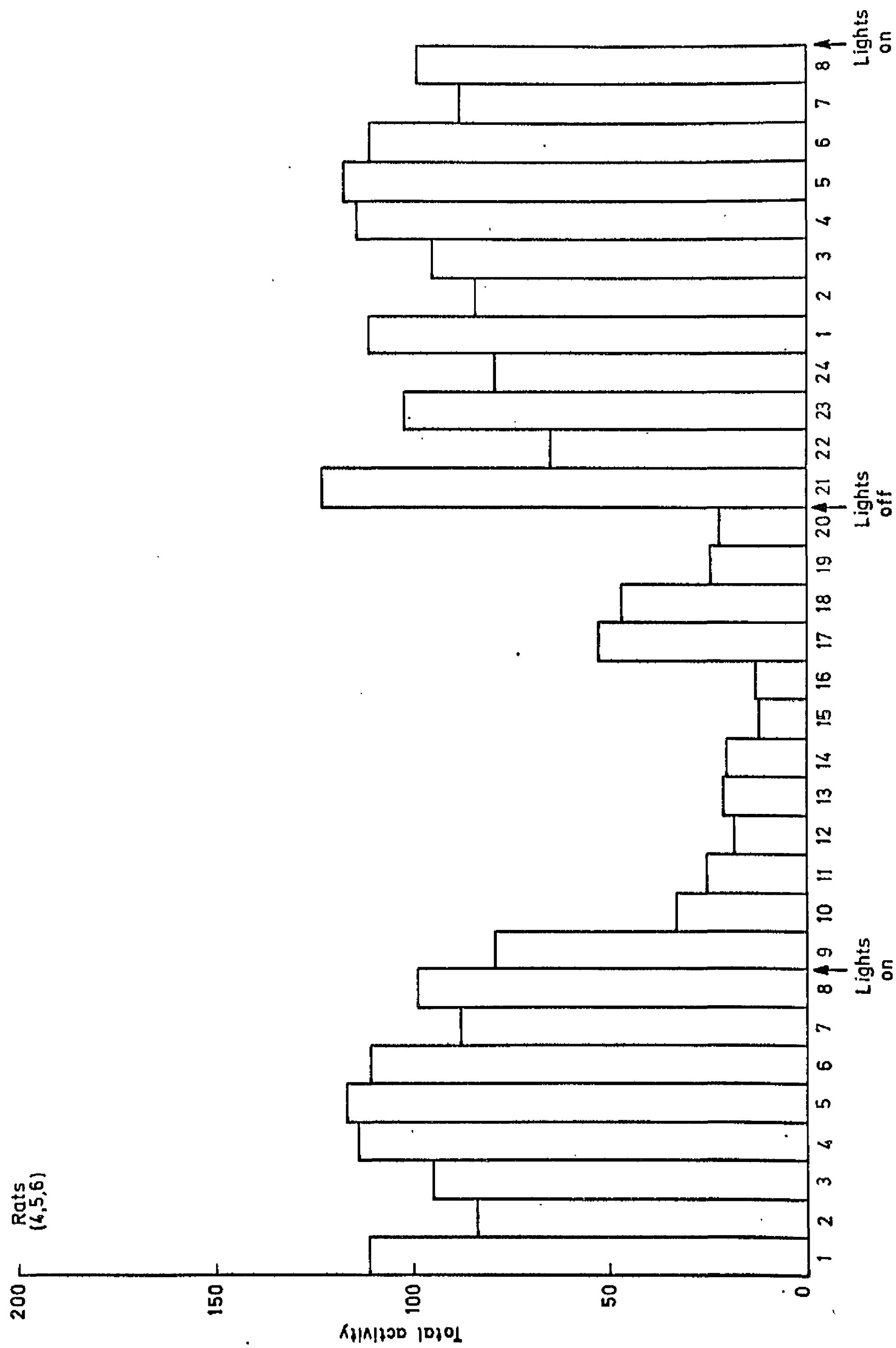

Rats (4,5,6)
Total activity
0
50
100
150
200
Lights on
Lights off
Lights on

Figure 7.3.

Figure 7.2. shows two peaks in the light - on part of the cycle, one from noon until 14,00 hours corresponding with lunch-time and the second between 16,00 hours and 18,00 hours corresponding with the general activity at the end of the working day. Only the second peak shows up in Figure 7.3.

The end of this initial nine day period coincided with the beginning of the Easter Holidays, which meant that for the next five days the laboratory would be unmanned and therefore free of noise. During this period the light-dark cycle was reversed to find out if the spontaneous activity pattern could be changed by a change of light stimulus. Figure 7.4. shows the response of the rats in the left portion of the room and Figure 7.5. that for the rats in the right compartment.

There was a marked change in the activity pattern showing that the rats' nocturnal habits are dependant on the absence of light.

DISCUSSION

Several points about the limitation of the method became painfully obvious during this short period but the results were more encouraging. The number of beam crosses taking place during the dark period was sufficiently large for them to show up any depressing effect of future experimental treatment yet well within the maximum counting capacity of the system should there be an exhilerating effect. A more even pattern of activity

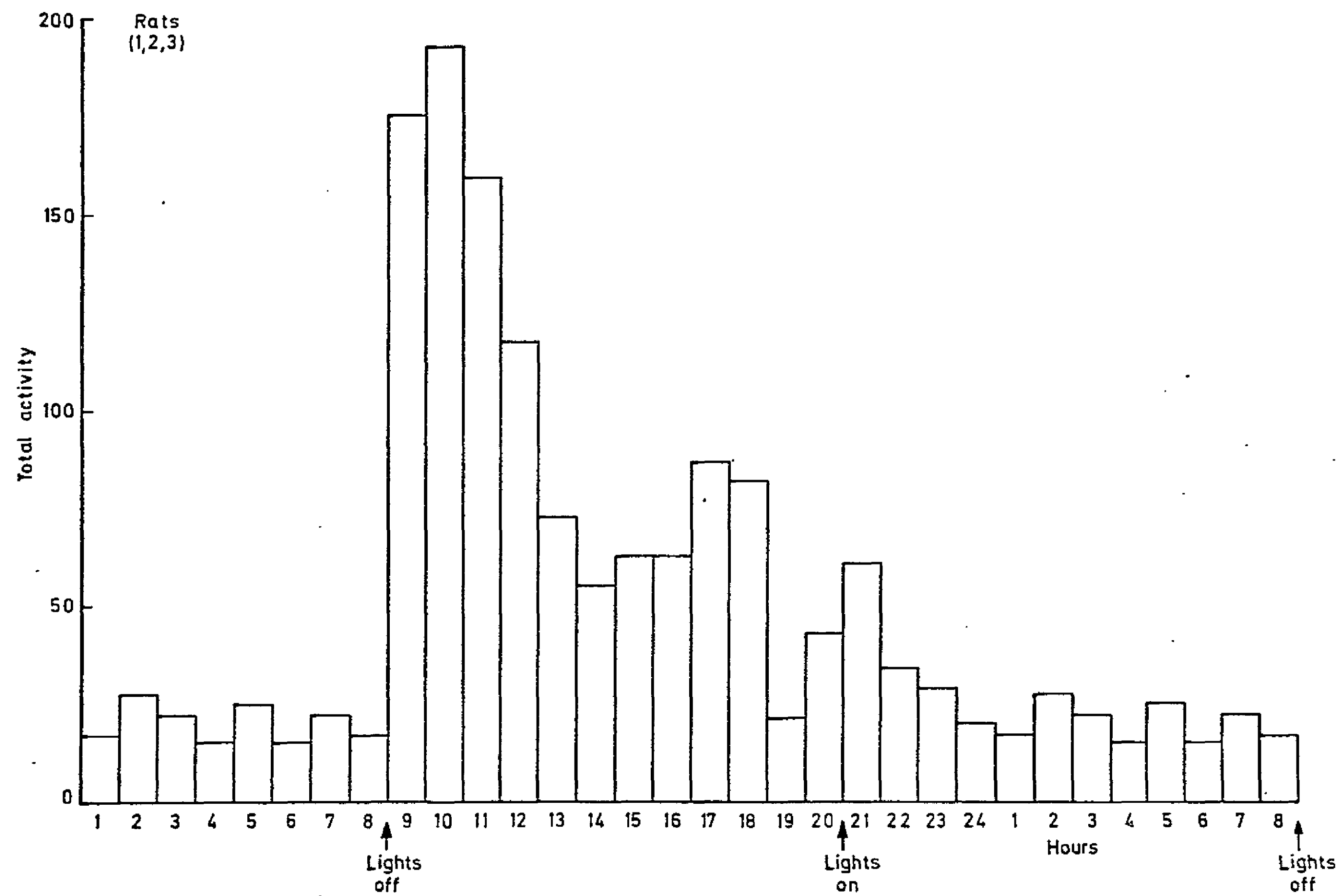

Rats
(1,2,3)
Total activity
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8
Hours
Lights off
Lights on
Lights off

Figure 7.4.

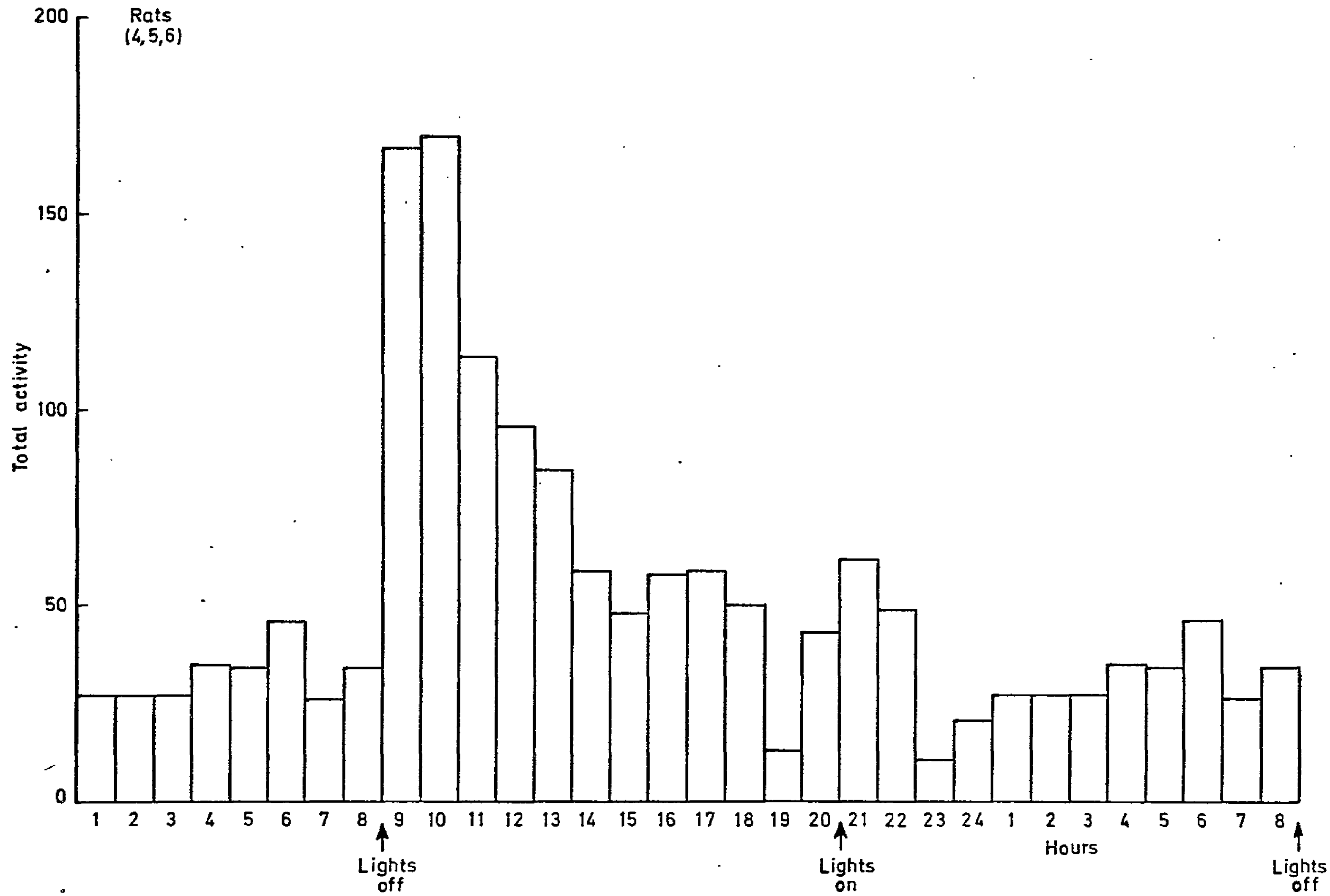

Rats
(4,5,6)
200
150
100
50
0
Total activity
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 1 2 3 4 5 6 7 8
Hours
Lights off
Lights on
Lights off

Figure 7.5.

was obtained by taking hourly totals (Figure 7.2.) rather than the fifteen minute totals (Figure 7.1.) obtained from the record. By reversing the day-night cycle for a short time the animals responded immediately by altering their activity pattern to fit the new cycle. Thus nocturnal spontaneous activity of the rat is a measureable quantity capable of responding to a change in light stimulus, albeit in this instance a rather gross one.

From the graphic presentation of the data for each rat similar to that shown in Figure 7.1. it was obvious that during the quiescent period the animals sporadic activity was generally random and so low compared to the active period that it was decided in future experiments to discontinue measuring it. Another reason for not recording the day-time activity was that there was some evidence to suggest that laboratory activity had an effect. A great deal of intermittent noise from the conditioning plant room passes back through the exhaust air duct into the room. The volume and frequency of interruptions depend upon the climatic conditions required in the other conditioned rooms, but one constant feature is the pumping of refrigerant out of certain parts of the system before the plant is switched off at the end of the working day, usually about 17,00 hours. This extra activity added to the general hub-bub of the laboratory probably accounts for the slight peak at 17.00 to 18.00 hours in Figures 7.2 and 3.

Yet another reason for abandoning the day-time recording was the effect which air-borne contaminants might have on the animals. The air-inlet to the room is situated on an outside wall, twenty feet up from the ground. The wind funnels between two buildings along this wall, and depending upon direction may bring exhaust fumes from a visitors car-park less than fifty yards away, also fumes from the airfield. As well as the usual products of combustion Burhans & Derau (1961) have shown that car exhaust contains large quantities of large ions (up to 10^6 ions/cc at the exhaust opening) with a normal positive to negative ratio and very few small ions. This would seem reasonable since the combustion chamber of a dirty engine contains all the necessary ingredients for the production of condensation nuclei and enough energy to ionise many of them. The effect of such quantities of large ions will be to deplete the air of its natural small ion content by providing slow-moving attractive nuclei. During the night complicating effects of this kind will be at a minimum since the laboratory is some way from a main road and there is no night flying on the airfield.

To return to the shortcomings of the method, the most obvious was that it was unreliable. Reliability was a pre-requisite of any recording system which would only be running during the night and at week-ends when no one would be about to periodically check its functioning. A single frame missing occasionally would have been admissable but usually when the flash failed, it did so several times in succession, so that a number of frames were missed. The cumulative total was always maintained but the distribution of activity within the blank period was lost.

For economic reasons and ease in processing the photographic technicians preferred the film to be as long as possible. This had certain advantages, but also serious disadvantages. Using a 200 ft cassette it was easy to calculate when it required renewing and easy to process automatically. But against this, it would have been embarrassing to find after a week's supposed recording that the camera had failed to progress the film, the flash had failed to work entirely or the development process had failed. Some system where a daily check on its efficiency could be made seemed a better prospect for the long-term continuous experiments envisaged.

Possibly the greatest drawback to the photographic method was the time spent analysing the records. Even if only twelve hour records were taken instead of twenty four hours the work involved in analysis is not reduced by half since during the day the number of movements is very small. It is a daunting prospect to start the analysis of 200 ft. of film with some 2,000 frames. The film was viewed using a film-strip adaptor through a standard 35 mm slide projector. These machines are designed for single frame viewing, however with some loss of quality, it was possible to see two consecutive frames, but continual slight adjustments to focus were necessary, also coping with several missing frames was very frustrating. The continual moving of the eyes from an illuminated screen to dimly lit paper to record the subtracted numbers was very wearing on the accommodating power of the eyes and added to the general tedium of the simple arithmetic. For these reasons the alternative punch-tape method of recording the data was devised.

ION COUNTING

The ion counter Philco Model ICF-6 proved to be unusable as purchased because of mechanical vibration transmitted from the air aspirating fan. Air is drawn down between the deflecting potential cylinder and the central collecting electrode, then at right angles through a side arm and blown out of the back of the instrument by a radial-flow fan. The whole unit is constructed of conventional thin-walled copper pipe rigidly plumbed together. The bottom of the deflecting cylinder fits tightly over a P.T.F.E. block on the top of the electrometer through the centre of which passes the collecting electrode, again this is a rigid connection. After passing through the insulating block the collecting electrode is connected via two high value resistances directly to the grid of the imput valve. In turn the electrometer box which is supporting this entire unit is screwed firmly to the main chassis of the instrument.

The vibration was eliminated by mounting the electrometer on a foam-rubber cushion, and sawing through the copper side limb leading to the fan. The continuity of this connection was restored by joining the saw cut with a piece of bicycle inner tube and the fan was suspended from an antivibration mounting on the top of the main instrument case.

Now the instrument was usable the limitations which led to the construction of a programmer to reverse the deflecting potential soon became apparent. With a better understanding of the importance of ion mobility it was also realised that the physical characteristics of the instrument namely the length of the collecting electrode and the fixed air flow rather limited its sampling range. In the operating instructions the suggested deflecting potentials ranged from 120 volts to 300 volts which corresponds to mobilities between 5×10^{-6} and 2×10^{-6} $m^2.v^{-1}.s^{-1}$ (0·05 and 0·02 cm/sec. per volt/cm.) The scale of the meter for setting the deflecting potential only extended upwards to 300 v which excluded the measurement of large ions and to count small ions (i.e. mobility greater than 1×10^{-4} $m^2.v^{-1}.s^{-1}$) required only 6 volts deflecting potential. With such a low value it was impossible to count naturally occurring small ions because their apparent number was of the same order as the electrometer drift. The manufacturers do point out that when low ion levels are being measured errors of 100% or more may result if drift corrections are not applied. Even when counting total small and medium natural ion levels (deflecting potential 300v) the most sensitive gain setting was required almost exclusively.

The conclusion arrived at was that this is a medium ion counter when used for measuring natural levels of ions, but when large quantities are being generated then it can be used with increasing confidence to indicate amounts within a limited spectrum. However, this does not preclude its use in the ion experiments proposed. It can be used to show the efficiency of ion removal and to monitor the experimental environment when small numbers of positive or negative are being added. It is, however, a sobering thought to wonder how extensively this instrument has been used in laboratory experiments on the assumption that it is a small ion counter. Because it requires some diligence to obtain values over a range of mobilities one is tempted to accept the counts at one deflecting potential setting only and in short experiments there is no time to do anything else.

Figure 7.6. is a picture of a piece from a typical ion counter recording with scale added. When the weather was suitable, serial measurements were made outside the front door of the laboratory, inside an office and then inside the experimental room.

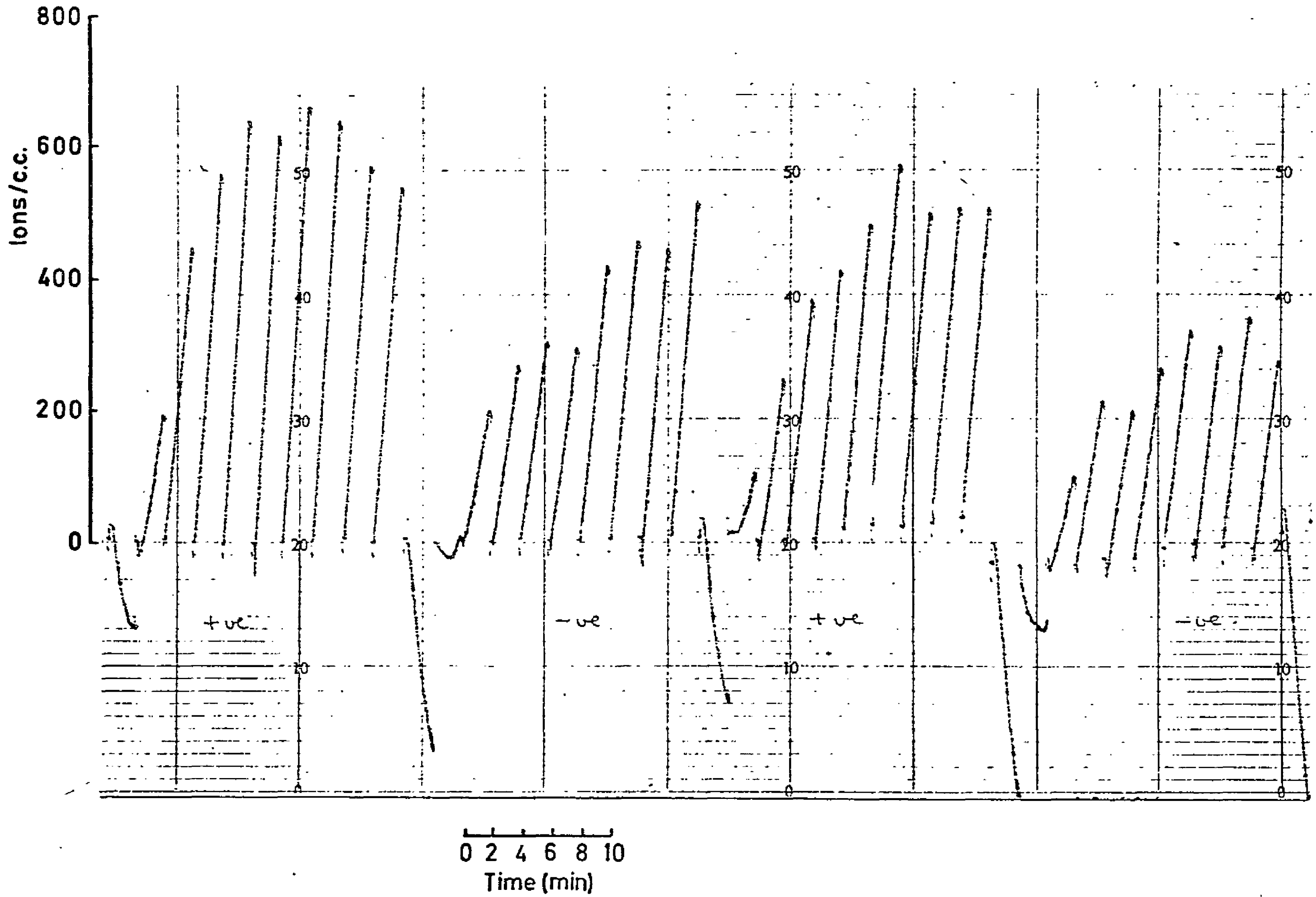


Figure 7.6. Ion Counts.

Because of slight gusts of wind the recording outdoors was rather erratic and only enough measurements were made to show that the levels inside and outside the building were essentially the same, This substantiates the findings of Shilling and Carson (1953) and Kähler (1934) (quoted by Chalmers 1957) that there are simultaneous changes of ion counts and electrical conductivity inside and outside buildings.

Using a 6 volt deflecting potential it was never possible to obtain a value for the natural levels of small positive or negative ions, but when artificially generated ions were blown at the counter it would respond immediately. So for the comparative measurement between outside and inside the building total ion counts were used, i.e. all ions with a mobility greater than 2×10^{-6} $m^2. v^{-1}s^{-1}$ were counted. The results showed that within the limits of serial sampling there was no difference in levels between outside and inside the experimental room and the fate of all the small ions had been sealed long before they entered the inlet duct.

CHAPTER 8

SECOND EXPERIMENTAL SERIES
EFFECT OF ELECTROSTATIC POTENTIAL

SECOND EXPERIMENTAL SERIES

AIM

To investiage the effect of electrostatic fields on the spontaneous activity and growth rate of rats.

INTRODUCTION

In the first experiment it was shown that the spontaneous activity pattern of laboratory rats was a measureable quantity and could be altered by a change of dark-light cycle. From measurements of the ion content of the air in the experimental room it was found that the small ion content was extremely low but medium ions did enter in recordable numbers. It was hoped to remove these ions by electrostatic precipitation in the space between the inlet duct and the animals' cages. As soon as the punch-tape method of recording activity was available two short experiments were carried out using a crude precipitator first in one side of the room, then in the other. By measuring the environmental conditions in the room and inside a cage it was soon realised that this was not the best way to achieve an ion-free atmosphere and that the air movement through the cages was inadequate for the proposed ion experiments. It was now obvious that a re-design of the duct system must be undertaken to ensure a proper flow of air through the cages to carry the small quantities of ions to the animals.

However, it was becoming apparent that space charge and the electrostatic potential on the animals must be a complicating factor in air ion experiments especially where large quantities of ions are being generated. In the present experiments where the animals are housed in plastic cages there are several ways in which static electricity could interfere. By simply walking about their cages the animals' fur will assume one sign of charge while the walls of the cage will become oppositely charged especially when the air is dry. Secondly, the passage of a current of air containing unipolar ions through the cage would tend to deposit them either on the wall of the cage or on the animal until the limit is reached where any succeeding ions will be completely repelled. This latter effect is very important in the practice of electro-aerosol therapy according to Wehner (1962) and also in air ion experiments according to Frey (1961) but Beckett (1961) during the post-conference discussion at the First International Conference on Ionization of the Air thought that Frey rather overstated the importance of the problem. Swann (1961) during the same discussion suggested a conductivity suit for patients but Frey thought that this would act rather like an ion drain and not be beneficial in bringing ions to the patient since in his experience ions go to the best earth. Frey's best earth is always his ion counter where there is an electrical suck as well as a fan to attract all manner of particles, and one can see Beckett's criticism since frequently there is no need to have the ion counter as a competitive attraction during experiments, and less reason during therapy. In the Russian clinics as reported by Baranova et al (1957) the general tendency is to earth the patient but this may be practiced as a matter of hospital routine for safety, rather than any other reason.

As already mentioned in Chapter 3, ion counters and ion generators especially corona discharge types do have their own surrounding electrostatic fields. Quite frequently these instruments are used very close to the experimental material with no comment about the strength of the fields involved or the effects they might have on the experiments. Knoll et al. (1961) however did comment, because they found that the electric field of their ion generator did increase the variance of their results although the mean was unchanged but it required rather extensive statistical treatment to show this effect. Bach (1967) also recognised the importance of static build-up on clothing and furniture in influencing the ion climate but he never suggested that electrostatic fields might have any influence believing that control of static is employed in his "Passive Technique" to preserve the ion content of the environment. In the pig-sties where tail-biting was rife he reported a higher than normal electrostatic field and just assumed that it was influencing the ions; if he measured them he didn't report the fact. Again in his investigation of the poultry house problem the higher mortality rate in one was ascribed to a change in the ion content of air as a result of a build-up of electric charge. It would have been very interesting to measure the more usual climatic parameters which seem to have been overlooked; the ventilation flow of air through the houses would influence their temperature and humidity as well as bringing in new ions and condensation nuclei. The wooden cladding is an excellent material for absorbing water vapour when the humidity is high and releasing it when the humidity falls, possibly maintaining a more even water vapour content in the air in that house and preventing charge build-up. From Bach's findings it would seem that wood has a better surface conductivity than masonite and this would be a function of the water content of the material. When the chickens were small the problem did not seem to be so acute. As the chickens grew their metabolic heat output would increase and the amount of water consumed and excreted would also increase, so that small differences in ventilation between the two houses could result in differences of effective temperature. He makes no mention of having considered these climatic effects although the remedy lay in the application of wetting agents to the surfaces on which the charges accrue.

In the natural environment there is a normal potential gradient increasing, from a defined zero on the earth, at the rate of + 100 volts per metre with height. Thus a standing man's head will be at a potential roughly 200 volts positive with respect to his feet and by virtue of this will attract negative ions and repel positive ones. Under certain conditions this potential is reversed so that the head becomes negative with respect to earth and will then attract positive ions. This has been suggested as one possible way in which some sensitive people are able to forecast impending thunder, and it may also be the mechanism of Robinson & Dirnfeld's "electrical chamsin".

Since in the proposed ion experiments both the ion generator and counter would be used in very close proximity to the animals and because of the inter-relationship between ions and electrostatic fields it was decided as a control to investigate the effects of the latter in the almost complete absence of the former. The experimental circumstances as they had evolved, namely a high rate of air change, of low ion content, in the room which gave good temperature control, but with virtual still air inside the animal's cages seemed to present a good opportunity to investigate the effects of various configurations of electrostatic potential round the animals.

METHOD

The same six rats were used throughout this series of experiments as were used in the first experiments.

In the ion precipitation part two metal plates 12" x 15" were arranged parallel to one another, horizontally in front of each of the four inlet ducts in such a way that the air flowed between them into the room. A potential was applied to the plates in one compartment while those in the other compartment were left unconnected. The lower pair of plates were at earth potential while the upper ones were at + 1000 volts. Twenty nights activity records were obtained using the new punch tape method of recording. At the end of this period the same potential gradient was applied to the plates in the other part of the room and the first ones disconnected - a further twenty nights activity records were obtained.

For the remaining experiments in this series the precipitation plates were discarded and the electrostatic potential was applied directly across the cages. Metal plates were placed under the cages in contact with the metal trolleys which constituted one plate of a condenser, the metal grid tops of the cages being the other. The power-pack of the ion generator was capable of producing potentials of $\pm$ 9000 volts without modification and all that was required to make it usable was to manufacture a suitable high tension plug for connecting into its output.

Since both parts of the room have a common air conditioning system it was hoped that each set of rats would react in the same way to any climatic influences. The rats in one side of the room were therefore left untreated to act as monitors of the environment while the others were subjected to a number of treatments which are summarized in Table 8.1.

TABLE 8.1.

No.	Treatment
1	1kV + ve. during the night only
2	1kV + ve. during day, 1kV -ve at night
3	2kV + ve. during day, 2kV -ve at night
4	2kV + ve. continuously
5	3kV + ve. "
6	4kV + ve. "
7	5kV + ve. "
8	No artificial electrostatic field

In table 8.1. it is always assumed that the bottom of the cage and surrounding rack is at zero potential and that the values quoted in the table are therefore with respect to that and are applied to the top of the cage.

While the untreated rats monitored the external influences, the treated rats acted as their own controls, by comparing the result of each treatment with that obtained in the immediately preceding experiment. The last experiment was conducted with no electrostatic potential applied across the cages, that is, the conditions were the same as for the control group and this sudden return to no artificial field conditions might show up a cumulative effect not noticed in the step-wise progression of the series.

PRECIPITATION EXPERIMENT

RESULTS

Using the punch-tape method four nights' records were collected. Since they corresponded so well, the precipitation experiment was started after a sticking counter had been replaced in the recording equipment.

Figure 8.1. shows the mean total activity for succeeding nights, starting with the preliminary four nights, followed by twenty nights in which a potential was applied to the plates in the right hand chamber - precipitation experiment 1. Experiment 2 part of the graph shows the results when the potential was applied to the set of plates in the other chamber. It was surprising to find that the activity of Group A (Rats 1 - 3) had increased so much from the initial four measurements. However from the rats' individual records, it was soon evident

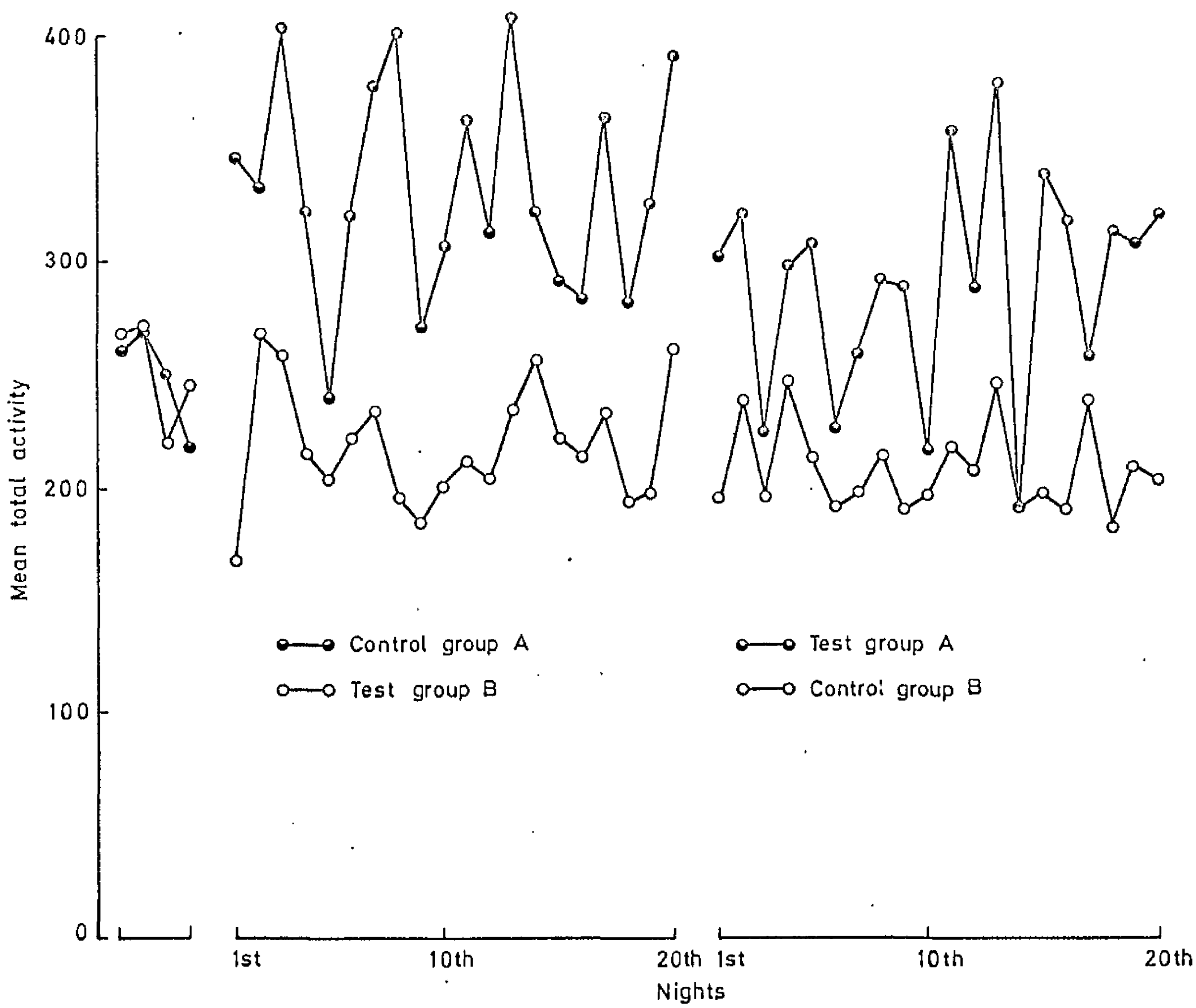


Figure 8.1. Precipitation Experiment.

that the activity of these three rats was much more erratic than Group B, as can be seen from Table 8.2.

Group	Treatment	Mean	s.e. Diff.	t	p
A	Control	333	39	9	$0 \cdot 001 > p$
B	Test	219			
A	Control	333	48	2·7	$0 \cdot 02 > p > 0 \cdot 01$
A	Test	291			
B	Test	219	24	1·3	not sig.
B	Control	209			

TAPLE 8.2.

Precipitation Experiment

By reversing the test condition in the second experiment it was hoped to show whether this was a group difference or due to the treatment. Table 8.2 summarises the results. Comparing groups in Experiment 1, it was confirmed that the rats belong to different populations. Testing the effect of the treatment on the groups, B indicated no effect but there was a significant difference in the other group. Since the difference only occurred in one group it was concluded that it was not due to the treatment but to some other effect which had stimulated Group A in the period when they were controls, this will be discussed later.

Figure 8.2. shows the distribution of activity within the twelve hour dark period. No alteration in pattern took place throughout this whole series of experiments, the height of the hourly peaks reflected the change in overall activity from one experiment to the next so the change in mean nightly activity was investigated to test the differences between treatments.

SUMMARY

Investigation of the physical characteristics of the precipitator showed that with the air entering the room moving at 400 ft/min ($2{\cdot}0 m.s^{-1}$) all the precipitator was achieving was to make the positive ions tend to go towards the floor and the negative ones rise. Since the air change inside the cage was entirely dependant upon natural convective currents the number of ions reaching the rats was uncontrolled.

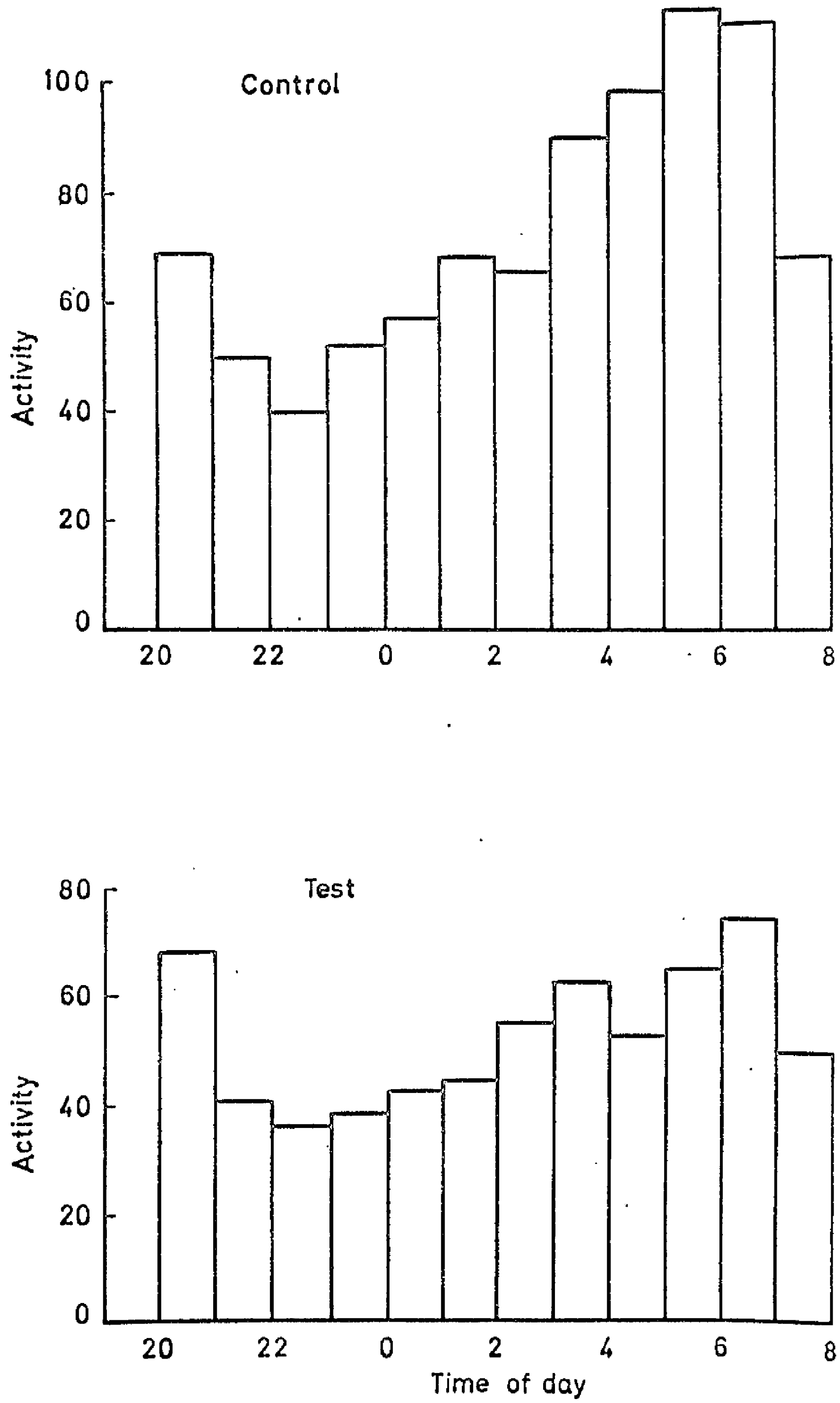


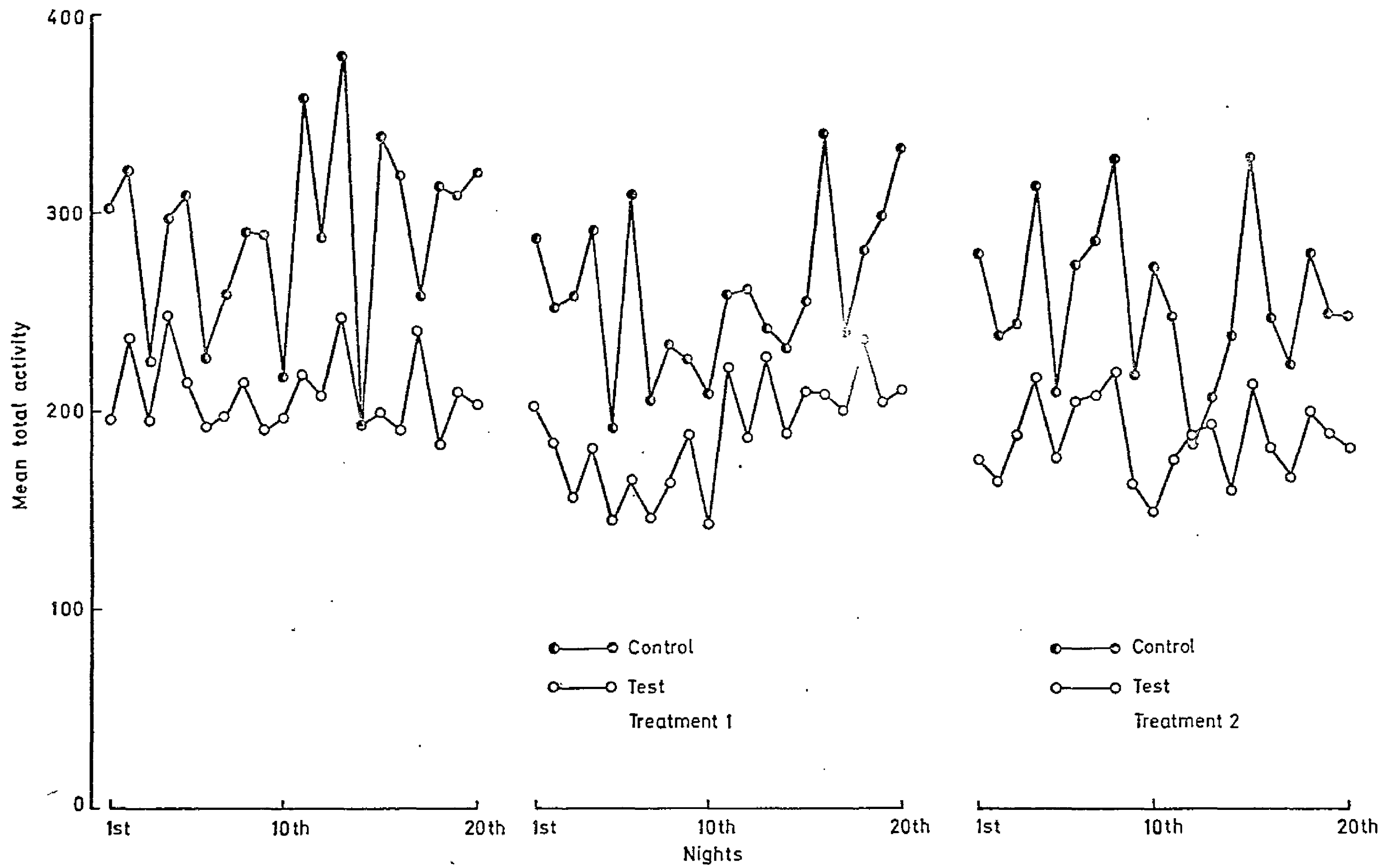
Figure 8.2. Dark Period Activity Pattern.

ELECTROSTATIC FIELDS

RESULTS

The mean total activity of the two groups for the series of experiments using electrostatic fields across the cage are plotted in Figures 8.3 to 8.6. The various treatments which Group B received are given in Table 8.1. in the method, while Group A which was more erratic, was retained as a monitor of the environment. Table 8.3. summarises the comparison of the means of the control periods which correspond to the test periods received by Group B. The first and last comparisons are the only two in which there is a slightly significant difference, in both cases "t" is just outside the 5% limit. From Figure 8.3. it will be seen that during Treatment 1 both groups exhibited a depression of activity on succeeding days followed by a recovery. Since both groups respond in the same way it is concluded that the effect is due to an extraneous source. There is a small increase in general activity in both groups in the last period, Figure 8.6., which is just significant in the case of the control rats. When both groups respond in the same way to undetected extraneous influences one feels that the test animals are likely to show a response to any direct effect of the various treatments.

Similar information for Group B, the test group is shown in Table 8.4. Treatment 1 has already been discussed. There was



400
300
200
100
0
Mean total activity
1st
10th
20th
1st
10th
20th
Nights
1st
10th
20th
Control
Test
Treatment 1
Control
Test
Treatment 2

Figure 8.3.

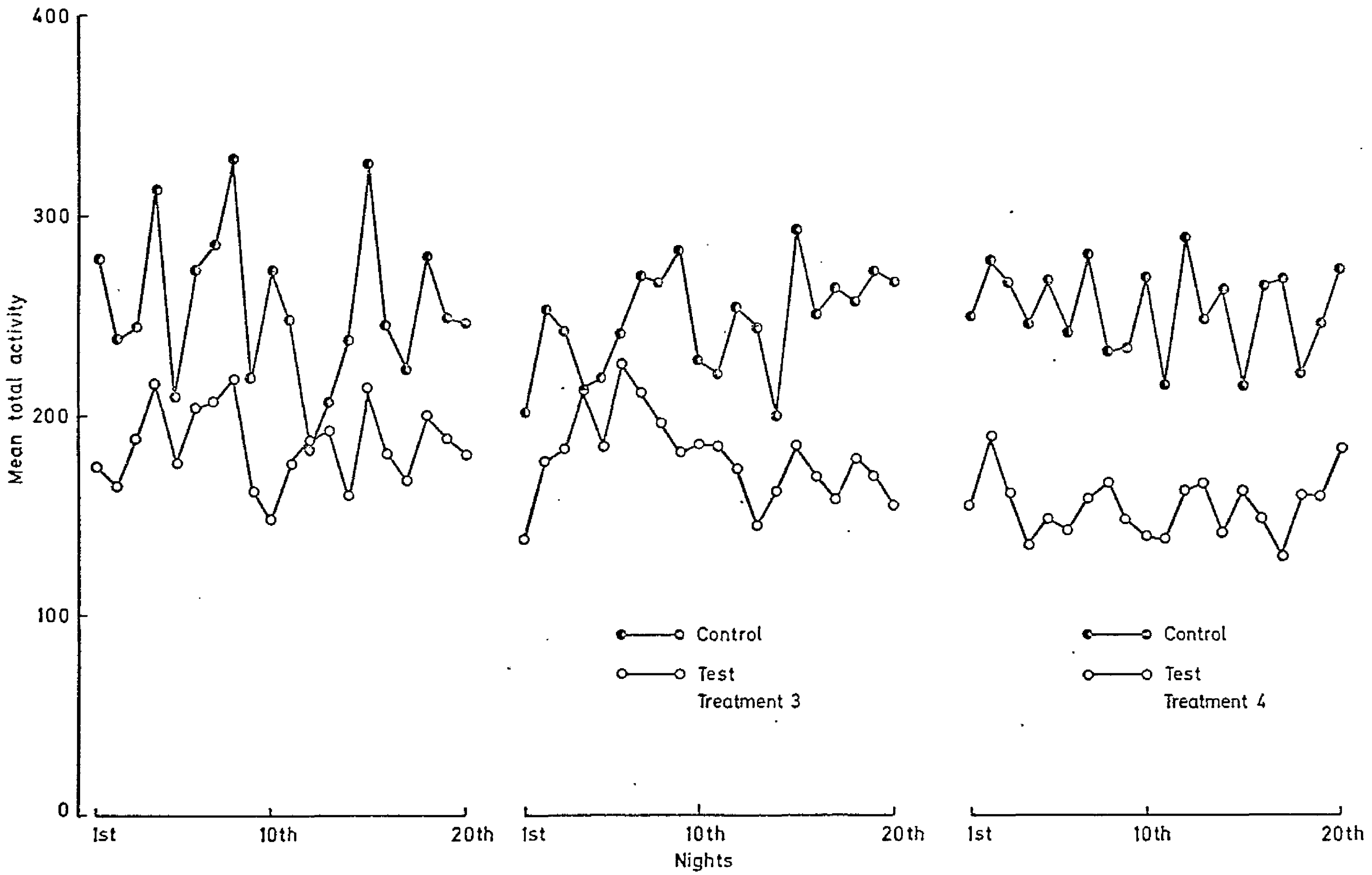
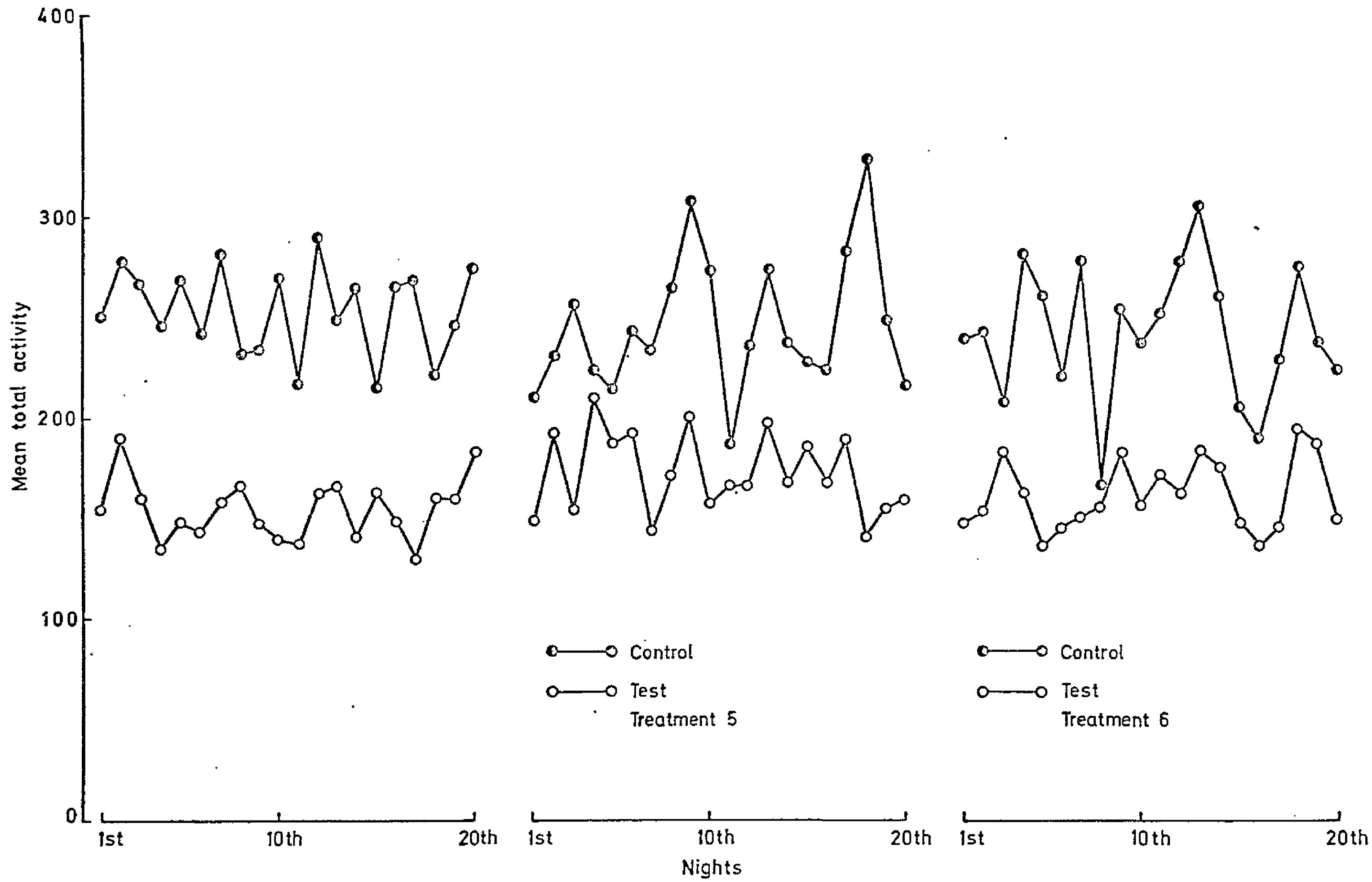

400
300
200
100
0
Mean total activity
1st
10th
20th
1st
10th
20th
1st
10th
20th
Nights
Control
Test
Treatment 3
Control
Test
Treatment 4

Figure 8.4.



400
300
200
100
0
Mean total activity
1st
10th
20th
1st
10th
20th
1st
10th
20th
Nights
Control
Test
Treatment 5
Control
Test
Treatment 6

Figure 8.5.

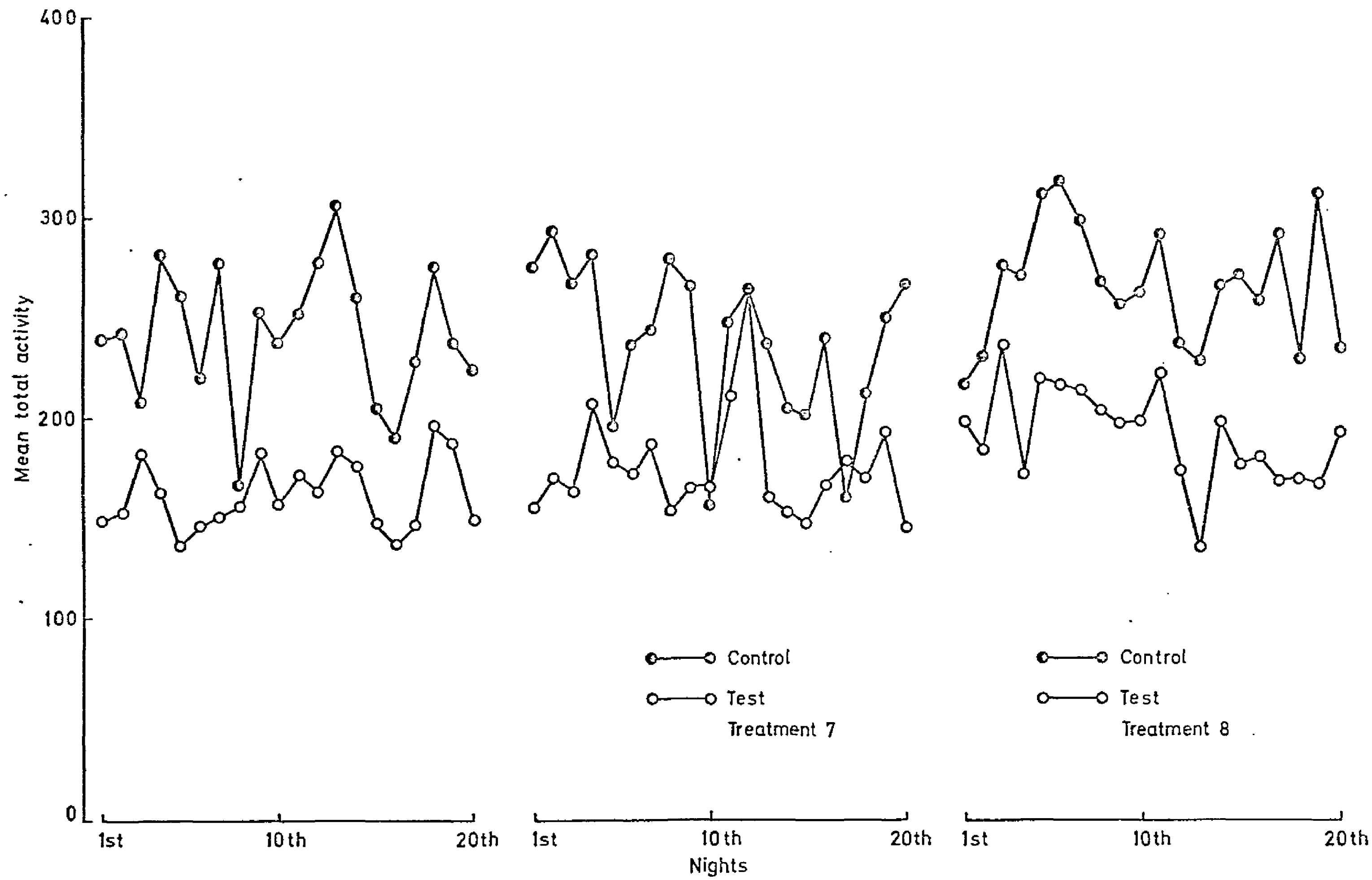

400
300
200
100
0
Mean total activity
1st
10th
20th
1st
10th
20th
1st
10th
20th
Nights
Control
Test
Treatment 7
Control
Test
Treatment 8

Figure 8.6.

Treatment period	Mean	Diff. s.e.	t	p
	291			
		44	2·1	0·05 > p > 0·02
1	260			
		39	0·39	not sig.
2	255			
		33·5	0·75	not sig.
3	247			
		24	0·91	not sig.
4	254			
		30	0·86	not sig.
5	246			
		35	0·33	not sig.
6	242			
		37	0·29	not sig.
7	239			
		35	2·3	0·05 > p > 0·02
8	265			

TABLE 8.3.

Control group

Treatment period	Mean	Diff. / s.e.	t	p
	209			
		24	2·1	0·05 > p > 0·02
1	189			
		24	0·42	not sig.
2	185			
		21	0·94	not sig.
3	179			
		23	4·5	p < 0·002
4	146			
		22	3·8	p < 0·002
5	173			
		19	1·82	0·1 > p > 0·05
6	162			
		23	1·85	0·1 > p > 0·05
7	175			
		26	1·04	not sig.
8	190			

TABLE 8.4.

Treated group

no effect from the next two treatments but then Treatment 4 seemed to produce a very profound response. Thereafter if the 5% level is accepted the remaining differences are not significant.

Looking at individual performances during Treatment 4, rat No. 5 which was normally the most active of the three was unnaturally subdued. If the data for Treatments 3, 4 and 5 is re-examined, (Table 8.5.) with rat 5 excluded the differences are no longer significant.

SUMMARY

From the results on this rather limited number of rats and within the small range of voltages applied there is no evidence to show that electrostatic fields per se have any effect on the spontaneous activity of the rat.

GROWTH RATE

The rats were selected so that the total weight of rat in either side of the room was the same. Normal growth rate follows an exponential curve which was the case with these rats, both groups growing at the same rate on the early part of the curve. During the first three treatments Figure 8.7. they remain together but thereafter both groups become rather erratic. Because only three rats per group were used, the size of the fluctuations of each was such that statistical treatment would emphasise this fact rather than expose any difference of treatment.

Treatment period	Mean	Diff. s.e.	t	p
3	156			
		21	0·25	not sig.
4	155			
		18	0·7	not sig.
5	159			

TABLE 8.5.

Treated group with rat 5 excluded

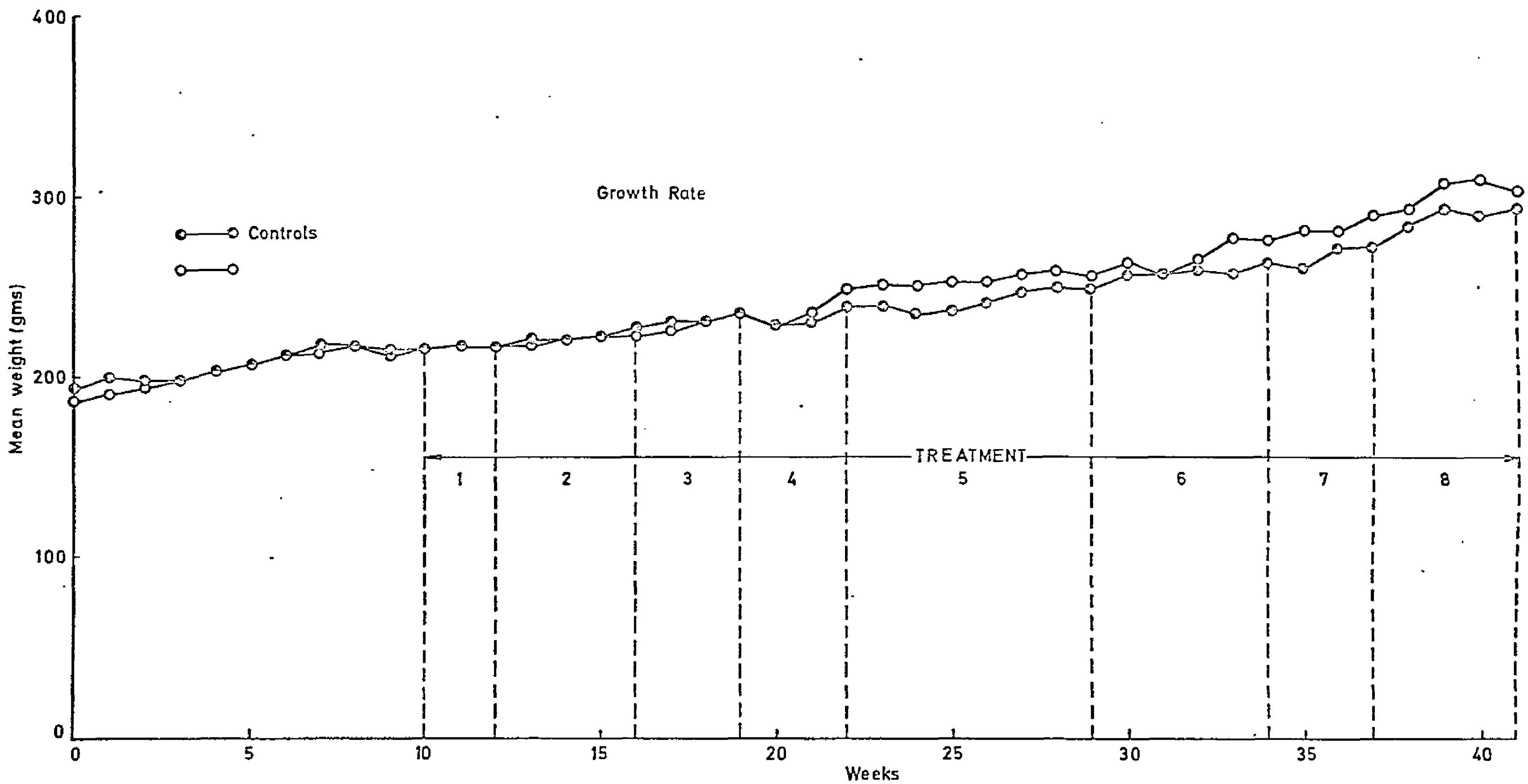

Growth Rate
Controls
TREATMENT
1
2
3
4
5
6
7
8
Mean weight (gms)
Weeks
0
100
200
300
400
0
5
10
15
20
25
30
35
40

Figure 8.7.

CHAPTER 9

THIRD EXPERIMENTAL SERIES
EFFECT OF AIR IONS

THIRD EXPERIMENTAL SERIES

AIM

To test the effect of adding small quantities of ions to the air on the spontaneous activity and growth rate of rats living in an ion free atmosphere.

INTRODUCTION

In the introduction to Part 2 of this discourse the reasons for carrying out these experiments were outlined. This is not the first time that rat activity has been measured in conjunction with air ions, Herrington & Smith (1935) investigated the effects of high concentrations of negative ions on this parameter and so did Bachman et al. (1966) using both negative and positive ions. Herrington & Smith's results were rather inconclusive and were never repeated. In their attempts to find out if there was a dose related pattern in the gross motor activity of rats Bachman et al. (1966) used very high quantities of negative and positive ions. Their results indicated that the area of low ion concentrations between + 10^5 ions/cc and - 10^5 ions/cc was a region of great sensitivity but they were unable to carry out more detailed observations. They concluded that the fluctuations in response could be responsible for some of the inconsistencies in the literature, for example, they noticed that by administering a dose of 1 x 10^6 negative ions/cc as used by Herrington & Smith on their rats, the response was likely to be the same as that using normal levels so it was not surprising that Herrington & Smith got inconclusive results.

In view of the findings of Bachman et al. it was encouraging to receive their paper soon after the decision had been made to use the spontaneous activity of rats to measure the effects of ion-free air and air with low concentrations of negative and positive ions.

After the previous series of experiments the six rats were returned to the animal house since they were about 18 months old and getting rather large for their cages, also, although the results of the series were negative three of the rats had been living in a high electrostatic field for some time. Looking at the activity records of this small population wide individual variation was evident, some were lazier than others while some were more erratic in their performance. It therefore seemed worthwhile to obtain twelve rats and make full use of the counting facilities with a view to selecting the most stable and consistent six rats for this series of experiments.

During the selection period the prefabrication of the box-like extensions to the room air-inlet ducts was carried out.

METHOD

Twelve rats were individually housed using both tiers of the trolley as described in the general method. Now that all twelve channels were being used to record activity data, the tape was difficult to read visually, however by a suitable programme the information was extracted by the laboratory's computer. Unfortunately the input tape was in very unorthodox form so that many of the checking procedures incorporated in computer language were missing, so to test its accuracy one tape was read visually. A piece of unperforated tape had dark bars drawn on it in register with the holes in channel seven. Using this as a backing to the tape from which the data was to be extracted, first, the activity of rats one to six was counted then by displacing the backing tape, rats seven to twelve. Since the digital counters of the photographic method were still functioning it was possible to use the overnight totals displayed on them to check independently that the computer was sampling its information in the correct order, initially it was typing out the totals from rats seven to twelve before one to six.

Records were obtained during one month which allowed the animals time to settle down and become accustomed to the cleaning and weighing routine. The six most consistent rats in activity performance were chosen as the group for the ion experiments, four of these were already on the top row of cages so only two had to be promoted, the other six were returned to the animal house.

Figure 9.1. shows the inverted L-shaped box which was constructed from wooden battens and hard-board to fit over the inlet ports of the air conditioning system. One was constructed for each compartment of the room, with outlet holes directly over the three cages. Transparent P.V.C. sleeves were fixed to the outlets and hung down over the tops of the cages which made removal very easy at cleaning time and also permitted the access of room light to the animals. The bottom ends were loosely tied round the tops of the cages to prevent flapping. A layer of extremely fine copper gauze which could be earthed, was fixed firmly over the exit ducts of the box to act as a filter both of dust and ions.

The top tiers containing the activity measuring systems were removed from the trolleys and remounted so that the ion counter could be placed under each cage. To measure the ions reaching any particular rat's position a spare cage was substituted in which a $2\frac{1}{4}''$ diameter hole had been cut, the ion counter was then placed underneath so that the ion collector tube projected up into the cage about one inch.

Figure 9.2. shows the position of the ion generator inside the hard-board box, by pointing it so that its own fan blew into the advancing air-stream a good mixing was obtained and the concentrations of ions in the three rat stations underneath were the same.

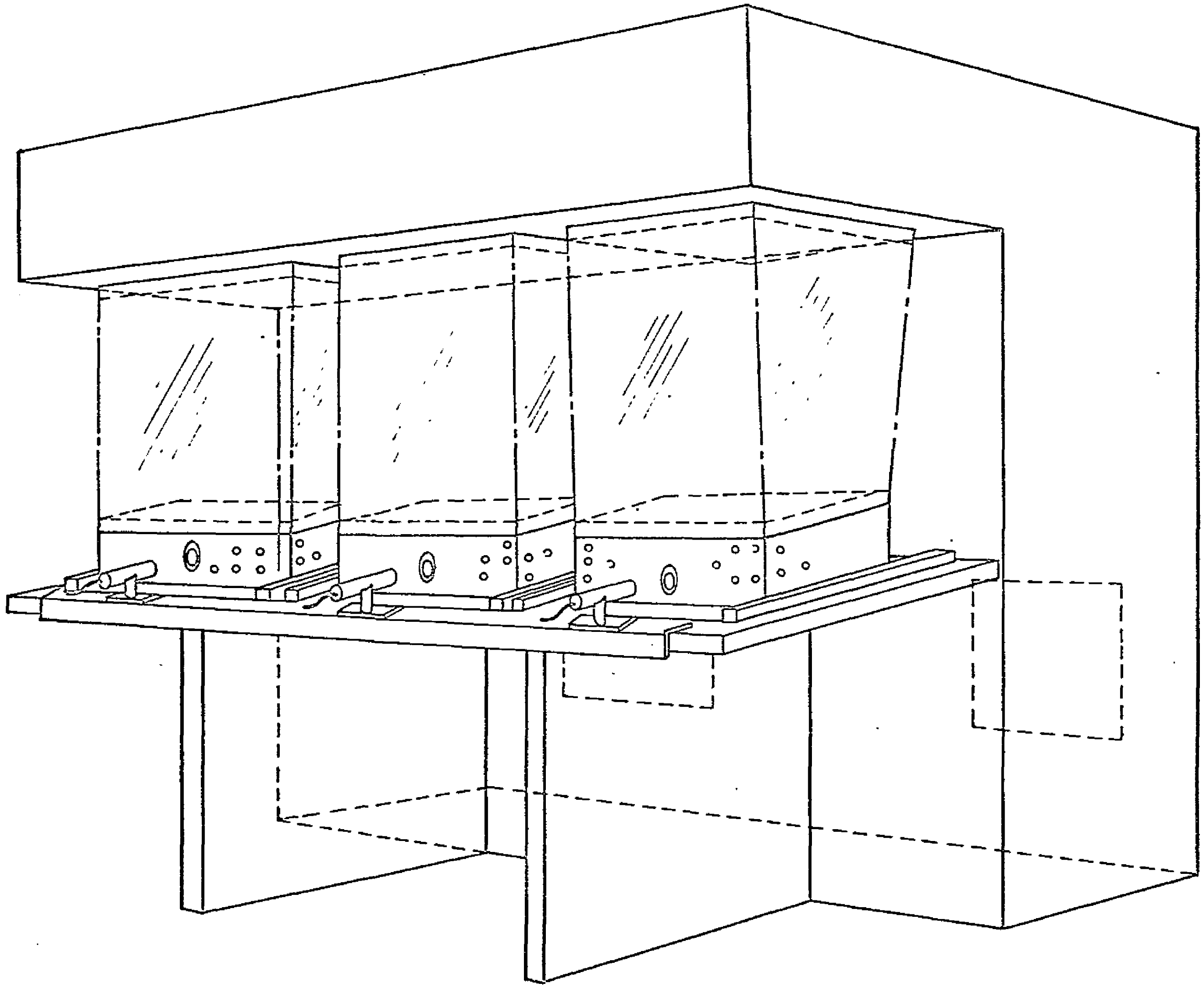


Figure 9.1. Modified Duct.

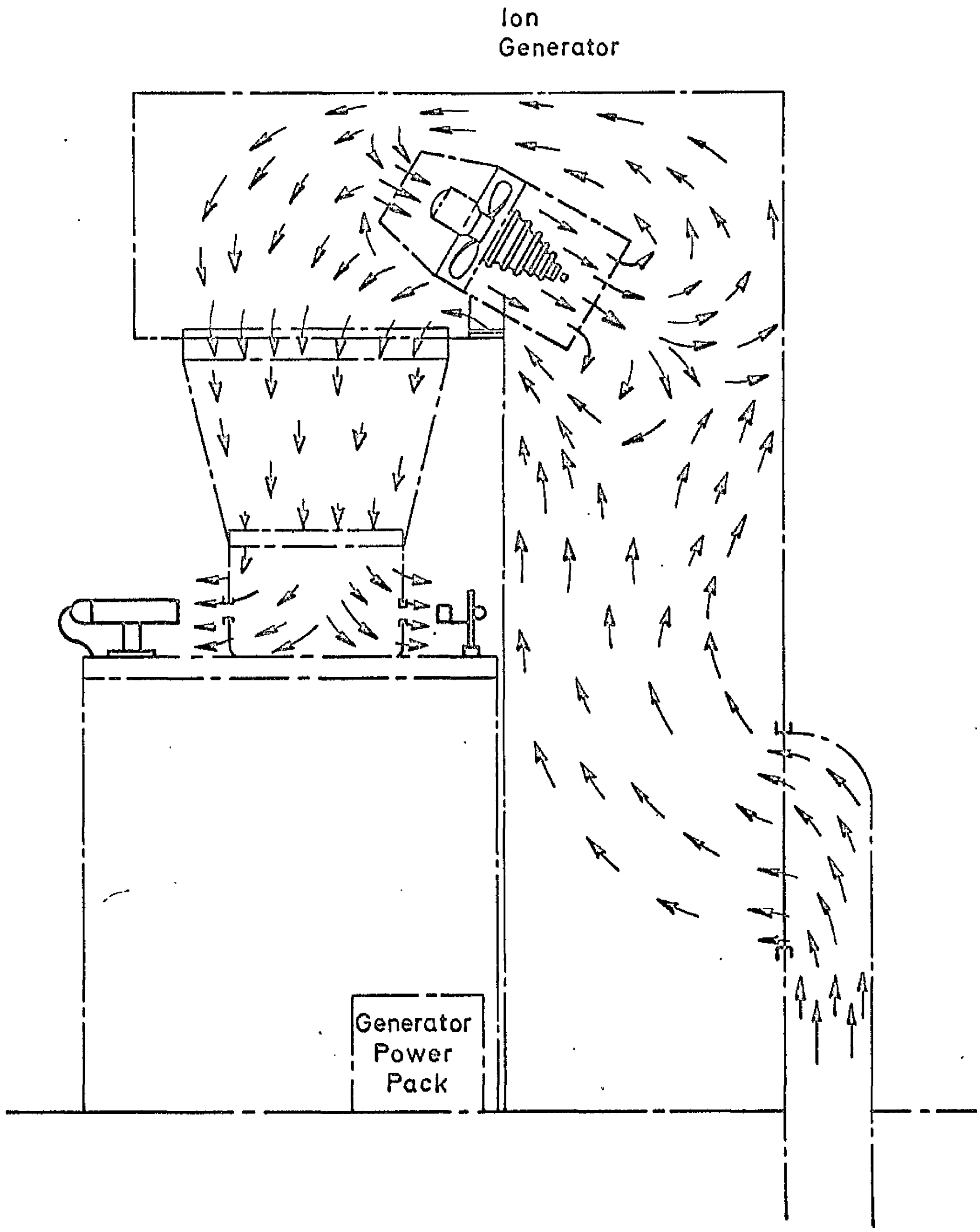


Figure 9.2. Position of Ion Generator Inside Duct.

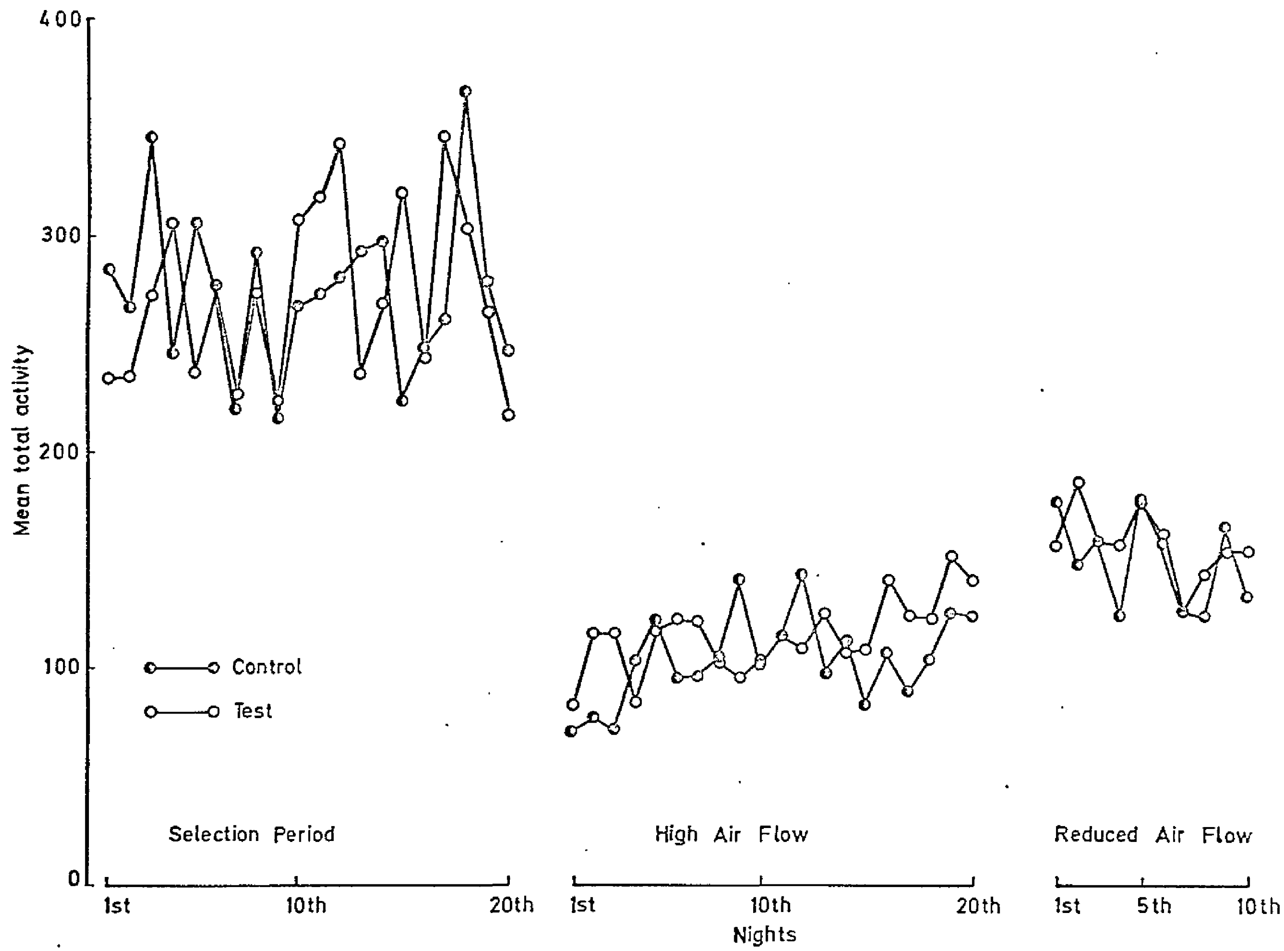
Measurement of the air-flow inside the cages was not easy because of the relative size of the instrument and cage and the direction of air-flow. In the previous series where the air-flow over the cages was horizontal and through them nearly zero, a kata thermometer was used to measure it. But now the airflow to be measured was in direct opposition to the natural convection over the thermometer so that the kata-factor was no longer applicable. The air entering the boxes from the room inlet ducts was moving at 400 ft/minute ($2 \cdot 0$ $m.s^{-1}$) and since the outlet area was greater than the inlet the figure of 300 ft/minute ($1 \cdot 5 m s^{-1}$) down the P.V.C. duct was reasonable but this was registered at the lowest possible mark on a Velometer so its accuracy is suspect. After the experimental series was completed a vane-anaemometer was available, capable of checking the air flow at the tops of the cages. The reading fluctuated between 70 and 100 ft/min ($0 \cdot 35$ $m.s^{-1}$ and $0 \cdot 5 m.s^{-1}$) which in a natural environment is almost a still air condition, but it represented a stress to the rats. Thus during the experimental series the rats were subjected to three air movements. During selection forced convection was absent, then, when first exposed to an airflow it was 300 ft/min ($1 \cdot 5$ $m.s^{-1}$) and finally it was reduced to under 100 ft/min ($0 \cdot 5 m.s^{-1}$) for the ion experiments. Air temperature while the air-movement was high in the room was steady at $25^{\circ}C$.

During the period of reduced air flow it fluctuated because of air layering in the room. The room thermostat was placed beside the rat cages for the ion experiments and recovery period resulting in a temperature fluctuating between 26°C and 28°C. The slightly higher temperature was used to partly offset the chilling effect of the air movement. Humidity varied between 40% and 50% at the start of the experimental series but gradually declined to below 30% by the end of the ion experiments reflecting the falling outside air temperature as winter began.

RESULTS

Since the selection of the six rats was carried out using the unmodified duct system the activity pattern within the 12-hour dark period was examined and found to follow the same distribution as the last set of rats, Figure 8.2. The mean total activity for the last 20 nights of the selection period is plotted in Figure 9.3. Analysis of the results summarized in Table 9.1. indicates that both groups belong to the same population.

The results of putting the animals into a stream of air is shown in the centre portion of Figure 9.3. followed by an improvement in activity with a reduced air flow. From Table 9.2. it will be seen that both groups of rats reacted in the same way to the changes in the airflow. The difference between the activity in the selection period and the high air flow period is highly



400
300
200
100
0
Mean total activity
Control
Test
Selection Period
High Air Flow
Reduced Air Flow
1st
10th
20th
1st
10th
20th
1st
5th
10th
Nights

Figure 9.3.

Treatment Period	Group	Mean	n	s.e. diff.	t	p
Selection	Test	273	20	39·7	0·21	not sig.
	Control	274	20			

TABLE 9.1.

Treatment Period	Group	Mean	n	s.e. diff.	t	p
High air	Test	116	20	19·2	1·9	not sig.
	Control	104	20			
Reduced air	Test	157	10	19·3	1·4	not sig.
	Control	149	10			

TABLE 9.2.

significant ($t = 15$) and so is the recovery achieved by reducing the air flow ($t = 8 \cdot 6$).

Figure 9.4. illustrates graphically the results of administering negative ions, followed by positive; followed by a return to the control unconditioned state. Table 9.3. analyses the significance of the findings. Between the two groups there is a slightly significant difference ($0 \cdot 05 > p > 0 \cdot 02$) when negative ions are administered but none under the other conditions. However, if the difference in performance of the test group under negative and positive ionization is examined the difference is not significant ($t = 1 \cdot 8$) at the 5% level and neither is the difference between positive treatment and the final control period.

GROWTH RATE

Figure 9.5. shows the pattern of growth rate for the two groups. Since the rats were selected in this series on activity performance there was an initial difference in the mean weights of the groups which was maintained through the experimental series. The effect of the changes in air movement is reflected in the growth rate but the recovery is very slow. Since the data is limited to three rats per group and the individual variation is large, any statistical treatment would emphasise this variation and be unrewarding in demonstrating any difference due to treatment. This was the advice of the Institute's statistician Miss H. Ferris to whom I am indebted for her assistance.

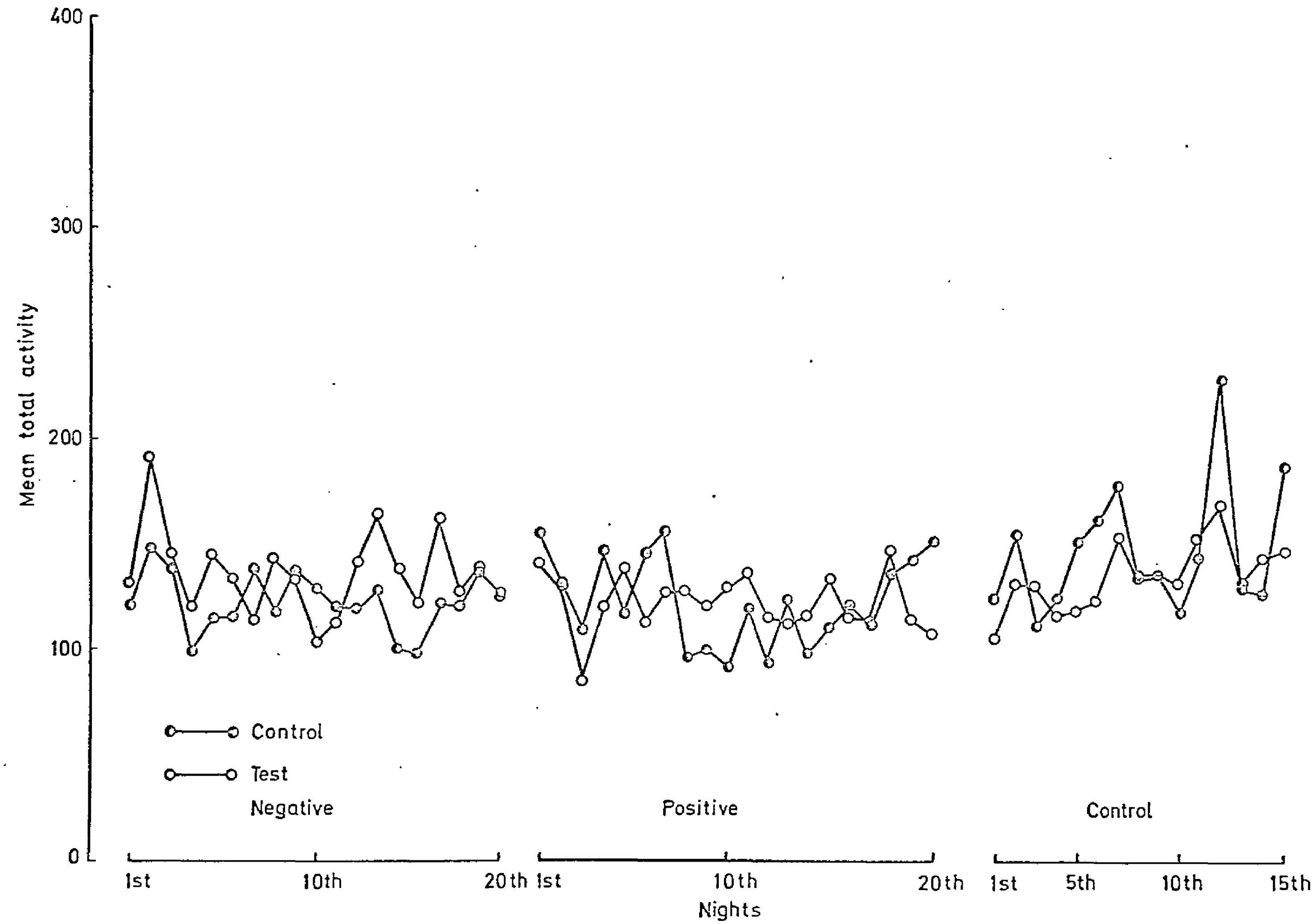

Mean total activity
400
300
200
100
0
Control
Test
Negative
Positive
Control
1st
10th
20th
1st
10th
20th
1st
5th
10th
15th
Nights

Figure 9.4.

Treatment Period	Group	Mean	n	diff. s.e.	t	p
Negative Ions	Test	136	19	22	2·3	$0 \cdot 05 > p > 0 \cdot 02$
	Control	122	19			
Positive Ions	Test	122	20	24	0·12	not sig.
	Control	123	20			
Recovery	Test	133	15	24	2·0	not sig.
	Control	145	15			

TABLE 9.3.

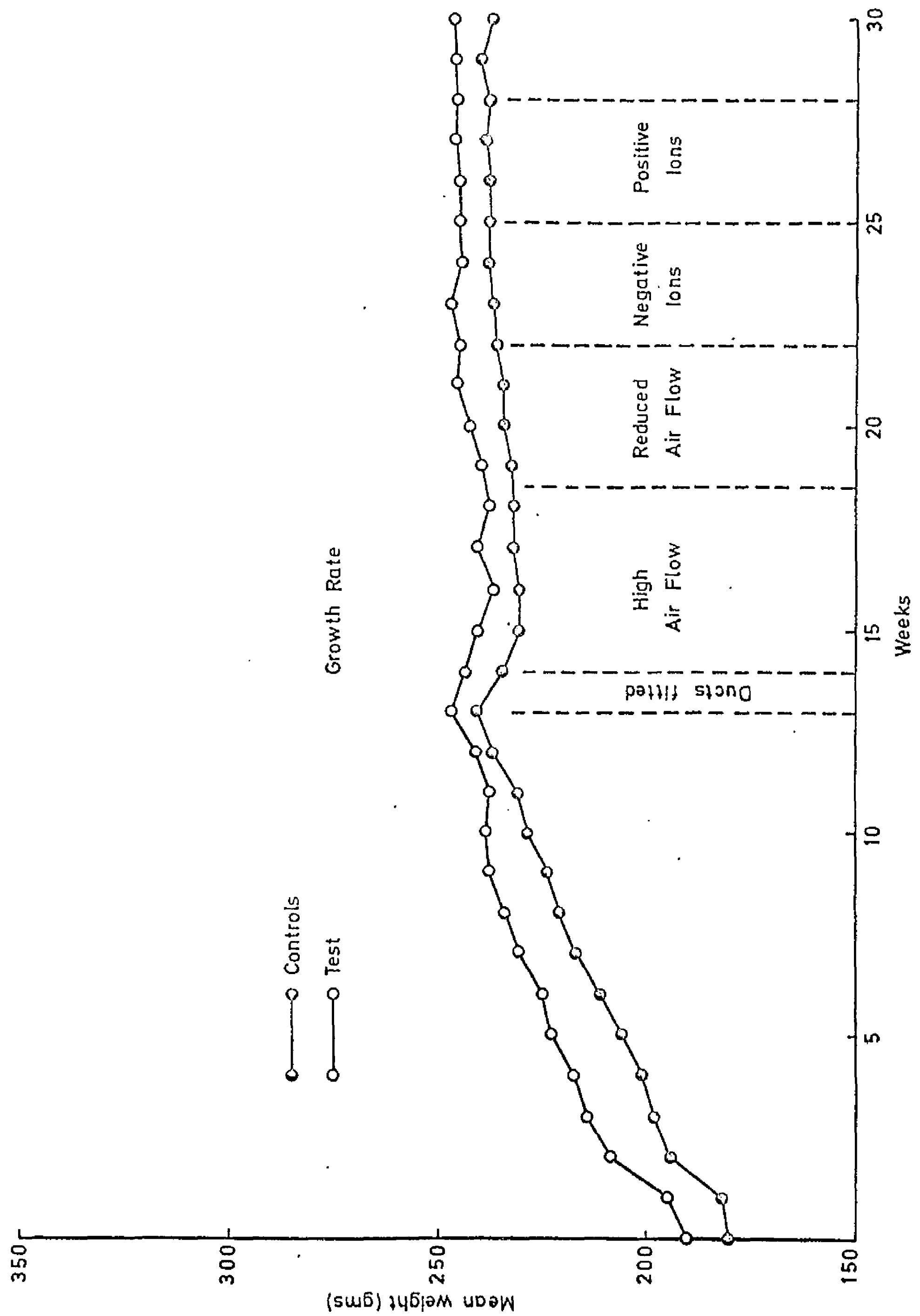

Growth Rate
Controls
Test
Mean weight (gms)
350
300
250
200
150
5
10
15
20
25
30
Weeks
Ducts fitted
High Air Flow
Reduced Air Flow
Negative Ions
Positive Ions

Figure 9.5.

ION MEASUREMENTS

Because of the limits of the ion counter already discussed it was impossible to maintain a steady ion level so spot checks were carried out with the ion generator maintained at a set level. In the experiments where negative ions were generated the ratio of medium/small was much larger (15:1) than when generating positive (8:1) . The same voltage was used on the corona tip for both signs of ions but it produced only 500 small negative ions/cc of air whereas when positive it produced 600 ions/cc. However by coincidence this ratio was 1·2:1 positive to negative, the same as found naturally but in the experimental condition the ions were not being produced simultaneously. Measurement in the control environment showed that the total positive count was about 400 ions/cc but the total negative never reached 300 ions/cc. Small ion measurements were not recordable.

The voltage on the corona tip was about 5 kv. There was another high tension source available with a maximum output of 3kv which was applied to a quickly manufactured corona tip in an attempt to produce air containing a mixture of small ions but this attempt was unsuccessful. Presumably because of recombination the few ions produced from the 3 kv source never reached the counter. The attempt to manufacture conditioning air with the proper ratio of small positive to small negative was therefore abandoned.

SUMMARY

Two groups of rats with matching spontaneous activity performances were easily selected. It was found that air flow over the rats inhibited both their activity and growth rate. By reducing the air flow to under 100 ft/min ($0{\cdot}5\ m.s^{-1}$) the activity pattern was improved but not restored to that under still air conditions. Replacing the normal quantities of first, small negative then small positive to an atmosphere which was ion free had no effect on either spontaneous activity or growth rate.

CHAPTER 10

DISCUSSION AND CONCLUSIONS

DISCUSSION AND CONCLUSIONS

At the end of the First International Conference on Ionization of the Air, the chairman in his closing remarks noted that in numbers there had been more papers dealing with the physics of air ionization than about the biological, medical and psychological aspects. This he thought was inevitable at a first meeting and very desirable since it might help to eliminate gross physical errors which had in the past bedevilled research in this field. I therefore make no apologies for having dwelt in Part 1 of this thesis so long on the physics of man's natural environment and the artificial climates being used in the study of this subject. Since the effect of ions on biological material has received so much attention over the past forty years with so little conclusive work (Krueger 1968) it was thought worthwhile to review the electrical constituents of the meteorological environment to see where exactly ions fitted in. Blackman (1923, 1924) in his experiments on growth rate of cereals concluded that the increased rate was due to the higher air-earth current when grown under discharge wires. He seems to be unique in his belief, although Tromp (1968) does not dismiss the idea. Since then the emphasis has been entirely on ions as the sole electrical parameter with any biological effect. However, they can be vastly influenced by electrostatic fields which has prompted Bach (1967) and Andersen (1965) to study the effects of fields on the ion climate rather than directly on biological material.

Because of man's natural adaptability and resilience it is difficult enough to demonstrate a change in either psychological or physiological performance with a small change in effective temperature. It is therefore not surprising that contrary indications are found when dealing with the nuances created by air ions especially if insufficient attention has been paid to controlling the normal climatic parameters. Perhaps this is one reason for using such high quantities of ions.

Environment

In considering the artificial environment, examination of ion generating equipment revealed that in all cases where ions are added more than one new parameter is involved. There are the ions themselves, also the air current to move the ions away from the generator head, the high potential to bias the ions and if it is a corona type there is an array of contaminants. The higher the quantities of ions produced the higher must be the biasing potential at the generator even if this is an α or β emitter type. If the ions are monitored at the same time, the situation is further complicated by the aspiration system of the collector and its own electrostatic field. In the experimental situation the simple addition of some ions results in several new parameters being added rather than only one.

For the reasons outlined in the Introduction to Part 2. the main object of the experimental series was to test the effect of ion free air on rat activity. To do this it is essential to have ions present in normal concentrations for the control subjects, and to have some means of removing them from the test environments. Examination of the air entering the room showed that it contained few small ions so the problem was one of adding ions to the normal level with all the attendant complications rather than precipitating them.

Originally it was hoped that the force of the air entering the room would have been sufficient to create a circulation through the perforated cages but measurement showed that this was not the case. The same series of measurements showed that to precipitate the medium ions present in the incoming air needed condenser plates a great deal longer than could be conveniently accommodated in the room. Precipitation by means of a grid had been ruled out earlier because it would have dispersed the air too much. To allay fears about the effect of electric potential build-up on the animals from ions the second experimental series was undertaken at this point.

Since no effect of electrostatic potentials up to + 5 kv was found any effect produced in the subsequent experiment must be due to either ions or lack of ions, air movement or contaminants generated as a bi-product with the ions. The modified ducts were constructed to ensure an air movement through the cages of sufficient strength that the fan of the ion generator had little effect other than to discharge the ions. Before the ion generator was tried the dramatic effect of the high air movement on both growth rate and spontaneous activity was found. The animals were left for a twenty day period under these conditions during which time the air temperature remained steady at 25°C. After this period the lids were removed from the ducts and the activity counts began to increase. The lids were replaced and the air flow reduced considerably at the expense of good temperature control. The compromise situation reached which gave reasonable activity counts was an air flow through the cages of 100 ft/min ($0{\cdot}5 m.s^{-1}$) and an air temperature which varied between 26°C and 28°C.

The suspicion that climatic parameters are important in ion experiments was greatly underlined by what had just been found. Laboratory animals lead a very sheltered life and an air flow of 100 ft/min obviously had a profound effect on growth rate as well as activity. The animals normally sought shelter under the food hopper and continued to do so under these adverse conditions but with the food just overhead literally at the tip of their nose it was surprising to find that growth rate was inhibited. Unfortunately no record of food and water intake was made at any time so it was not possible to say if their consumption was altered.

The most obvious explanation of the finding is that the air movement even with an air temperature of 25°C was having a chilling effect. For this reason the temperature was allowed to rise up to 28°C which is man's critical temperature and he does not possess the fur coat of the rat. Perhaps his mechanisms for physical heat regulation are better than the laboratory rat. To increase the air temperature any further might have aggravated the situation by imposing a heat stress on the animals which would also increase their lethargy. With the reduced air flow and air temperature fluctuating between 26°C and 28°C reasonable counts were being obtained and the twelve hour activity pattern had been restored.

Baramova et al. (1957) mentioned that negative ions as administered therapeutically had no effect on normal people. Frey (1961) put this another way when he framed the hypothesis that some type of stress be it illness, age, fatigue, fear or whatever was a necessary precondition for ion effects to appear. His belief that negative ions may be regarded as an anti-stress agent has claimed and is still claiming support, (Pogrund 1969). If Frey's hypothesis was correct by administering negative ions to the rats in the duct there was probably a better chance of obtaining an increased activity with this climatic stress situation and similarly by adding positive ions the activity of the rats might be further depressed. Stressed rats might be more responsive to the low ion concentrations administered than non-stressed. The results did not bear this out but Frey's hypothesis is not disproved since only normal levels were administered and not a therapeutic dose. Since no response to either positive or negative ions was obtained there was no need to decide whether the corona discharge generator was producing contaminants.

RAT ACTIVITY AS AN INDEX OF ION EFFECTS

This is not the first time that rat activity has been used as a measure of the effects of air ions. Herrington and Smith (1935) kept a colony of rats in an atmosphere of (1×10^6 ions/cc) small negative ions from the age of twenty-one days until three hundred days. They found that the test group increased their activity compared to the controls but only after the hundred and seventy-fifth to two hundredth day. They also measured growth rate and haemoglobin but neither of these parameters showed any effect of the negative ions.

Ions were produced from a single corona point maintained at

15 kv, the discharge from which was visible in the dark. To measure activity, eight animals only from each group of fifty were removed to individual activity cages for four hours each day. Whether they were the same eight rats each day is not stated. Strict insulating procedures were observed in the colony cages so the test animals would most certainly be charged when removed from the large cage. The nature of this charge would vary from individual to individual and also be a function of size both of which could account for the effect of the ions not appearing until after the hundred and seventy-fifth day. What was probably being measured in the activity cage was a conditioned reflex which was the result not of ions but of an electric shock as the animals were moved into the activity cage.

Backman et al (1966) also used rat activity to measure the response to increasing dosage of both negative and positive ions. Again they measured the rats activity during the day but for only forty-five minutes during which time the animals were exposed to their particular treatment. It would appear that each rat was exposed only once in a complicated routine in a small chamber. The results indicated a complex dose related response which is hard to justify because the test really only examined the reaction of each individual rat once when placed in a completely foreign situation. Also the control level of ions (19×10^3 ions/cc S.D. 204×10^3) at which the animals were tested was much higher than the level of small ions found naturally which it was supposed to represent. The same pattern of response would probably have been found if the same procedure had been carried out without ions. A wide individual variation in activity response was shown in the present series of experiments and the same was found in the animals reaction to handling. A beaker was used to catch and retain the animals for weighing. Most rats learnt to walk into the beaker after a few weeks but some never responded and had to be coaxed every time. Similarly some rats groomed themselves when in the beaker being weighed while others were persistent escapees. Certainly the first exposure to any treatment is not a very good indication of the animals subsequent behaviour, and to ascribe the differences found by Bachman entirely to various levels of ions is questionable.

Spontaneous activity as a measure of ion influence was ineffectual in the present series of experiments. From this one may conclude either that natural ion levels have no effect or that the test was not sensitive enough. The test was sensitive to a change of light pattern and to a difference of air movement of 0 to 300 ft/min which changed the thermal environment of the rats, This finding underlines the importance of controlling climatic parameters in the study of ion effects. If the effect is so delicate, can it have any significant influence in the natural environment? It would be satisfying to have some simple explanation, like ions, to account for all the depression of thundery weather or the Foehn type winds but so far the indications are not encouraging, perhaps a closer inspection of the climatic environment may be more rewarding. In one of their most recent papers Krueger et al (1968) state that the major objection to the acceptance of ions as active agents has been the failure to establish beyond all reasonable doubt in critically controlled experiments, that air ions are the only agents which can be indicated as the cause of a given change. They admit that the criticism is valid but think that ion effect has been shown in a few instances one of which is the Bachman et al. experiment on rats mentioned earlier and the validity of which is questionable. Coming from one who has devoted so much time to research in this field, one is left to conclude that natural levels of ions must have an insignificant role where their supposed effects are so easily masked.

GROWTH RATE

Herrington and Smith measured the effect of negative ions on growth rate and found no effect. Worden (1953) studied the effect of negative and positive ions on the weight of selected organs. Negative ions stimulated some organs to grow, positive had no effect. They weighed the animals before sacrifice but did not comment on whether the ions had any effect on gross weight so one is led to assume that either they didn't test this or the test showed no difference. If the latter is the case it would fit in with Herrington's finding and what was found in the present series of experiments. The inhibition of growth found when the air was blown over the animals indicates that this parameter is more sensitive to climatic change than ion influence.

ELECTROSTATIC FIELDS

Although the results of the series of experiments using electrostatic fields proved negative the field strength was very low compared to charges which may be found normally. The geo-electric field of 100 $v.m^{-1}$ is not high but potentials generated on clothing and on various electrical appliances such as television sets can be very high. Macromolecules and particles such as pollen in the atmosphere must become charged as they are blown along and this charge must influence their ultimate destination. Krueger (1968) in the defence of the possible effect of minute quantities of ions enlists as an example that the male silk worms can respond to a sex stimulant from the female in concentrations of molecules less than 200 per cc of air. Unlike ions these are rather special molecules and one wonders if electrostatic charge might also have a contribution in helping them to reach their target. Similarly the destination of charged pollen and other allergens may be influenced by electrostatic fields, effects which led Bach to the practice of Passive Technique for the allieviation of asthma symptoms. Just how great the influence of electrostatic charge is or its importance in the biological field is difficult to assess since so little work has been carried out. Even in school physics the teaching of electrostatic electricity seems to have a relatively minor role in the curriculum.

CONCLUSIONS

From the present series of experiments it was shown that:

1. Spontaneous rat activity was a measurable quantity but there was considerable individual variation.
2. By suitable selection it was possible to obtain comparable groups.
3. The effect of electrostatic fields up to 5 kv had no effect on spontaneous activity or growth rate of rats.
4. There was no difference between ion free air, air containing natural levels of small positive ions or negative ions on spontaneous activity and growth rate of rats.

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