THE PENETRATING COMPONENT OF COSMIC RADIATION IN THE UPPER ATMOSPHERE

THESIS

submitted by

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for the degree of

DOCTOR OF PHILOSOPHY

University of Edinburgh

May 1952.

CONTENTS

CHAPTER I.

INTRODUCTION.

The primary object of this research was to establish with accuracy the variation of the vertical intensity of the penetrating component of cosmic radiation as a function of altitude in the neighbourhood of Edinburgh, geomagnetic latitude 59°N. By the use of Geiger-Mueller counters connected in coincidence to form vertical telescopes, and carried to great heights by free balloons, it was intended to measure the intensity of the penetrating radiation from ground level to within 1 per cent of the "top of the atmosphere".

At this time (July 1947) the altitude variation of the total cosmic ray intensity was regarded as fairly well established. Counter measurements, notably those of Pfotzer[1], had shown an increase in the total vertical intensity from ground level to a maximum in the region of 100 mb.* Beyond this point the coincidence rate decreased rapidly.

Similar experiments had been performed with telescopes containing sufficient lead absorber to exclude

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* All pressures will be given in millibars. For a given altitude, the pressure in mb. is numerically practically equal to the residual atmospheric depth in gm./cm.^{2}

the soft radiation, to determine the altitude variation of the penetrating component. The results published prior to 1947, however, disagreed with one another both qualitatively and quantitatively, and the discrepancies between them could not readily be explained in terms of either the various geographical locations at which the measurements were made, or the different geometrical arrangements used in the counter telescopes. A summary of these results is now given.

Among the first observations to be published were those of Dymond[2], who, in 1939, made a series of three balloon flights near Edinburgh using triple coincidence counter telescopes. The soft component of cosmic radiation was excluded by two similar lead blocks, symmetrically interposed between counters, which gave a total of 10 cm. of absorber to be penetrated. The counts were transmitted by radio and recorded on the ground. The results of three flights indicated that the vertical intensity rose to a maximum at a pressure of about 100 mb., and decreased beyond this point. The maximum intensity occurred at the same pressure as the peak of the Pfotzer curve for the total vertical radiation, and in this region the coincidence rate had increased to approximately 9 times the ground level value. Owing to the weight of absorber required, it had been necessary to use small counters giving a ground counting rate of 0.4 coincidences per minute. The statistical fluctuations during a flight were therefore large, and the observations were not considered to be complete when the work had to be broken off at the outbreak of war.

In 1940, Ehmert[3] presented the results of two flights conducted at Friedrichshafen, latitude 49° N, during the previous year. Again three counters in coincidence were used, the lead absorber, distributed as before, being 9 cm. thick. After a continuous rise from ground level, the intensity was found to level off at about 130 mb., and to remain fairly constant between this pressure and 30 mb., with a barely significant indication of a maximum around 80 mb. The intensity in this range is given as 12.2 times the ground rate.

After a preliminary report in 1939 giving the results of the first flight which reached 90 mb., Schein, Jesse and Wollan[4, 5], in 1940, published the data obtained in two ascents made at Chicago, geomagnetic latitude 52.5° N. In order to investigate the possible production of penetrating particles by non-ionizing radiation a complex counter arrangement was used, but the intensity of the hard component was effectively measured by a triple coincidence telescope shielded by 8 cm. of lead. The counts were recorded photographically, this system necessitating recovery of the balloon-borne apparatus. The results again showed a continuous rise in intensity in the lower part of the atmosphere, but a point of relatively low statistical weight indicated a maximum around the 90 mb. pressure level, with a rapid decrease at lower pressures. The peak intensity was about 11 times the ground rate.

Finally, in 1941, the Chicago group[6] presented the consolidated results of an extensive series of flights at latitude 51° N, in which different arrangements of counters in three-, four-, and five-fold coincidence were used, and the thickness of lead absorber was varied from 4 to 18 cm. The minimum pressure attained was 27 mb., and up to this level the intensity of the hard component was found to increase continuously, the coincidence rates being sufficiently independent of the absorber thickness for the data from all flights to be represented by a single curve. Contrary to all previous results there was no indication of a maximum at pressures greater than 27 mb. The intensity at maximum altitude is given[7] as 16 times that at ground level.

In the present experiments it was intended to make use of the more advanced techniques developed by 1947 to investigate the obvious discrepancies in these previous results. It was particularly necessary to clarify the situation with regard to the possible existence of a maximum at high altitude, since this has an important bearing on the production of penetrating secondary particles by the primary beam. At the same time it was desired to obtain information of greater statistical accuracy than that of the previous results, and with the improved types of rubber balloons available, to extend the observations at the important low pressure end beyond the existing limit of 27 mb.

To reach the necessary altitudes with the rubber balloons employed, it was essential to keep the balloon-borne apparatus light. Since a considerable fraction of the load was concentrated in the lead absorbers, which could not safely be reduced in thickness below 8 cm., a strict upper limit was placed on the dimensions of the counters which could be used, with a resulting restriction on the coincidence rate of the telescope. The statistical fluctuations to be expected in a single flight were therefore large, and the required accuracy of information could only be obtained by the consolidation of the results of a series of flights made with identical equipments. While this method of approach entails the expenditure of a large amount of time and labour on the construction of many similar pieces of apparatus it has the possible advantage of revealing any large day to day variations in intensity. Consolidation of the results of the separate flights is of course contingent on agreement between the various sets of data being within the expected experimental errors.

Owing to the geographical location of Edinburgh, and the prevalence there of westerly winds, the use of any method of recording cosmic ray data which necessitated recovery of the balloon-borne equipment was impracticable. All essential information had therefore to be transmitted by radio and recorded at a ground station during the progress of a flight.

The system employed for the transmission of data in the 1939 series of flights at Edinburgh[2] had not been entirely satisfactory, and in the present series a different site for the ground station was used. It was therefore considered advisable, after deciding on the most suitable method of radio communication, to check the efficiency of the transmission system by means of a series of Test Flights. Simplified versions of the transmitter were released on three occasions during the development of the final equipment. These test equipments contained no counters, but the cosmic ray signals were electronically simulated, and useful information was collected on many of the difficulties to be overcome. The Test Flights are not separately described, but many references to them are made in the text.

By March 1950 eight flights with identical equipments containing vertical triple coincidence counter telescopes of the type shown in Figure 29(a) had been completed, data having been obtained in seven of them. The results were consistent with one another to within experimental errors, and the improvement with each successive flight in the statistical accuracy of the consolidated data was by this time becoming small. Reliable measurements had been obtained right up to the 3.6 mb. pressure level, so this series of flights, which will be referred to as F1-F8, was regarded as complete.

In designing the balloon-borne apparatus for flights F1-F8 the policy had been to obtain maximum reliability and to expedite construction by simplifying the electrical circuitry as far as possible. Accordingly, only a single radio channel was provided for the transmission of cosmic ray signals, and no attempt was made to observe more than one type of cosmic ray event in a single flight. The development and construction of the transmitting and receiving equipment are described in Chapters 2 and 3.

On completion of the first series of eight flights the same policy was continued, and in nine other ascents a radio system of basically the same design was used in conjunction with other types of counter telescopes. The modifications required for transmission of coincidences of greater multiplicity, or to cater for different counting rates, are mentioned in the appropriate sections of the following Chapter.

The next series of ascents, after flights F1-F8, was not directly connected with the vertical intensity measurements. The object was to detect showers of penetrating secondary particles produced by ionizing primaries in a lead block mounted in the telescope. A five-fold coincidence telescope, the geometry of which is given in Figure 29(b), was designed to select the desired events, which would most probably be penetrating showers occurring in the top lead block. Coincidences were obtained at high altitudes, but the counting rate was low, and three flights F9-F11, were required before reasonable statistical accuracy was obtained.

In a third series of flights, F12-F16, the telescope was designed to assess the correction which should be applied to the results of flights F1-F8 in order to eliminate the effect on the vertical counting rate of coincidences caused by shower particles coming in from the side and discharging all three counters simultaneously. Where this precaution was previously observed by other workers, the influence of these lateral showers was found to be negligible, but the differences in the counter telescopes employed made it advisable to check this result in the present case. Accordingly, equipments were constructed with counters suitably disposed in four-fold coincidence, as shown in Figure 29(c), for the detection of side showers. Apart from the addition of two parallel-connected police counters, and the necessary extensions to the associated circuitry, these equipments were identical to those used in flights F1-F8. Contrary to previous findings, a significant counting rate was obtained in the first two ascents with this type of telescope, and the form of the counting rate-pressure curve was sufficiently interesting to warrant a further three flights being made in an attempt to obtain observations at pressures lower than 10 mb. This particular object was not achieved, however, as the minimum atmospheric pressures attained in these extra flights were 16 mb. in both F14 and F15, and 14 mb. in F16. The range of observations was not extended, but the results of the first two flights were well confirmed and the statistical accuracy of the experimental data was considerably improved.

Lastly a single flight, F17, was made with the same type of vertical triple coincidence telescope as used in F1-F8, except that no lead was included, in order to measure the altitude variation of the total vertical intensity of cosmic radiation. The observations were consistent with the results obtained by other workers, and this measurement was not repeated.

These seventeen flights were released during the last three years, operations being largely confined to the occasional anticyclonic periods during the summer months. Delays due to unfavourable weather were numerous, but, except in the summer of 1951, suitable wind conditions occurred with sufficient regularity for the rate of release to keep pace with the rate of production of the transmitters.

In all eases take-off was timed for half-an-hour after sunrise, since it is around this time that the wind conditions in the lower atmosphere are most calm, and electrical interference from passing motor vehicles is at a minimum. It was necessary to wait till after sunrise because the transmitting apparatus was maintained at a fairly constant temperature by the usual method of enclosing it in a doubled-walled cellophane gondola.

By attaching to the balloon rigging a postcard offering a suitable reward to the finder 75 per cent of the transmitters were recovered. In no case was the landing point more than 80 miles distant from Edinburgh, so all results may be considered as having been obtained at geomagnetic latitude 59°N.

CHAPTER 2.

THE TRANSMITTING EQUIPMENT.

(i) Transmission requirements.

During a flight, it was necessary that the radio signals transmitted to the ground station by the balloon-borne equipment should denote, firstly, the occurrence of each cosmic ray event of the type under observation, and, secondly, the atmospheric pressure level attained by the transmitter at any given time. In addition, it was considered to be advisable during the initial flights, to monitor the thermal conditions inside the transmitter, so a signal controlled by temperature was also required. It was therefore necessary to employ a system of transmission in which these three independent sets of data could be transmitted on a single carrier frequency.

The problem of devising a suitable modulation system was simplified by the fact that it was not necessary to transmit pressure and temperature signals simultaneously. Flight records of sufficient accuracy would be obtained if each of these variables could be measured at short time intervals. It was essential, however, in order to derive the maximum amount of data from each flight, that the cosmic ray channel should be continuously operative, and that the transmission of coincidence pulses should be unaffected by the simultaneous transmission of pressure or temperature information.

The transmitter was necessarily of low-power, and therefore all the signals had to be readable at poor signal to noise ratio. Under these conditions, receiver tuning at the ground station would be facilitated and communication most easily maintained, if the carrier frequency were constantly being transmitted. For reliable observations to be obtained at low signal strength, particularly in the identification of coincidence pulses, the greatest possible immunity from all forms of electrical interference was required.

The highest accuracy was desired in the measurement of atmospheric pressure, especially at great altitudes. This, coupled with the most important consideration, that of reliability in action, made it necessary that the operation of the transmitting equipment should be as independent as possible of all factors such as battery voltages likely to vary during a flight.

(ii) Measurement of pressure and temperature.

Chiefly as a result of the availability of components, it was decided to adopt the system of pressure and temperature measurement developed for the standard British meteorological instrument, the Kew radio sonde. This type of radio sonde, which has been fully described by Dymond[8], is in large scale use at meteorological stations for the determination of upper atmospheric conditions. Carried to great altitudes by a free balloon, it transmits to the ground station a cyclical sequence of signals corresponding to the pressure, temperature and humidity of the atmosphere. The signals consist of three audio frequency (700-1,000c./s.) modulations, superimposed in turn on a 28 Mc./s. carrier. The audio frequencies are controlled by pre-calibrated

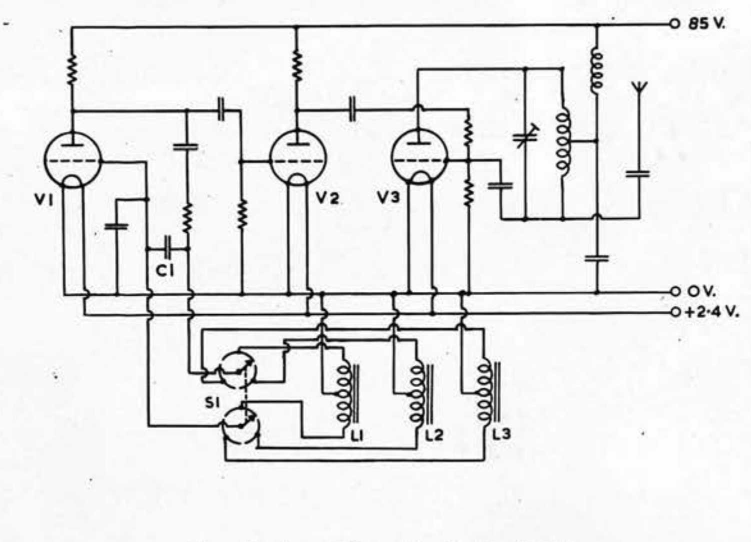

Figure 1. Kew radio sonde circuit diagram.
(for component values see Figure 26)

variable inductors, L1, L2, L3, (see Figure 1) the operation of which is described later. Each inductor is connected in turn across the condenser C1 by the switch S1, to form the tank circuit of the audio oscillator V1, the switch being operated during a flight by the rotation of a wind mill in the vertical slip-stream.

The valve V2 forms a buffer stage. It provides some amplification of the audio signal, but its main function is to isolate the R.F. and A.F. oscillators in order to maintain the stability of the latter.

The radio transmitter V3 generates the 28 Mc./s. carrier. It is grid-modulated to a depth of 100 per cent by the output of V2. The aerial is an end-fed half-wave dipole, and the aerial current, with selected valves and the normal H.T. of 85 volts, is of the order of 20 ma., corresponding to a radiated power of 28 milliwatts. By increasing the H.T. to 120 volts in the present series of flights, an aerial current of about 35 ma., or a radiated power of 86 milliwatts was obtained. With the aerial systems and carrier frequency in use, this power was found to be sufficient to maintain communication over an estimated distance of up to 100 miles, when the transmitter was at high altitudes. Although this figure rather severely restricted the number of days on which the wind conditions were suitable for a flight, the range of air to ground communication does not vary rapidly with the radiated power, and the improvement to be expected from the adoption of a more powerful transmitter was not considered likely to offset the increase in battery consumption.

Measurement of pressure.

The principle of operation of the variable inductors in the A.F. oscillator circuit is illustrated in the case of pressure in Figure 2. The inductor is wound on a core of six U-shaped mumetal laminations,

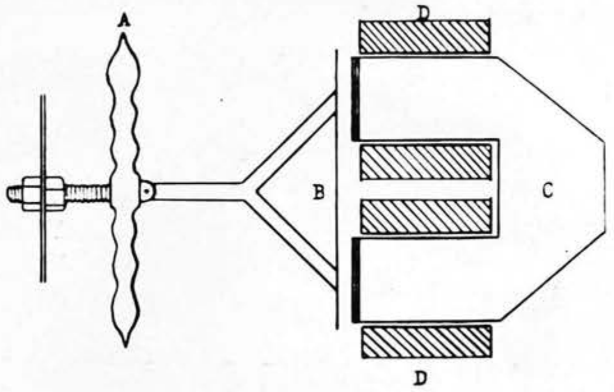

Figure 2. Pressure element (schematic).

A - Aneroid capsule.
B - Moving armature.
C - Mumetal laminations.
D - Inductance windings.

whose ends are turned up to form flat pole pieces. The flux linkage, and therefore the inductance of the windings, vary according to the position of a moving armature consisting of a single mumetal stamping. In the pressure unit the armature is rigidly attached to an aneroid capsule so that a decrease in atmospheric pressure, causing the capsule to expand, narrows the air gap between the armature and the pole pieces, and increases the inductance of the unit. This reduces the frequency of the audio oscillator. Movement of the armature by the amount to be expected during a high altitude flight causes the audio frequency to vary over a range of just over 200 c./s.

In the standard Kew radio sonde pressure unit, the aneroïd capsule is made of steel. When the element is in normal adjustment, it has a sensitivity varying from 1 c./s. frequency change for 8 mb. change in pressure at ground level, to 1 c./s. per 3.5 mb. at high altitudes. In order to increase the sensitivity at low pressures, the single steel aneroid capsules were replaced by double capsules (supplied by Messrs. Kelvin, Bottomley and Baird) made of Phosphor bronze. These consist of a main capsule of slightly lower sensitivity than the normal steel component, in series with an

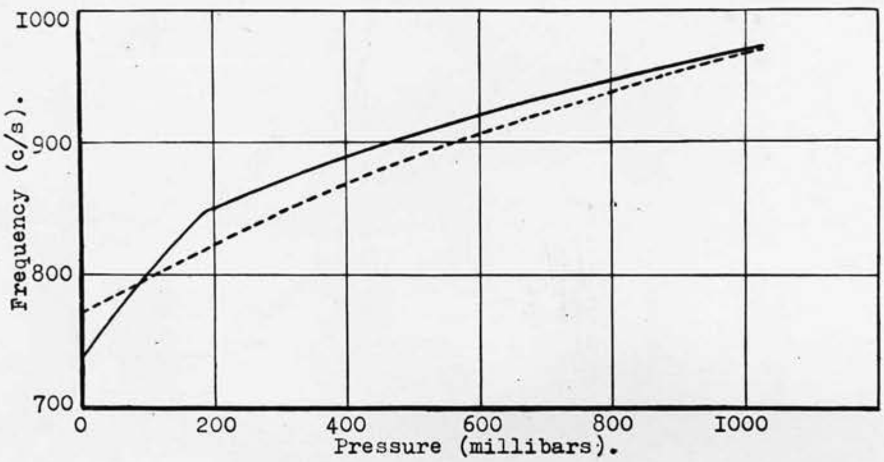

Figure 3. Pressure calibration curves with phosphor-bronze double aneroid capsule (full line), and standard single steel capsule (dotted line).

auxiliary capsule which remains collapsed until the external pressure has dropped to about 200 mb. The auxiliary capsule then begins to open, and at lower pressures the position of the armature is controlled by the expansion of both capsules. As a result, the pressure sensitivity at very low pressures is increased to about 1 c./s. per 1.2 mb. variation in pressure. From Figure 3, which shows typical calibration curves with a double and a single capsule, it will be seen that the point of opening of the auxiliary capsule is denoted by a marked discontinuity.

The double capsules were accommodated inside the standard pressure unit, by providing adaptors to

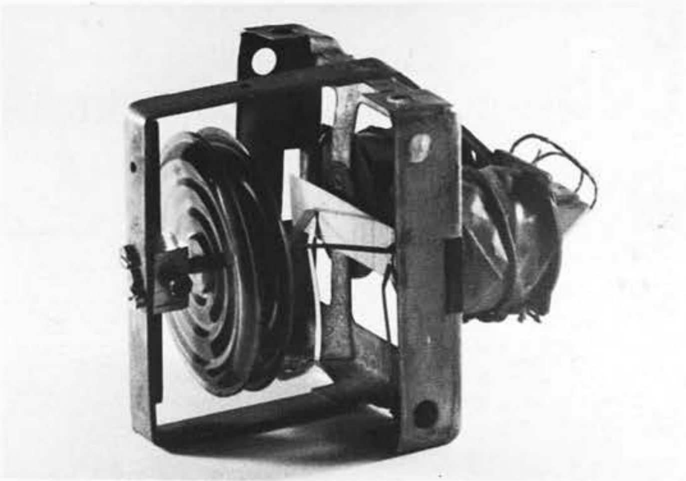

Figure 4. Pressure element.

anchor the fixed side of the capsules to the frame, while the moving side was pinned to the armature connection sufficiently tightly to avoid any backlash. Figure 4 shows the complete pressure unit.

Temperature coefficient of the pressure unit.

The Kew radio sonde pressure unit is sensitive to change in temperature, the following being the most important contributing factors:

(a) Variation in the elastic constants of the aneroid capsules.

(b) Change in the resistance of the inductor windings.

(c) Variation in hysteresis and eddy currents in the mumetal, and change in permeability.

The cumulative effect is of sufficient magnitude to make it necessary to correct for temperature most of the pressure readings taken during a flight. To enable this to be done, each pressure calibration was repeated at different temperatures, and correction curves were compiled. It was first established that for a given pressure the variation of frequency with temperature was practically linear, and thereafter each pressure unit was calibrated at $+55^{o}$C., $+15^{o}$C. and at -25^{o}C. The $+15^{o}$C. calibration was then taken as the master curve, and the other data were used to calculate the corrections for a 40^{o}C. rise or fall in temperature. A typical example of the correction curves so obtained is shown in Figure 5, in which the correction to be applied to the observed frequency is plotted against the observed frequency. A rise of 40°C. causes an increase in transmitted frequency of about 1 c./s. between

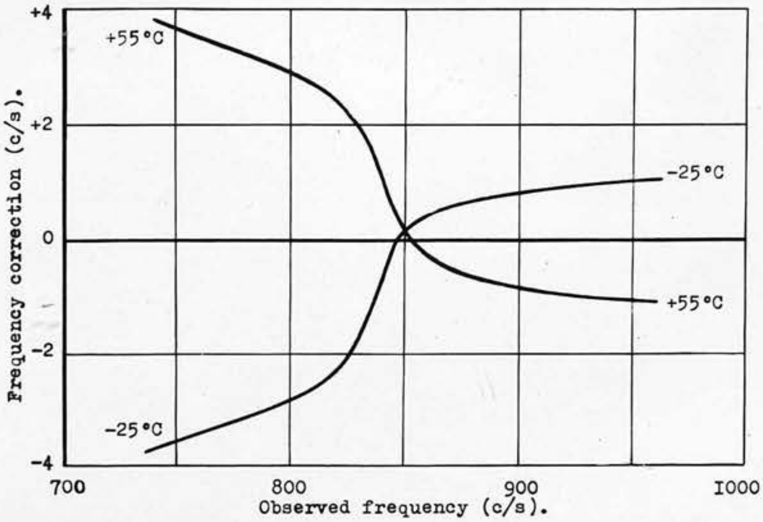

Figure 5. Temperature correction curves for pressure element.

960 c./s. and 900 c./s. for this particular unit. The frequency correction is therefore negative in this region, but decreases in magnitude with decreasing frequency, and becomes positive at about 850 c./s. It reaches a maximum positive value of about 4 c./s. at the lowest frequency obtained. This indicates that 4 c./s. will have to be added to a transmitted frequency of about 740 c./s. if the temperature is +55°C., and proportionally less at temperatures between +15°C. and +55°C. The effect of a drop of 40°C. is exactly similar, but of opposite sign.

The frequency correction at low pressures for a given change in temperature, is similar in magnitude to that for the standard pressure unit with the single steel capsule (see reference 8), but the greater sensitivity of the double capsule considerably reduces the corresponding pressure correction. The form of the correction curves is unusual. By comparison of Figures 5 and 3 (full line), which refer to the same pressure unit, it is apparent that a correlation exists between the opening of the auxiliary capsule at a frequency of about 850 c./s., and the rapid variation of the temperature correction in the same region. The effect of an increase in temperature on the elastic constants of the auxiliary capsule must be such as to cause expansion to commence at a slightly greater pressure.

In all flights the internal temperature of the transmitter when at high altitudes was greater than +15°C., and in most cases the maximum temperature coincided roughly with the attainment of maximum height. This had the unfortunate result that the temperature correction was largest at the times when the greatest pressure accuracy was required. A normal maximum temperature in the region of +35°C. necessitates a frequency correction of about 2 c./s. which is equivalent to a pressure correction of approximately 2 mb. At minimum pressures of the order of 10 mb. this correction becomes important, and for this reason it was not possible to discontinue temperature measurement, with the resultant simplification of the transmitter, even after the temperature variations during a flight could be fairly accurately forecast.

Accuracy of pressure measurement.

The accuracy of pressure measurement of the Kew radio sonde is of the order of ±5 mb. due to casual errors, and ±2 mb. due to systematic errors. These figures were established[8] by comparison of transmitted pressure data with the altitude of the transmitter obtained directly from radar information, but they are only applicable to radio sondes in routine meteorological use. Although it has been impossible to make a direct determination of the errors in pressure measurement during the present series of flights, a reliable estimate can be formed from the figures quoted for the standard instrument.

The casual error of up to 5 mb. is due almost entirely to the application of a rather arbitrary temperature correction, a standard set of correction curves being used for all instruments. In meteorological flights the pressure unit is usually subject to temperature variations of about 75°C., which, with the steel capsule, may lead to pressure corrections of up to 35 mb. at high altitudes. When the range of variation of temperature is reduced to about 30°C., as in the present case, the maximum pressure correction when using the double capsule drops to just over 2 mb. This very considerable reduction in the corrections to be applied must greatly decrease the possible margin of error. In addition, the production of individual correction curves for each pressure unit, coupled with an exact knowledge of the temperature conditions during a flight, increases the relative accuracy of each correction. It is probable that casual errors in pressure measurement in the present series of flights have not amounted to more than a small fraction of a millibar at any pressure.

The systematic errors are partly due to the application of large control corrections. This is the correction required to adjust the transmitted pressure frequency to the calibration frequency at ground level immediately prior to a flight. That it is necessary, is due to several causes, the most important being:

(a) The use of different battery voltages during calibration and flight.

(b) Secular changes in the pressure sensitive element, including deformation due to mechanical shock.

The effect of the former is minimised in the design of the radio sonde, and an unavoidable variation of about 0.5 volts in the initial battery voltages causes less than 0.2 c./s. frequency change. The importance of the latter depends mainly on the time lag between calibration and flight, which, in the present case was much shorter than in meteorological practice.

During this interval the equipments were subject to a minimum of handling.

An important source of systematic error included in the figure of 2 mb., but which is not applicable here, is the use of different frequency standards during calibration and flight. In the present series the same standard audio oscillator was used each time, and its frequency stability was under continuous observation.

The control correction was applied as a constant correction to all transmitted pressure frequencies, a procedure which can only be justified if the frequency error is known to be independent of pressure. Experiment showed that this was only approximately true, and that under certain conditions the control correction required at low pressures could be as much as twice that necessary at ground level pressure. The average value of the control correction in this series of flights was about 0.5 c./s., and in no case was it over 1.7 c./s. (compared with the maximum accepted meteorological value of 5 c./s.) so the greatest error introduced at low pressures by the application of a constant control correction is unlikely to have been more than 0.5 mb.

Any further systematic error due to differential thermal lags between temperature and pressure units, or between different parts of the pressure unit, is greatly reduced by the relative constancy of the temperature inside the transmitter. The errors due to a normal variation of battery voltages during a flight, and those caused by changes in the frequency calibration of the standard oscillator are likely to have been small.

From these considerations, it is estimated that the measurement of pressure during this series of flights has involved an error of not more than ±1 mb. in the most important range below about 150 mb., and not more than ±2 mb. at greater pressures. Evidence in support of this estimate lies mainly in the consistency of the experimental results, but an excellent check on the calibration stability was obtained on two occasions when transmitters were recovered undamaged after flights. In neither case had the calibration significantly changed.

Measurement of temperature.

The Kew radio sonde temperature unit is similar in design to the pressure unit, and works on the same principle. A bimetal strip, substituted for the aneroid capsule, is arranged to curl up with increasing temperature, thereby increasing the air gap between the inductor and moving armature, and raising the audio frequency. A typical temperature calibration curve is shown in Figure 6. The sensitivity, fairly linear over the range +60°C. to -40°C., is of the order of 1.7 c./s. per °C. To allow of sufficiently accurate correction of the pressure frequency, it is necessary to know the

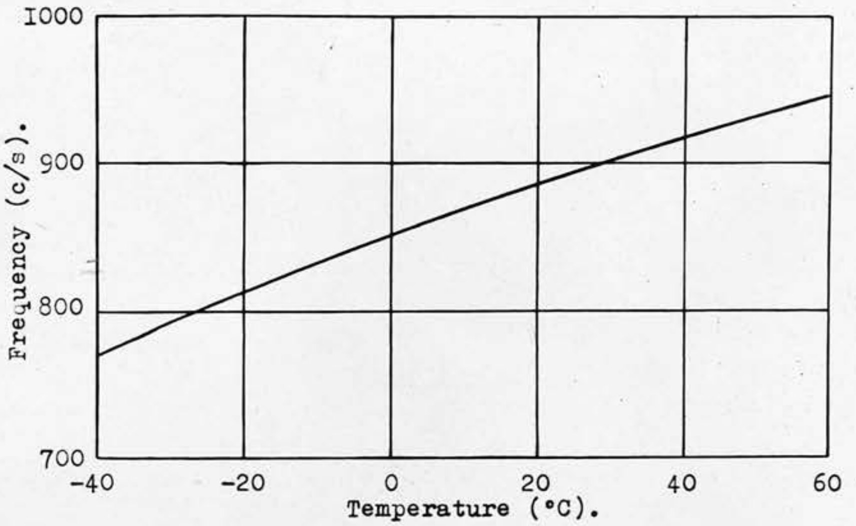

Figure 6. Temperature element calibration curve.

internal temperature of the transmitter with an accuracy of ±2°C. This accuracy is available with careful use of the standard temperature element. Again the control correction required for a particular unit was measured a few minutes before release, and applied as a constant correction to all temperature frequency readings during the flight.

Calibration procedure.

A tank of the standard Meteorological Office pattern was obtained for calibration of both pressure and temperature units. This consists essentially of a large double-walled cylindrical container, the inner chamber being surrounded by a bath of trichlorethylene which may be heated by means of an electric element, or cooled by the addition of solid carbon dioxide. The meteorological elements are calibrated in the inner chamber, which can be evacuated to minimum pressures of the order of 5 mm. Hg. Operation of a fan inside the tank, and circulation of the trichlorethylene by means of an impeller minimise temperature gradients in the enclosed volume. During calibrations, the meteorological units inside the tank are connected by fly-leads to the remainder of the transmitting equipment standing outside. The longer connections required were found to cause no appreciable alteration in the audio frequencies.

For calibration of a pressure unit, a mercury in glass manometer of reading accuracy better than 0.2 mm. was connected to the tank. All possible precautions were taken to have the transmitter working under flight conditions, and the stability of the standard oscillator was checked. The calibration chamber was then evacuated in stages, at a temperature of +15°C., and simultaneous readings of pressure and transmitted frequency were taken. Since the tank was not completely vacuum tight it was necessary to control the rate of pumping by means of a needle valve, so that the internal pressure could be stabilized before a measurement was made. Each pressure calibration was repeated at +55°C. and -25°C., a procedure which, in addition to providing the data for the temperature correction curves, checked the stability of the radio sonde oscillator over a period comparable with the duration of a flight. Any drift in transmitted frequency due to falling battery voltages became apparent as a lack of symmetry in the correction curves. Two corrections were required to reduce the manometer readings to absolute pressure values. The first took into account the temperature coefficient of the manometer, while the second, a constant correction of 0.4 mm. Hg., was required to remove a small zero error, and to bring the manometer readings at ground level pressure into agreement with the corresponding standard barometric heights.

Calibration of a temperature unit was extended over a much wider range (+65°C. to -40°C.) than was to be expected during a flight. An interval of some 15 minutes was required before each reading of temperature and transmitted frequency was taken, to allow the unit to reach thermal equilibrium. All temperature measurements were made by means of a calibrated thermocouple and microammeter. One junction was positioned close to the element under calibration, while the other was immersed in melting ice.

Modifications to the Kew radio sonde.

Several alterations to the standard Kew radio sonde circuit (Figure 1) were found to be necessary.

These are enumerated below, and the modified circuit is given in Figure 26.

(1) The use of a wind mill rotating in the slipstream to turn the switch S1 is not satisfactory at atmospheric pressures below about 50 mb., and it was therefore necessary to employ a small d.c. electric motor for this purpose. The motors used were "Electrotors" model 240, made by REV Motors Ltd. Although designed for use on 4.5 volts, they give a satisfactory performance on 2.4 volts, and rotate at some 3,500 r.p.m. The current

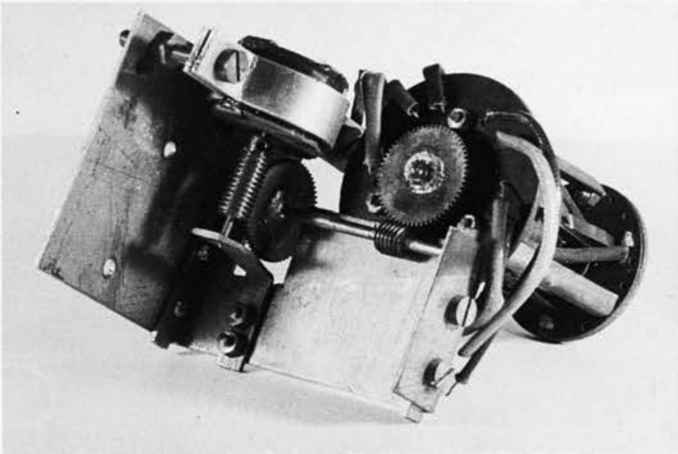

Figure 7. Switch and motor unit.

consumption is then just under 200 ma. Two 60:1 worm drives between motor and switch gave a switching speed of approximately 1 cycle per minute. The torque available from the motor at 2.4 volts is very small, so careful alignment of the gearing was required, and friction in the first bearing had to be reduced to a minimum. The switch and motor unit is illustrated in Figure 7.

(2) The radio sonde switch provides for the transmission of a humidity signal. Since this was not required, two switch positions were connected in parallel for the transmission of "pressure", leaving the third position for "temperature".

(3) In order to obtain the greatest possible sensitivity in the transmission of cosmic ray signals, the percentage modulation of the carrier at the audio frequencies was reduced from the normal 100 per cent to about 30 per cent. With a Hartley R.F. oscillator grid-modulated in the manner shown, it is not possible to obtain a modulation depth between 30 and 100 per cent. There is, however, a position of instability in which the depth fluctuates rapidly between these two limits. The reduction in modulation depth was accomplished by potentiometering down the audio input to V2 by means of resistors R7 and R3 (see Figure 26). R7 was empirically chosen for each equipment, so that the modulation depth was as great as possible without causing instability. Since the percentage modulation increases slightly with increasing audio frequency, this was done on the ground level pressure signal, the highest audio frequency to be transmitted during a flight.

(4) It was found during the first two Test Flights that a tendency existed for spurious pulses, closely resembling cosmic ray pulses, to be transmitted at either the

make or the break of any of the switch contacts. This was mainly due to the grid of V1 being left disconnected at certain points of rotation of the switch. The mode of operation of the switch can be understood from Figure 8. Three sets of contacts, of which one set is shown in Figure 8(a), are arranged round a central pawl as indicated in Figure 8(b), the pawl being rotated by the motor. The pawl is shaped to allow only one set of contacts to be closed at any one time, and therefore to connect in circuit only one variable inductor. For a

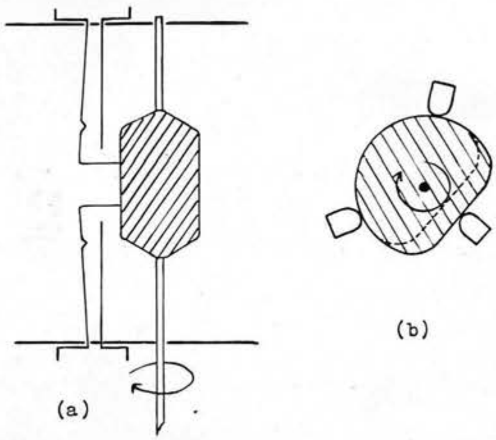

Figure 8. Kew radio sonde switch construction.

period between the opening of one set of contacts and the closing of the next, the grid of V1 is left floating. By filing away part of the pawl as shown by the dotted line in Figure 8(b), it is possible to arrange that before one set of contacts opens the next set has already closed, the grid of V1 then being continuously connected to ground via the inductors. For the third Test Flight the switch was treated in this manner, and the spurious pulses were eliminated. A switching cycle of 60 seconds then consisted of roughly 35 seconds of pressure frequency and 15 seconds of temperature frequency, separated by two 5 second periods of higher "change-over" frequencies due to the two inductors being connected in parallel.

(iii) <u>Transmission of cosmic ray signals.</u>

The use of a single carrier frequency, and the Kew radio sonde system of telemetering pressure and temperature data, restricted the choice of methods of transmitting cosmic ray signals. It was necessary to superimpose the coincidence pulses on the continuous 28 Mc./s. carrier which already bore a variable frequency audio modulation. Only one type of cosmic ray event was to be observed in each flight, so the simplest system of transmission was to use the coincidence pulses to modulate the carrier to a depth of 100 per cent, each coincidence being denoted by a quiescent period of pre-determined duration.

Owing to the location of the ground station considerable difficulty was to be expected in combating local electrical interference. One great advantage of quenching the carrier lies in the fact that whereas a cosmic ray event is denoted by a sudden decrease in carrier level, an interfering signal generally corresponds to an increase in signal strength, and therefore the two can be distinguished by suitable electronic circuitry. At 28 Mc./s. the most troublesome form of interference comes from the ignition systems of passing vehicles, and consists of a succession of very short duration electrical impulses. The coincidence signals can be made long compared with these interfering pulses, which can then be filtered out. This lengthening of the transmitted pulses also increases the intrinsic sensitivity of the system, and makes possible the direct operation of a mechanical recorder to provide a permanent flight record of the cosmic ray data.

It was necessary to test the efficiency of this system under operating conditions, which was one of the main reasons for carrying out the Test Flights. In all three Test Flights the counter pulses were simulated by means of the simple circuit of Figure 9. The 0.23 μF

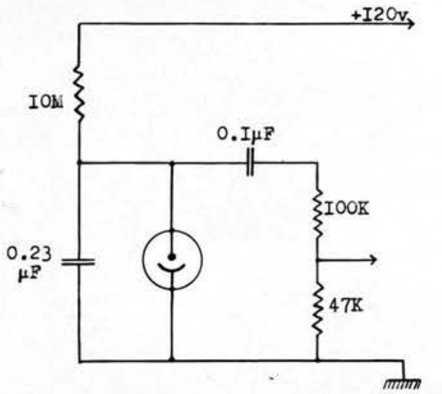

Figure 9. Test Flight coincidence simulator.

condenser charging through the 10M resistor and discharging through the neon tube, produced a succession of negative pulses at approximately 10 second intervals. These pulses fed through the 0.1 μF condenser, and potentiometered down, before being passed to the grid of the radio sonde transmitter valve, were of sufficient amplitude and suitable duration to quench the carrier for about

20 milliseconds.

The Test Flights showed that this system of transmission would be satisfactory, provided the depth of audio modulation on the carrier were reduced to about 30 per cent. With the ground equipment designed to detect the cosmic ray signals, it was found that the sensitivity increased with pulse length up to a duration of 30 milliseconds, but that the improvement was not rapid beyond this figure. The quiescent periods of the carrier represent a loss in effective counting time and necessitate a correction to the observed coincidence rates. On this score no unnecessary lengthening of the pulses was desirable, so the pulse circuitry associated with the counters in the complete equipments was designed to quench the carrier for 30 milliseconds at each coincidence. The pulse circuitry is described in Section (vi) of this Chapter.

(iv) Geiger-Mueller counters.

Since a large number of Geiger-Mueller counters was required for an extensive series of flights, it was necessary to use a commercial product. The most suitable counters available were of the type G.M.4 made by Cinema Television Ltd., and these have been used throughout. The construction is illustrated in Figure 10. The cathode, 11.5 cm. in length, is formed of thin sheet copper sprung into a cylindrical glass envelope of external diameter 2.1 ± 0.1 cm. The anode, a 0.13 mm. diameter tungsten wire, is surrounded at each end by a glass capillary projecting a short distance into the cathode cylinder. One end of the wire is taken to the external anode connection, while the other is sealed inside the glass envelope to prevent electrical leakage to the adjacent cathode connection. These counters are

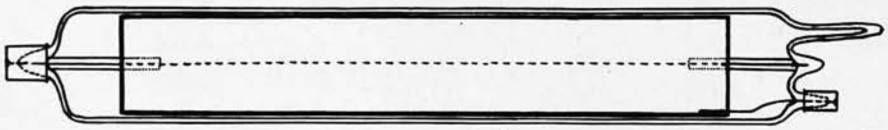

Figure IO. Cinema Television Counter Type G.M.4.

very light, the average weight being 33 gm. The density of the glass envelope in the region of the cathode, lies, in the majority of cases, between 0.22 and 0.28 gm./cm^2., while the cathode density is fairly constant at 0.08 $gm./cm^2$.

Counter filling.

The initial batch of counters obtained from the manufacturers contained a normal argon-ethyl alcohol filling. In no case was the plateau length greater than 200 volts, and the plateau slope was generally about 0.1 per cent per volt. The threshold voltages varied from 1,160 to 1,220 volts, this variation further reducing the effective plateau length of a set of counters for use in coincidence.

It was necessary to improve on this performance. Refilling the counters with argon-alcohol mixtures, gave, in most cases, plateaux 200-250 volts long at slopes of 0.04-0.06 per cent per volt. The threshold voltages could be equalized by filling the counters in batches. Extensive experiments designed to discover the optimum argon and alcohol pressures, and to remove impurities from the filling, produced no further improvement in plateau characteristics.

The argon-alcohol counter suffers from the disadvantage that it cannot be used at low temperatures. Normal alcohol filling pressures in the region of 1.5 cm. Hg. correspond to the saturation vapour pressure of ethyl alcohol at about +3°C. On cooling the counter below this temperature the alcohol begins to condense, the threshold voltage falls, and the plateau shortens. With a G.M.4 counter containing the optimum argon-alcohol filling, this effect became noticeable at +5°C, and at temperatures below 0°C the counter went into spontaneous discharge immediately the operating voltage was raised above the threshold value. During the Test Flights the internal temperature of the radio sonde at all times remained well above +5°C, but it was considered advisable to substitute for the ethyl alcohol another quenching agent with a saturation vapour pressure greater than the optimum filling pressure down to a much lower temperature.

Ethylene, being suitable from this point of view, was tried. The commercial ethylene was purified by pumping it slowly through two vapour traps. The first, surrounded by solid carbon dioxide, removed any water vapour, while the second, immersed in liquid oxygen, condensed the ethylene and allowed other possible impurities such as hydrogen and oxygen to pass on to the pump. On completion of pumping and removal of the liquid oxygen, the condensed ethylene was allowed to evaporate into a flask which could then be attached to the counter filling line.

On testing a batch of counters with an argon-ethylene filling, it became apparent that the plateau characteristics with the new quenching agent were greatly improved. An investigation of the performance at different filling pressures showed that plateaux extending for over 400 volts could readily be obtained. The argon pressure could be varied over the range 6-10 cm. Hg without greatly affecting the plateau length or slope, the threshold voltage rising slowly with increasing pressure. The ethylene pressure was more critical, the threshold voltage and plateau length increasing as the pressure was increased up to 1.5 cm. Hg. Beyond

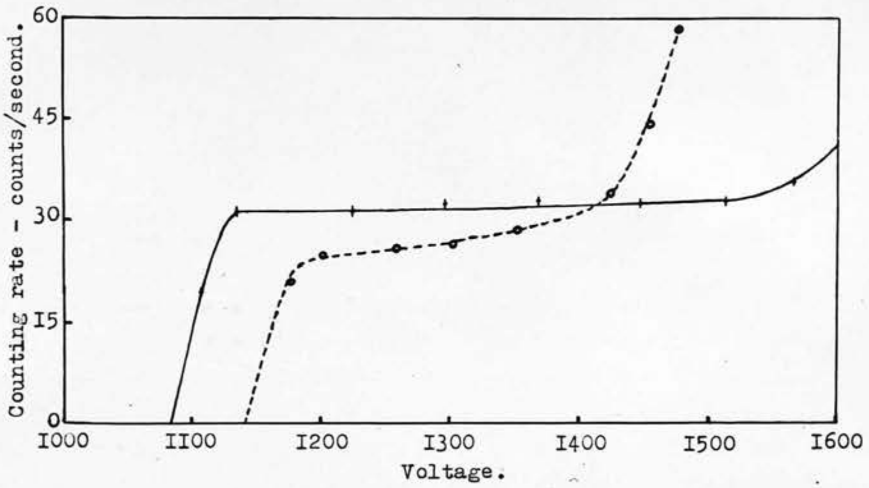

Figure II. Counter Plateaux with an Argon-Ethylene filling (full line), and with the optimum Argon-Ethyl alcohol filling (dotted line).

this pressure the threshold voltage continued to rise rapidly, but with no compensating increase in plateau length. The optimum filling for a G.M.4 counter was found to be:

Argon pressure = 7.1 cm. Hg (83%)

Ethylene pressure = 1.5 cm. Hg (17%)

With this filling the threshold is at 1,060-1,080 volts, and the plateau slope, about 0.02 per cent per volt on filling, rises to not more than 0.04 per cent per volt after considerable use. The counter performance was found to be practically independent of temperature variation in the range +60°C to -60°C, no change in slope being detected, and the threshold remaining constant to within 5 volts. Figure 11 shows a typical plateau with an argon-ethylene filling, together with the plateau taken for the same G.M.4 counter with the optimum argon-alcohol filling.

It was now possible to reject all counters whose plateaux did not extend from 1,100 to at least 1,500 volts. The performance of many counters which initially failed to pass this test, could be improved by heating them in air until the cathode surfaces were slightly oxidised, and eventually, since no adverse effect on the characteristics was ever observed, all the counters were treated in this manner. The proportion of counters meeting the 400 volt plateau requirement, and therefore suitable for use in the transmitting equipments, was about 80 per cent.

Photosensitivity.

The G.M.4 counter cathodes are markedly photosensitive. The background counting rate in normal daylight may be several times greater than the rate with the counters blacked out. This effect was reduced but not eliminated by the oxidation of the cathodes. All light was therefore excluded from the counters in the balloon-borne equipments either by fitting paper covers over the ends or by painting the glass.

Counting life.

In many cases the performance of a counter with an argon-ethylene filling deteriorated rapidly after about 10^7 counts, the failure generally coinciding with the appearance on the anode wire of a point source of corona discharge. Polymerisation of the ethylene, an essential feature of the quenching mechanism, is greatly accelerated by this corona, and if a counter is left discharging for a few minutes, complete destruction of the plateau may result. The relatively short counting life of the argon-ethylene counters was not a serious disadvantage in the present work, since no long periods of intensive counting occurred during the actual flights. It was necessary, however, as mentioned later, to limit the amount of counting in the preliminary determinations of the resolving times of the pulse control circuits.

Counter efficiency.

The efficiency of the counters is less than unity owing to the finite possibility of a high-speed particle passing through the active volume of the counter without giving rise to the formation of an ion pair.

If the probability that a single ion pair will initiate a discharge is taken as unity, the efficiency E of a counter may be expressed in the form,

$$E = 1 - e^{-slp}$$

where s is the specific ionization in the counter filling for high speed particles (the number of primary ion pairs per cm. of track at atmospheric pressure), p the gas pressure expressed in atmospheres, and l the average path length of the particles through the counter.

The mean path length has been computed by Swann(9) for some special cases; for a long cylindrical counter it approximates closely to the geometrical internal diameter. For argon s = 29.4(10), but no corresponding experimental value is available for ethylene. Since the molecules of the two gases contain roughly the same number of electrons (Argon 18, Ethylene 16), their specific ionizations should be approximately equal, and no great error will be introduced by attributing the total filling pressure to argon. The percentage efficiency of a G.M.4 counter with the optimum argon-ethylene filling is then calculated to be 99.85.

This figure was verified experimentally by counting penetrating cosmic ray particles with a vertical telescope of three identical counters. Triple coincidences, and double coincidences between the two outer counters, were simultaneously recorded. In one experiment 1,025 minutes counting gave 2,000 double and 1,976 triple coincidences, which indicates an efficiency for the central counter of 98.80±0.25 per cent. This is somewhat lower than the theoretical value, but a correction for the effect of side showers remains to be taken into account.

Double coincidences due to showers will be more frequent than triple coincidences from the same cause. An approximate value for the triple shower rate was obtained by moving one counter just out of line with the other two. In 2,130 minutes counting, 34 shower coincidences were obtained, a rate of 0.96±0.16 counts per hour. It is impossible to determine the double shower rate directly, however, and those indirect methods which are described in the literature involve inordinately long periods of counting to achieve sufficient statistical accuracy. With two counters placed in the same horizontal plane at a separation similar to the spacing in the vertical telescope, the coincidence rate gave corrections of much too high a value, presumably due to the effect of horizontally moving radiation. When the counters were screened from this radiation by lead absorbers, coincidence rates of about 2.5±0.3 counts per hour were obtained, giving a correction again more than sufficient to bring the experimental value for the efficiency into line with the theoretical figure.

When counting double and triple coincidences as above with a simple threefold telescope, Greisen and Nereson[11] have found that over 90 per cent of the apparent inefficiency of the central counter is actually due to the effect of showers, and, in general, refined experiments have shown no great discrepancy between theoretical and experimental efficiencies. In these circumstances the theoretical value of the efficiency of the counters in use may justifiably be regarded as sufficiently reliable for present purposes. With an efficiency of 99.85 per cent, the losses in a triple coincidence telescope are less than 0.5 per cent, so the effect on the coincidence rate is negligible.

Counter recovery time.

The efficiency of the counters is also reduced as a result of the finite recovery time following a discharge. A particle passing through the counter during this period may cause no new discharge, or if the counter has partially recovered, the pulse produced will be smaller than usual.

An E.M.I. Waveform Monitor type 3794B was available for accurate determination of recovery times, the following procedure being employed. A G.M. 4 counter, with associated circuitry identical to that used during a flight, is stimulated by a radium source to a fast rate of counting. The counter pulses are fed to the Waveform Monitor, the single sweep facility being used. Each sweep of the time-base is then initiated by a counter pulse, these synchronising pulses appearing as a single stationary pulse at the start of the time-base. If the time-base duration is longer than the recovery period of the counter, and the counting rate is sufficiently high, in general at least one further counter pulse will appear on each sweep. The amplitude of this second pulse will depend on the state of the counter at the instant of its production. Following each synchronizing pulse is a well defined "dead" period in which no second pulse can be produced. After this comes the recovery stage during which pulses can be observed on the Monitor screen, their amplitudes depending on the extent of recovery of the counter. Since these second pulses are produced at random intervals after the initiating pulses, they appear on the screen graduated in amplitude

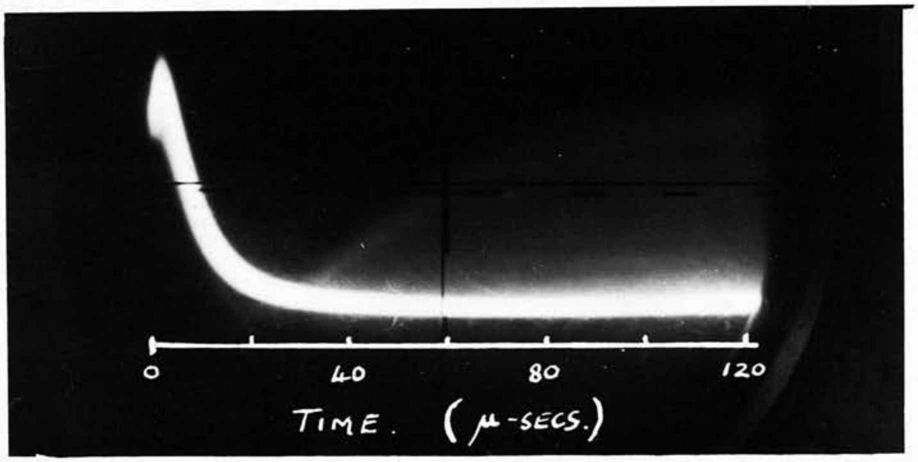

Figure 12. Counter recovery time.

along the time base. Figure 12 is a long exposure photograph of the Monitor screen. Since the synchronizing pulse occurs in the same position on every sweep of the time-base, it appears on the photograph as a thick bright line. After a "dead" period of some 30 microseconds, the build-up of pulses occurring during the recovery stage can be seen, the brightness being greatly reduced since pulses in this interval appear only as transients within the envelope. The time required for complete recovery is about 90 microseconds, a figure obtained from the calibrated X-shift control of the monitor. This calibration was checked against the output of a 50 kc/s. crystal controlled oscillator.

The effective recovery time will obviously depend to some extent on the minimum pulse size required to operate the circuitry associated with the counters, and therefore, for a given circuitry, on the voltage applied to the counters. The average counter potential during a flight may be taken as 1,350 volts, while the minimum potential for reliable transmission of data is about 1,200 volts. The normal pulse at 1,200 volts corresponds in amplitude to the pulse after a recovery period of about 75 microseconds when operating at 1,350 volts. From counter to counter no great variation in these figures has been observed, and in all cases the effective recovery time lay within the limits 75±5 microseconds.

Effective counter length.

It was necessary to ascertain the effective dimensions of the G.M.4 counters, both in order to compute the absolute intensity of cosmic radiation from the observed counting rates, and in order to indicate the minimum lead absorber dimensions necessary for complete screening of the counter telescopes.

Several methods are available for determination of the effective length of a cylindrical counter, but the majority of them entail very long counting periods to achieve reasonable accuracy. One expeditious method is illustrated in the inset to Figure 13. A radium source,

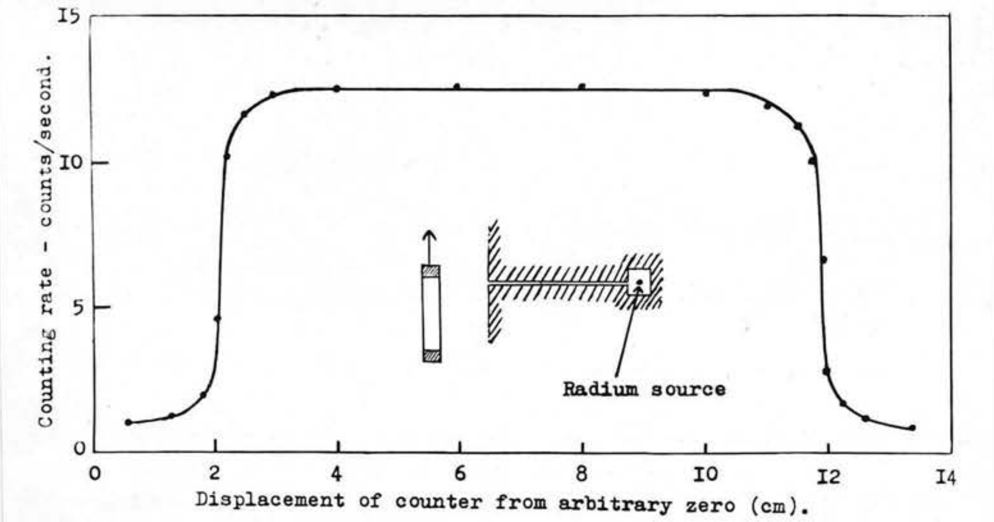

Figure 13. Effective counter length using γ-ray beam.

completely walled in by thick lead blocks apart from a slit some 20 cm. long and 1 mm. wide, produces a well collimated beam of γ-rays. The counter under test is mounted on a travelling microscope carriage, and the variation in its counting rate is observed as it is traversed lengthwise across the γ-ray beam. A typical result is shown in Figure 13, which indicates an effective length, in this case, of about 10 cm. The accuracy of this experiment is limited by the finite width of the slit, and by the impossibility of eliminating completely the scattering of secondary electrons into the active volume of the counter when the γ-ray beam is directed close to the ends of the cathode cylinder. The method was found to be useful for the comparison of effective lengths, but the absolute accuracy of measurement was limited to about ± 2.5 mm.

A more exact determination of effective counter length, with the added advantage of counting cosmic ray particles, was obtained in the following manner. Three identical counters, ABC, are set up in the form of a

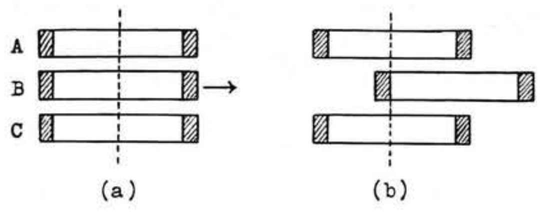

Figure 14. Counter arrangement for measurement of effective lengths.

vertical telescope as shown in Figure 14(a), the ends of the cathode cylinders being accurately lined up, and the triple coincidence rate due to cosmic radiation is measured. Counter B is the counter under test, and the shaded areas at the ends represent the inactive volumes of the counters. The two halves of counter B on either side of the broken central line must contribute equally to the coincidence rate. If, now, counter B is moved to the position shown in Figure 14(b), only its left-hand half is included in the solid angle of the telescope, and, apart from second order effects such as the east-west assymetry of cosmic radiation, the coincidence rate must be halved. Conversely, if counter B is traversed until the coincidence rate falls to half its original value, then it must have been moved through half its effective length. Since the counting rate remains fairly high in this position and the approximate half-length is known beforehand, it is possible to obtain an accuracy of ±1 mm. with 48 hours counting by using this technique.

Figure 15 is a graph of the coincidence rate against displacement of the centre counter as obtained in one experiment. The counting rate with zero displacement is 272±4 counts per hour. Since the important

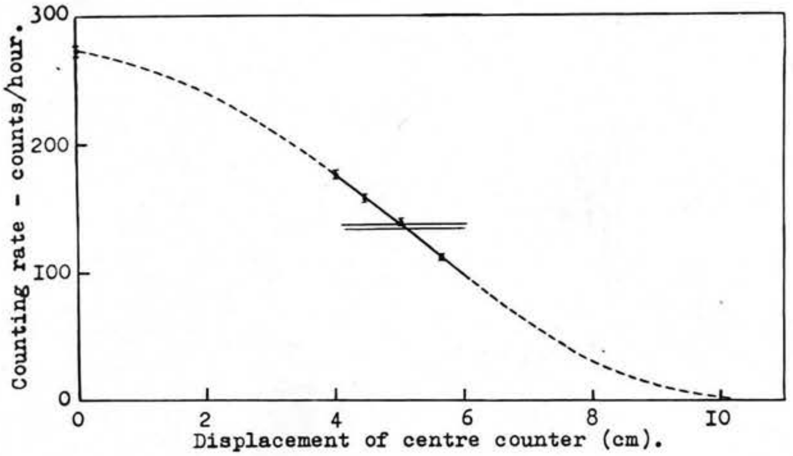

Figure 15. Effective counter length using cosmic ray particles.

region of the curve is nearly linear, the displacement required to reduce the coincidence rate to 136±2 counts per hour (indicated by the two short parallel lines), is sufficiently well defined by plotting the four counting rates shown, and in this case corresponds to an effective length of 10.2±0.1 cm.

The effective lengths of three counters were measured by the second method, and the results extended for several more using the γ-ray technique. From these experiments it was concluded that in all cases the effective length of the G.M.4 counters agreed to within 1 mm. with the geometric distance between the inner ends of the glass capillaries surrounding the anode wire. It was found that this result was not significantly affected by variation of the counter voltage over a range of 100 volts in the centre of the plateau. The distance between capillaries was measured on a large number of counters, and the effective length calculated to be 10.0±0.3 cm.

Effective counter diameter.

Owing to the scattering of electrons out of the walls into the active volume of the counter, the method of using a γ-ray beam is not suitable for accurate determination of the effective diameter of a counter. It is well known, however, that for a cylindrical counter the effective dimension agrees closely with the physical internal diameter of the cathode, and it was therefore considered sufficient to check this result for one counter. The method which was adopted is due to Street and Woodward[12], and is sketched briefly below.

Three identical counters, A B C, are arranged to form a vertical telescope as shown in the inset to Figure 16. The ratios, N_t/N_d, of the triple coincidence rate ABC to the double coincidence rate AC, are measured for various displacements of counter B. When the displacement, S, is zero, the triple rate is at a maximum, and the ratio N_t/N_d is equal to the efficiency of counter B uncorrected for the effect of side showers. The coincidence rate AC due to shower particles alone, is constant throughout the experiment, and the shower rate ABC does not vary greatly when counter B is given a small displacement. Since N_d is constant, and N_t decreasing as S is increased, the effect of side showers on the ratio N_t/N_d will increase with the displacement, and corrections must be applied.

By decreasing the counter spacing in the present experiment, and so increasing the double coincidence rate, the effect of showers on the value of N_d was made negligible. The shower rate ABC was evaluated by measuring the counting rate with counter B just out of line with A and C. This gave a correction of 1.2 counts per hour which was applied to all values of N_t, but which only became significant when the displacement was approaching the value of D, the effective counter diameter, and the coincidence rate was low.

Assuming that the counters behave as uniformly sensitive rectangular areas, the approximate theoretical expressions for the value of the ratio N_t/N_d as a function of the displacement S, are

$$\text{for } S < D/2, \quad N_t/N_d = E\left[1 - 2(S/D)^2\right]$$

$$\text{for } S > D/2, \quad N_t/N_d = 2E\left[1 - S/D\right]^2$$

where E is the counter efficiency. In Figure 16 the theoretical curves are drawn for effective diameters of 1.8 cm. and 2.0 cm. All the experimental points lie

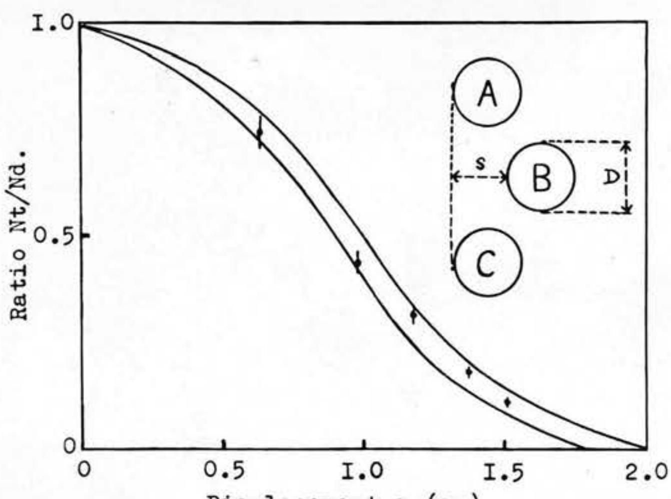

Figure 16. Effective counter diameter.

within these limits, and agree well with an effective diameter equal to the internal geometric diameter of the cathode, in this case 1.88 cm. Measurements taken on a large number of G.M.4 counters gave a value for the effective diameter of 1.95±0.10 cm.

(v) High tension supply for Geiger-Mueller counters.

At individual counting rates of the order of 5,000 counts per minute, the mean value of the total current consumption of three G.M.4 counters connected in parallel is not more than 2 microamps. Because of this negligible current drain, the use of batteries to provide the counter supply would have been relatively inefficient, and would have increased considerably the weight of the balloon-borne equipment. It was therefore necessary to design a supply unit operating from the 120 volt radio sonde battery, and capable of generating a suitable high potential output.

Various forms of portable high voltage supply units for use with counters are described in the literature. The majority depend on the production of a succession of large voltage pulses by an induction coil, the pulses being rectified and smoothed to provide the counter supply. In some cases[13, 14] the current through the induction coil is interrupted by a mechanical device such as the contacts of a buzzer, while other systems[15, 16] are completely electronic in action. The latter type was preferred as being the more reliable, and the less likely to generate electrical interference.

The supply unit described by Huntoon[15] was suitable as regards lightness and simplicity, and was made the subject of initial experiments. In this circuit (lightweight version), the anode current of a normally conducting pentode valve is repeatedly interrupted by feeding to its control grid negative pulses obtained from a circuit containing a flashing neon tube. An iron-cored choke forms the anode load of the pentode, and the large pulses of back e.m.f. are rectified by a triode and smoothed by a high voltage working condenser. A supply unit of this type was constructed, and although the performance of the circuit was otherwise satisfactory, it was found that an input current of at least 7 ma. at 120 volts was required for an off-load output of 1,400 volts. While this power could have been supplied if necessary, it would have represented the major portion of the battery drain of the complete balloon-borne equipment, and some reduction in this consumption was very desirable.

A result similar to the above was obtained when the neon tube circuitry was replaced by a blocking oscillator, the increased amplitude of the induced voltage pulses due to the more steeply fronted waveform of the oscillator being offset by the current requirements of the extra valve. Although this type of circuit also had to be rejected, it led to the idea of using a single oscillator valve to produce directly the high voltage pulses. The conventional type of blocking oscillator gave disappointing results with a highly inductive anode load, but efficient operation was eventually achieved with the circuit shown in Figure 17.

V9, the oscillator valve, produces a succession of high voltage pulses of back e.m.f. across the anode winding of T1. These pulses are rectified by the triode V8, and charge to their peak value the smoothing condenser C16. This condenser then provides a source of high potential at low current drain, which is suitable for supplying the counters.

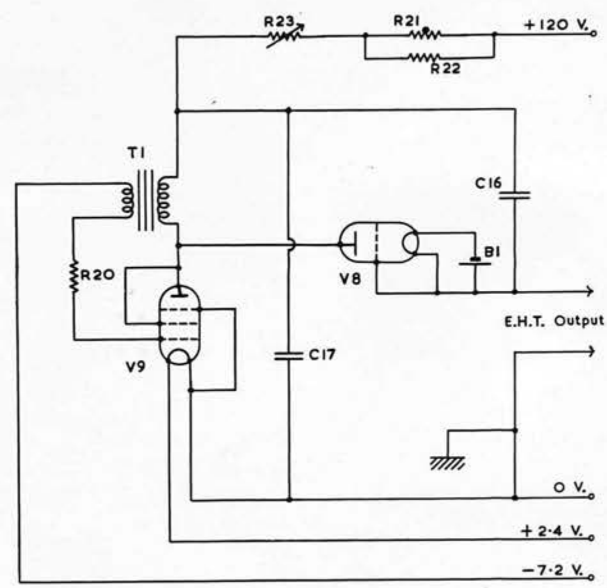

Figure 17. E.H.T. supply unit circuit diagram. (for component values see Figure 26)

The pentode valve V9, which is normally passing current, is connected so that its anode and control grid circuits are very closely coupled through the transformer T1. The transformer is phased so that a potential rise at the pentode anode is reflected as a potential drop at the control grid. Since this causes a further rise in the anode voltage, the valve is obviously in an unstable state, and under suitable conditions oscillations are to be expected. A theoretical analysis of the conditions necessary for oscillation of circuits of this type, including a description of the practical results obtained with different transformer ratios, has been published by Vecchiacchi[17]. It is shown that when the reactive coupling between anode and grid circuits is very close, relaxation oscillations are produced at a frequency much lower than the fundamental of the LC circuit, the capacitance in this case being mainly the self-capacity of the transformer windings. The period is essentially determined by the impedance of the pentode valve. A study of the waveforms in Figure 18 shows that during the major portion of the cycle the rate of change of anode and grid voltages is slow, being controlled by the rate

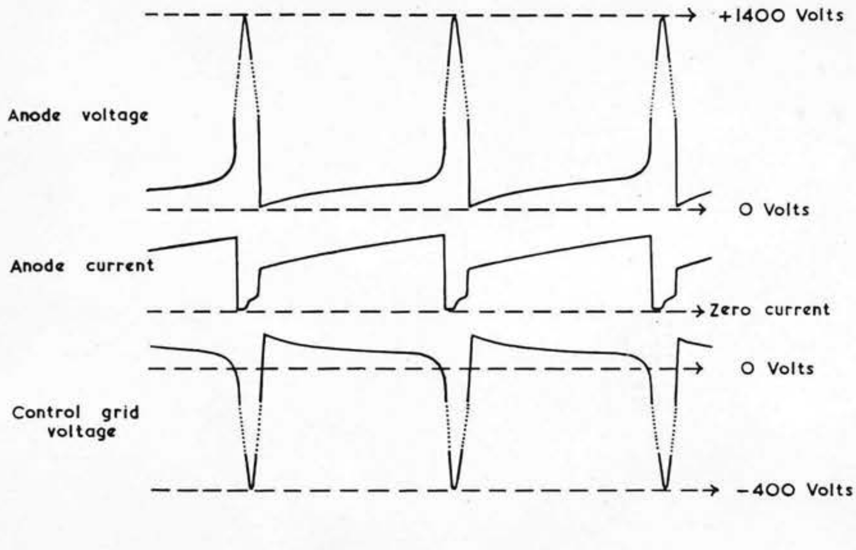

Figure 18. E.H.T. supply unit oscillator waveforms.

of flow of current from the transformer windings through the valve. Owing to the shape of the mutual valve characteristic, the rate of rise in anode voltage increases more rapidly as the grid voltage falls towards cut-off value, with the result that cut-off occurs abruptly. On cessation of the anode current, a pulse of back e.m.f. occurs across the transformer secondary winding, the anode swinging positively since the tendency is to maintain current flow through the valve. The valve being cut-off during this stage, the duration of the high voltage pulse depends only on the transformer characteristics. With the present design it amounts to about one sixth of the complete cycle.

The blocking oscillator is a 2-volt R.F. pentode (Mazda type VP23), the anode and screen grids being strapped, and the suppressor connected to the negative filament line. The variable resistance R23, decoupled by C17, permits adjustment of the E.H.T. output over the plateau range of the counters. The section of R23 left in circuit at normal output voltages also provides adequate decoupling of the H.T. line. On the carrier transmitted by the balloon-borne equipment the E.H.T. oscillator note is barely audible, and the only noticeable effect is a very slight beating with the audio signals at certain frequencies. The grid stopper R20 is not essential to the operation of the oscillator, but it was found to reduce the current consumption of V9 for a given voltage output. No suitable diode being available, a triode (Mazda type HL23) with grid strapped to filament is used as the rectifier.

Since the filament of the rectifier, V8, and the associated wiring are at E.H.T. potential, a separate heater supply is necessary. In flights F1 and F2 small 2.4 volt accumulators which had had a long shelf life were used for this purpose. Transmission of cosmic ray signals failed after 35 minutes in flight F1 and after 67 minutes in flight F2. The balloon-borne equipment used in flight F1 was not recovered, so the cause of failure could not be determined. On recovery of the equipment used in flight F2, the trouble was traced to this accumulator providing the rectifier filament supply. The internal connection between the negative plate of the battery and the negative terminal had been open-circuited by acid corrosion. It was definitely established that this had caused the second failure, since a discharge test after repairing the break showed that the battery was still almost fully charged. The accumulators were therefore discarded in favour of 1.5 volt dry cells (Ever Ready type U11). This type of cell heats the 2 volt filament of an HL23 valve sufficiently for efficient rectification, and the run-down time of about 7 hours leaves the necessary margin for checking operation before take-off.

Transformer design.

The original E.H.T. supply units incorporated a commercial audio transformer (Elstone type LF35), of high primary and secondary inductance, which was satisfactory in operation and was used in flights F1-F3. Further experience showed, however, that the insulation between windings in this component was insufficient for the purpose in hand, too great a percentage having to be rejected. In addition, the maximum temperature for reliable operation was about 35°C., surface leakage along the paper former becoming serious above this point. The Elstone transformers were therefore replaced after flight F3 by a component designed for greater reliability.

The new transformers were individually wound on bobbins turned from thick vulcanite rod. End and side views of the bobbin are shown in Figure 19(a) and (b) respectively. All walls, including the partition between anode and grid windings, were 0.12 cm. thick. Up to 14 laminations of the dimensions shown in Figure 19(c) could be accommodated inside the bobbin, the type of alloy having little effect on the performance. The anode winding consisted of 5,000 turns, and the grid winding of 1,250 turns of 43 S.W.G. enamelled copper wire. Winding was of necessity done by hand on a lathe, great care being required to prevent turns at widely

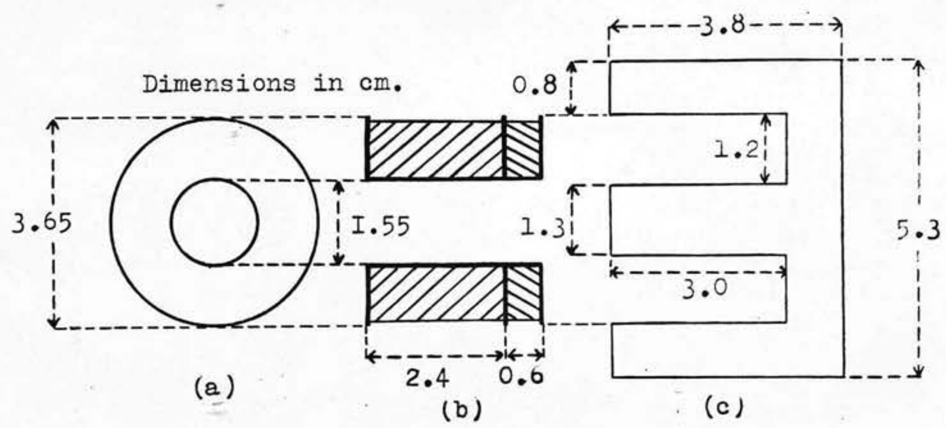

Figure 19. Transformer bobbin and laminations.

different potentials from touching. There was not sufficient room to interleave the windings.

43 S.W.G. wire is the finest which can be used without causing difficulties due to the variation of E.H.T. output with change in temperature. With 45 S.W.G. wire a rise of 10°C. causes a drop of 25 volts in an output of 1,350 volts. This effect, which is mainly due to the change in resistance of the transformer windings, is still detectable with 43 S.W.G. wire but it is much less pronounced. An output of 1.350 volts does not then drop by more than 20 volts for a 50°C. rise in temperature. In flights F1-F3, when Elstone transformers were in use, the temperature coefficient was too great to be neglected. Its effect was minimised by the inclusion of a negative temperature coefficient resistor R21 (S.T.C. Brimistor type CZ2) as part of the anode

load of V9. The resistance of the Brimistor falls with a rise in temperature, raising the anode voltage of V9, and compensating for the reduced efficiency of the transformer at the higher temperature. Exact compensation is not possible owing to the non-linear characteristic of the Brimistor, and a parallel combination with a fixed resistor R22 was found to give the best compromise.

Vacuum impregnation of the transformers greatly increases their reliability. The impregnating material used was a mixture of high melting point paraffin wax (4 parts), with sufficient petroleum jelly (1 part) to prevent cracking at low temperatures. The following procedure was employed. The wax, in a small container, was heated to about 80°C. and placed under a bell-jar. The transformer without its laminations was suspended above the container, the bell-jar was evacuated, and then the transformer was dropped into the molten wax. Pumping was continued until bubbling due to the escape of air and water vapour from the windings had ceased, a process taking some 20 minutes. The vacuum was then suddenly released, forcing the wax right to the innermost layers of the windings. On removal of the transformer, the windings were bound with Empire tape and the whole covered with a protective layer of wax.

Construction of E.H.T. unit.

Since the E.H.T. unit was required to operate at very high altitudes in atmospheric pressures of a few mm. Hg., stringent precautions were necessary to prevent the occurrence of corona discharges from the high potential wiring. The importance of this was increased by the low current capacity of the high voltage supply, a discharge current of only a few microamps causing serious reduction of the E.H.T. voltage. An obvious method of avoiding this trouble was to construct the supply unit in an air-tight container which would remain at ground level pressure throughout a flight. It was considered however, that this method would involve unnecessary complications, and that covering all exposed high potential points with wax was, in this case, a simpler solution. Both Apiezon Wax "W" and paraffin wax were used for this purpose, but the former is to be preferred on account of its higher melting point (80°C.), its closer adherence to a variety of surfaces, and its lesser tendency to crack at low temperatures.

In constructing the supply units the valves V8 and V9 were de-based and the metallising removed. The external leads to the electrodes were given the maximum possible clearance, and then the hollow round each valve pinch was filled with wax. The unit was designed so that all the high potential wiring, with the exception of the grid lead to V9, was sandwiched between two paxolin plates. The complete assembly is shown in Figure 20.

Valves, transformer and smoothing condenser were mounted on the top plate and waxed into position. All wiring between the plates was covered with wax, the lower plate being perforated to facilitate this operation. Four terminals were provided for the battery supply input, and two well insulated leads carried the rectifier filament supply, one of these leads also being connected to the counter supply line. The grid cap of V9, a high potential point, was removed, connection made to the protruding wire, and the joint then waxed over. The

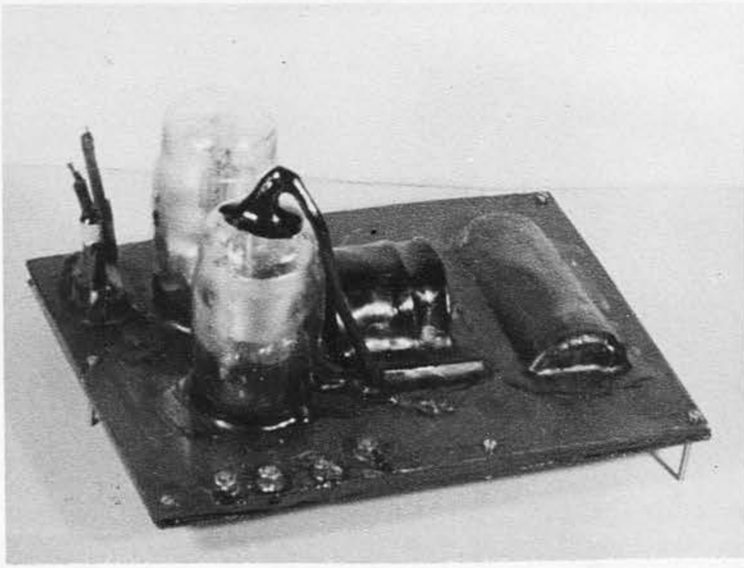

Figure 20. E.H.T. supply unit.

filament supply battery for V8 was enclosed in a cemented polystyrene container. To prevent the possibility of the box cracking on reduction of the external pressure, a very small perforation was made at one end and coronas suppressed by lining the interior with cotton wool.

E.H.T. unit performance.

The counter supply units were designed to run off a 120 volt battery. For a given supply voltage the current consumed depends mainly on the inductance and resistance of the transformer windings. If a sufficient number of turns are employed, an output of 1,400 volts can be obtained at a battery drain of less than 0.2 ma. However, the regulation is then unavoidably poor, and it is more suitable to use fewer turns of thicker gauge wire. With the transformer design specified above, the required output is obtained at a current consumption of about 1 ma.

The weight is about 320 gm. for the main unit, plus about 90 gm. for the rectifier filament battery and container.

Figure 21 shows the relation between output voltage and output current. The decrease in voltage is

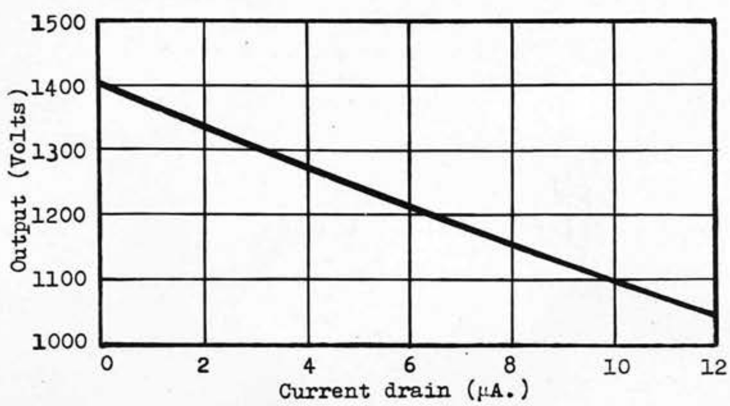

Figure 21. E.H.T. supply unit regulation.

practically linear for increasing drain, and amounts to about 30 volts per microamp.

The amplitude of the ripple on the output voltage depends on the current drain, but is not greater than 3 volts peak to peak at fast counting rates. Both battery and mains driven versions of this type of high voltage supply unit have been in use over long periods in the laboratory. Under constant operating conditions the output voltage is extremely stable, but it drops by about 15 per cent for a reduction of 10 per cent in the input voltage.

Ideally the counter supply voltage should remain constant throughout a flight. This could not have been realized in practice with the type of supply unit employed, and although the use of counters with unusually extensive plateaux made the stability of the E.H.T. supply unit much less critical, it is necessary to consider the probable variations during a flight. The most important causes of fluctuation in counter voltage are the following:

(a) The effect, already discussed, of temperature change on the transformer efficiency.

(b) Alterations in battery voltages during a flight.

(c) The variation in counter current consumption with counting rate.

The effect of (a) has probably been small in all flights, the variation in E.H.T. voltage amounting to not more than 20 volts in flights F1-F3, and to not more than 10 volts in other flights. The magnitude of the fluctuation due to (b) can only be estimated. Normally the battery voltage is stable to within 1 volt over a period comparable with the duration of a flight, when tested on run-down in the laboratory. The resulting variation in E.H.T. voltage should be not more than 15 volts. This, of course, does not take into account possible failure of one or more individual battery cells. Complete failure of one cell, apart from its effect on the internal resistance of the battery, would lead to a drop of 35 volts in the counter supply. There has, however, been no evidence of any tendency towards cell failure during a flight, and it is unlikely that there has been any marked drop in E.H.T. voltage from this cause. This leaves the effect of (c) to be considered, the variation due to changes in counter drain. The dependence of output voltage on output current shown in Figure 21 relates to a supply unit with the component values and operating voltages shown in Figure 17, and with sufficient laminations inserted into the transformer for the frequency of oscillation to be about 350 c/s. This type of supply unit was used with all three-counter telescopes, when the maximum drain was expected to be about 1.2 microamps. This would cause a drop of 30-35 volts in an off-load voltage of 1,350 volts.

The regulation of the supply unit depends on the frequency of oscillation of V9, and when a greater number of counters were to be supplied, certain modifications to the power unit became desirable. The oscillatory frequency could be raised to about 750 c./s. by removal of some of the transformer laminations, and the resultant decrease in the maximum obtainable output voltage countered by decreasing the control grid bias to -4.8 or -2.4 volts, and by reducing the value of R20. The same output voltage range could then be covered, and with five- or six- counter telescopes the maximum variation in E.H.T. voltage due to counter drain was again under 35 volts. Under these conditions the battery consumption of the supply unit increased to about 1.8 ma.

The total variation in E.H.T. voltage during a flight from these various causes should not have been greater than the following:

(a) A drop of 10 volts near the point of maximum altitude due to temperature rise.

(b) A drop of 15 volts in the later stages of the flight due to the probable fall in battery potential.

(c) A drop of 35 volts when the counting rates of the individual counters were at a maximum during the ascent and descent.

The total drop to be expected is at no time likely to have been greater than 50 volts. With a normal take-off potential of 1,375 volts and an effective plateau range of 1,200-1,500 volts there was ample margin for this variation.

(vi) <u>Pulse control circuitry.</u>

Although various arrangements of counters were used in different flights, the transmitted signals in every case were required to denote the occurrence of a coincidence between all the counters in the telescope. The function of the pulse control circuitry was therefore to produce a negative pulse of suitable duration and amplitude to quench the R.F. oscillator for 30 milliseconds, only on receipt of simultaneous short negative pulses from all counters. For simplicity the description will be confined to the circuit designed for use with a triple coincidence telescope, and the modifications required when dealing with coincidences of higher multiplicity will be listed separately.

The well known circuit developed by Rossi[18] for coincidence recording forms the basis of the pulse control stages. Three pentode valves operate into a common anode load of value about 1M, which is large compared with the D.C. resistance of any one of the valves at zero control grid bias. As a result the rise in voltage at the common anodes remains comparatively small when one or two valves are cut-off by the negative counter pulses fed to their control grids. When a triple coincidence occurs, and all three valves are cut-off together, the impedance of the valves in parallel becomes high compared with their common anode load, and a much larger positive output pulse is obtained. These output pulses are therefore roughly separable into three groups, corresponding in increasing order of amplitude to single, double and triple coincidences, and selection of the desired triple coincidences is reduced to the simple problem of picking out the pulses of greatest amplitude. The facility with which this may be accomplished depends mainly on the ratio of amplitudes of the pulses corresponding to triple and double coincidences, and this quantity is known as the discrimination of the circuit.

Early experiments using Mazda VP23 R.F. pentodes showed that a discrimination of 10:1 could be obtained. Difficulties were encountered, however, when the circuit was operated in close proximity with the R.F. oscillator, due to the alteration in bias caused by rectification of induced high frequency voltages on the Rossi valve control grid leads. Decoupling was unsatisfactory, and shortening of the grid leads was found to be the only effective cure. The Rossi valves had each to be positioned with the control grid connection within 1 inch of the corresponding counter anode. Mounting valves of normal size so as to achieve this would have entailed placing an appreciable amount of cosmic ray shower producing material close to the counters, which it was desired to avoid. Sub-miniature R.F. pentodes, Hivac type XWO.75A, were therefore adopted for use in the

Rossi stages. With these valves the optimum discrimination obtainable of 7:1 was amply sufficient, but to achieve this figure considerable care in matching valves was required.

The pulse control circuitry used in flights F1-F8 is shown in Figure 22. V5, V6 and V7 are the three Rossi valves, the negative counter pulses being fed to their control grids through high voltage working condensers C13, C14, C15. The positive pulses developed across the common anode load R11 are passed through C12 to the grid of a triode V4 which is biased well beyond cut-off. Under normal operating conditions the amplitudes of pulses due to single, double and triple coincidences are about 0.5, 3 and 15 volts respectively, so the bias of -9.6 volts leaves a considerable safety margin for the rejection of all but triple coincidences. The bias is lifted each time a triple coincidence occurs, and a short negative pulse is produced at the anode of V4. It is necessary to lengthen this pulse to about 30 milliseconds. The simple but effective method employed is to reflex the circuit, feeding back the short pulse from V4 anode through C11 to the screen grids of the Rossi valves. As a result, each triple coincidence pulse initiates a flip-flop action between V4 and the Rossi circuit, the negative pulse fed to the Rossi valve screens holding these valves in a cut-off state, so that their anodes rise to full H.T. potential and a large

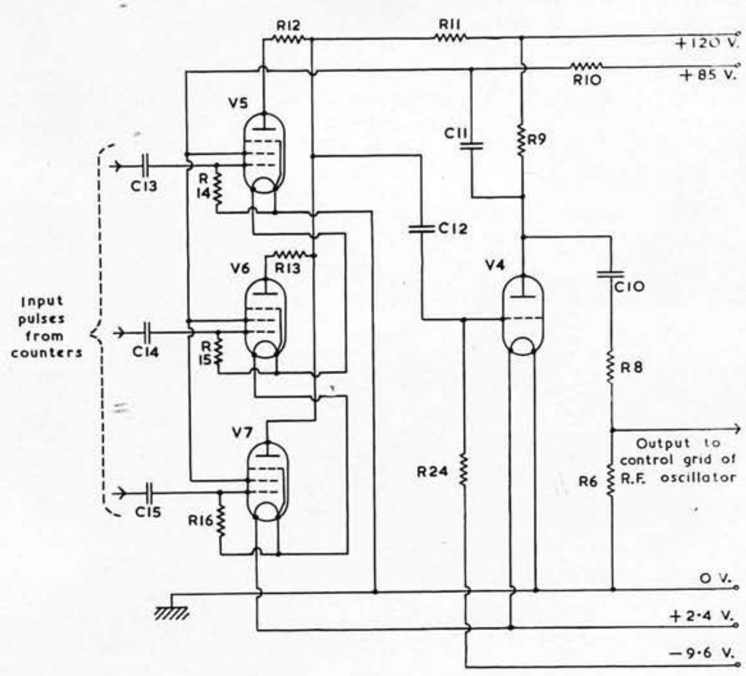

Figure 22. Pulse control circuitry.
(for component values see Figure 26)

positive pulse is passed to the grid of V4 which remains conducting. This state is maintained for the period of the flip-flop cycle, which is governed mainly by the time constants of R24, C12 and R10, C11, the circuit then relaxing and returning to its stable condition with the Rossi valves conducting and V4 cut off. By suitable choice of component values the duration of the negative pulse at V4 anode is lengthened to the desired value. To some extent the requirements of good discrimination, short resolving time (discussed later), and reliable flip-flop action producing a pulse of the correct duration, conflict with one another, and the component values and voltages shown in Figures 22 and 26 represent the best possible compromise. The long negative pulse at the anode of V4, now of amplitude nearly 120 volts and with a sharp leading edge, is fed through C10 to the grid of V3. It is potentiometered down by resistors R8 and R6, the inclusion of R8 also serving to prevent the operation of V3 being affected by inter-stage coupling.

The XWO.75A valves used in the Rossi circuit have a filament consumption of 33 ma. at 0.75 volts, so it was convenient to run three of them in series across the 2.4 volt L.T. supply. This gave rise to the difficulty, owing to the potential drop down the filament chain, that the effective anode voltage was not the same for each valve. The mean anode potential being about 2 volts, this effect was important and could seriously impair the discrimination of the circuit. The difficulty was overcome by the inclusion of resistors R12 and R13 as part of the anode loads of V5 and V6 respectively. These resistors were empirically chosen for each equipment to equalize the anode currents of the three Rossi valves. Using well matched valves the magnitudes of R12 and R13 are small compared with the main anode load R11, and the presence of these resistors does not interfere with the normal operation of the circuit.

The discrimination obtained with the circuit of Figure 22 varies considerably with the characteristics of the individual XWO.75A valves. The minimum accepted figure was 5:1, with the double coincidence pulses unable to lift a bias of -3 volts at a counter voltage of 1,350 volts.

The reliability of the flip-flop action was checked by an experiment in which the number of transmitted triple coincidences was compared with the number of pulses appearing at the anode of V4 in the same period. The equipment recording transmitted counts responded only to lengthened pulses, while a scaler coupled to V4 was capable of accepting long or short pulses. Over a long period the two counting rates were found to agree, and for a wide range of supply voltages there was no loss of counts due to failure of a triple coincidence pulse to trigger the flip-flop.

Resolving time.

In addition to genuine coincidences caused by the passage of a single particle through all the counters of a telescope or by a cosmic ray shower, accidental coincidences arise when the counters are simultaneously discharged by two or more random particles. In practice these accidental coincidences are counted if all the counters are actuated within a short time interval. The longest interval, t, between pulses at which an accidental is recorded as a genuine coincidence is known as the resolving time of the circuit. For a triple coincidence telescope, the rate of accidentals N_{123} is given in terms of the resolving time and the individual counting rates of the counters N_1, N_2, and N_3, by the relation

$$N_{123} = 3N_1N_2N_3t^2 \ .$$

This is an approximation, but the error introduced by neglecting higher powers of t is small when the resolving time is short. During a flight the individual counting rates become relatively high at certain altitudes, so a short resolving time is necessary if a negligible rate of accidental coincidences is to be obtained.

The resolving time of the Rossi circuit is determined mainly by the time constants of the control grid circuits, but a lower limit of just under 1 microsecond is set by the finite breakdown time of the counters. In designing the present equipment it was convenient to adopt a suitable type of blocking condenser C13, C14, C15, and to reduce the value of the grid leaks R14, R15, R16, until a sufficiently short resolving time was obtained. As the value of the grid leaks is reduced the counter pulses are more and more severely differentiated, with a consequent decrease in amplitude as well as in duration, and as a result the output pulses from the Rossi circuit also become smaller. Since the initial amplitude of the counter pulses depends on the counter over-voltage, there is a critical counter operating potential below which the output pulses from the Rossi stages due to triple coincidences are of insufficient amplitude to lift the bias on V4. Reducing the grid resistors will therefore increase the minimum amount of over-voltage required for operation of the pulse circuitry, and so reduce the effective plateau length of the counter telescope. At the selected value of 68K an over-voltage of 100 volts is necessary, and reliable operation is obtained with counter voltages in the range 1,200-1,500 volts.

An output pulse from the Rossi circuit due to an accidental coincidence is of the same amplitude as the pulse due to a genuine coincidence only if all the counters are discharged simultaneously. Since the trailing edges of the counter pulses are by no means sharp, any time lag in the discharge of one counter will lead to the production of a pulse of amplitude intermediate to the groups corresponding to triple and double coincidences. The resolving time is therefore affected by the minimum pulse size required to operate the circuitry following the Rossi stages. This made it necessary, when determining experimentally the resolving time of each equipment, to ensure that the operating conditions were so far as possible identical to those obtaining during a flight.

In measuring the resolving time of the pulse circuitry the following procedure was employed. The balloon-borne equipment under test was placed with the counter telescope horizontal, and the counters were stimulated to fast individual rates of counting by means of a radium source. The counting rates N_1, N_2 and N_3 of the three counters, and the triple coincidence rate of the telescope were measured. The observed coincidences are mainly accidental events, but a correction is required to eliminate the effects of cosmic ray showers and horizontally moving radiation. This correction was evaluated by removing the radium source, and observing the coincidence rate at a low individual counter background rate. The difference of the two coincidence rates gives the rate N_{123} due to accidental events. In one experiment the following figures were obtained. During a period of 8 hours stimulated counting with $N_1 = 17,600$, $N_2 = 18,100$, $N_3 = 14,900$ counts per minute, a total of 52 triple coincidences were recorded. After removing the radium source, counting continued for a further 108 hours, in which time 103 coincidences occurred, indicating a correction of just under 1 coincidence per hour. Of the 52 observed coincidences it can therefore be assumed that about 44 were due to accidental events. The resolving time calculated from the formula above is found to be 4.9 ± 0.4 microseconds.

This determination of resolving time entailed a total of about 8×10^6 counts per counter, which represents a large part of the counting life of an argon-ethylene filled counter. To reduce the possibility of counter failure during a flight, the resolving time measurements carried out as a routine test on each completed equipment were therefore of an even lower statistical accuracy. Since close tolerance components in identical layouts were used in each case, no great variation in resolving time was to be expected, and, in practice, agreement with the above figure to within a statistical error of 1 microsecond was obtained for each three counter telescope.

Flights F9-F11.

In flights F9-F11 the measurement of a five-fold coincidence rate necessitated the use of five parallel Rossi valves. The only modifications required to the remainder of the circuitry to regain optimum performance were the reduction of R11 to 820K, and of R10 to 68K. Three of the XWO.75A valve filaments were run directly across the L.T. supply as before, and the remaining two were heated in series with a suitable dropping resistor. Small resistors were again used to equalize the anode currents of the Rossi valves, and a discrimination of over 4:1 between five- and four-fold coincidences was obtained with closely matched valves. Measurement of resolving times by the method described above was quite impracticable with telescopes containing four or more Rossi valves, intense stimulation for a very long period being required to produce a significant number of accidental coincidences. This, of course, indicates that a negligible number of accidental coincidences would arise during a flight, and therefore that an exact knowledge of the resolving time is not required. By selecting the Rossi valves and associated counters in groups of three, and disconnecting the remaining Rossi valves, it was possible to show that the resolving time remained at about 5 microseconds in all cases.

Flights F12-F16.

During the course of these experiments the XWO.75A valves became obsolete, being superceded by the type XFW10. The latter valves, which were used in the Rossi circuit from flight F12 onwards, have a filament consumption of 25 ma. at 0.625 volts. Considerable difficulty was experienced in matching valves in order to obtain satisfactory discrimination. It was necessary to connect all filaments in parallel, and heat them through a 50 ohm variable resistor. The value of resistor R11 was much more critical with the XFW10 valves, and suitable values in the range 900 K to 1.1 M had to be selected for each equipment used in flights F12-F16. The screen resistor R10 was again 75 K. A discrimination of 4:1 between four- and three-fold coincidences was obtained in every case, and no appreciable change in resolving time was observed.

Flight F17.

In this flight a high coincidence rate was expected. To reduce counting losses, the period of the flip-flop cycle was shortened to 20 milliseconds by reducing C12 to 0.23 μF. The three XFW10 valves were heated in parallel; the anode load R11 and screen resistor R10 were 1.2 M and 75 K respectively. Between triple and double coincidences the discrimination was 5:1, and the resolving time was again close to 5 microseconds.

(vii) Power Supplies.

In all flights the high and low tension power supplies were provided by batteries of similar design to the Meteorological Office Mark III types mentioned in reference 8. These are improved versions of the Mark I batteries used for the Kew radio sonde, the quantity of inactive material in the electrodes being reduced to a minimum in order to give a better capacity - weight ratio. In both H.T. and L.T. sections, the positive electrodes consist of a layer of lead peroxide mounted on a grid of metallic lead, and the negative electrodes are plates of amalgamated zinc. The batteries, which require no initial charging, provide an e.m.f. of approximately 2.4 volts per cell on filling with an electrolyte

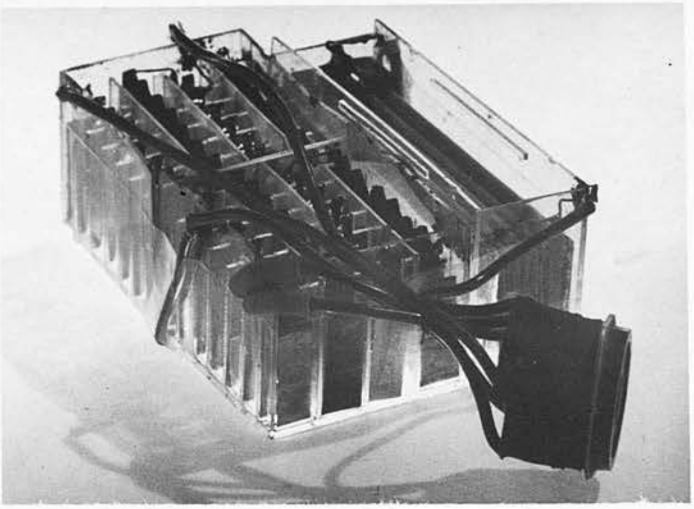

Figure 23. Complete battery unit.

of sulphuric acid (specific gravity = 1.27). By saturating the electrolyte with mercuric sulphate, the surface of the zinc plates is freshly amalgamated at the time of use. The cell walls in the H.T. section, and the outer cases are moulded in cellulose acetate.

Owing to the difficulty of providing adequate insulation between adjacent cells at widely different potentials, it was necessary to obtain the required H.T. voltage by means of two separate 65 volt batteries each containing 28 cells. 4 cells of one battery formed a bias section of 9.6 volts, and the remaining 52 cells provided the 120 volts H.T. supply. Intermediate voltage tappings were obtained by soldering wires direct to the inter-cell connections.

The complete battery unit is illustrated in Figure 23, with the L.T. section, a single multiplate 2.4 volt cell, on the right.

A sample of each batch of batteries obtained

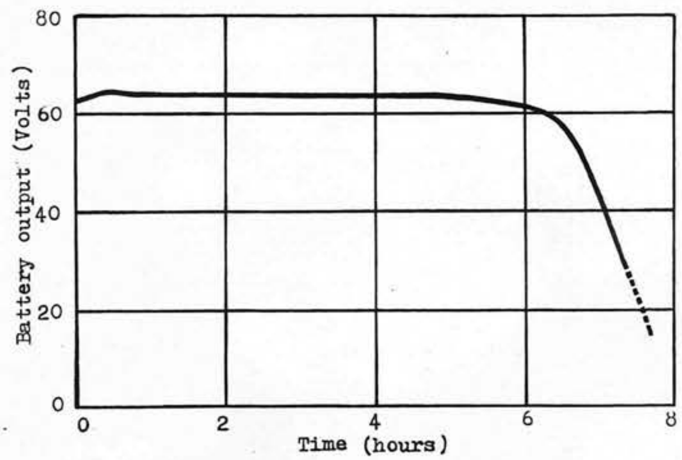

Figure 24. Discharge characteristic of 65 volt H.T. section at constant current drain of 9.2 mA.

from the manufacturers (Barnard Accumulator Co.), was tested on discharge in the laboratory. Figure 24 shows a typical voltage-time curve for a 65 volt H.T. section at a constant current drain of 9.2 ma. After an initial rise of about 1.5 volts due to decreasing internal resistance, the output voltage is stable to within 0.5 volts for the first 5 hours and drops rapidly after 6 hours. This type of discharge characteristic is well suited to the present work. Most of the initial rise occurs during the testing of the equipment prior to release, the battery voltage becoming steady before take-off.

A flight normally lasted for about 3 hours, with a current consumption of 8-9 ma., so ample margin was left to provide against any possible decrease in battery capacity with storage life.

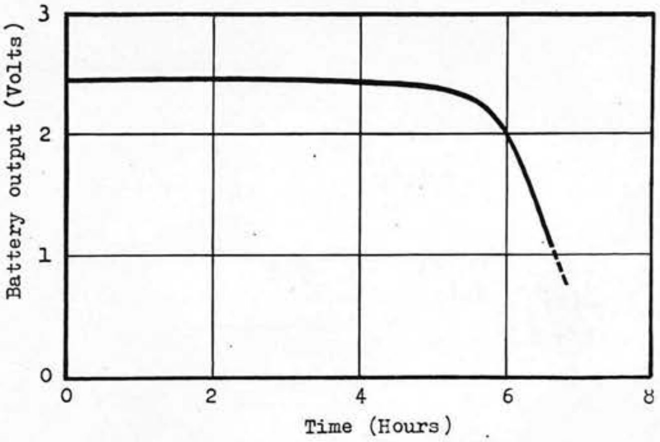

Figure 25. Discharge characteristic of 2.4 volt L.T. battery at constant current drain of 550 mA.

The discharge characteristic of an L.T. battery is shown in Figure 25. A current output of 550 ma. can be maintained for at least 5 hours at 2.44±0.04 volts. This capacity is adequate to provide the 500-550 ma. required by the transmitting equipment for the duration of a flight.

These run-down tests showed that trouble might be experienced due to the destruction of the negative plates in the H.T. batteries at the zinc-air-acid boundary, probably a result of faulty amalgamation of the zinc. The soldered connections between electrodes are protected from acid corrosion by a covering of anti-sulphuric paint, and extension of the painted area on the negative plates in each cell to below acid level was found to eliminate the trouble. This treatment was therefore adopted as a routine safety measure on each H.T. battery.

The batteries were most easily filled by the use of a large fountain pen filler, this instrument also providing a means of extracting any excess acid added to the cells of the H.T. section. The filling operation was completed about 1¼ hours before take-off, to reduce the discharge time required for the internal resistances of the batteries to fall to their minimum values. After filling, a layer of viscous oil was floated over the acid in the batteries, to preserve insulation between cells by preventing any splashing of the acid due to the motion of the balloon-borne equipment during the flight.

The weight of a single 65 volt H.T. battery with acid and oil is about 270 gm. At a discharge rate of 9 ma. the capacity is not less than 55 ma.-hours, so the capacity-weight ratio is at least 13 milliwatt-hours per gram. An L.T. battery with acid and oil weighs about 184 gm. The minimum capacity of 3,000 ma.-hours at a discharge rate of 550 ma., corresponds to a capacity-weight ratio of 32 milliwatt-hours per gram.

(viii) Construction of transmitting equipment.

The complete circuit diagram of the balloon-borne transmitter used in flights F1-F8 is shown in figure 26, followed by a list giving the values, ratings and tolerances of the components employed. To some extent the choice of values and ratings was influenced by the ready availability of components of suitable type, and for this reason the ratings of many of the capacitors and resistors are greater than actually necessary for reliable operation.

A complete equipment of the type used in flights F1-F8 is shown, without its cellophane coverings, in Figures 27 and 28, from which some idea of the component layout and the physical dimensions may be obtained.

The framework is constructed of aluminium strips, right-angle sectioned where additional mechanical strength is required, and held together by bolts or by aluminium rivets. It is designed to be carried aloft by two cords attached to the balloon rigging. These cords are threaded through eyelet holes in the projecting lugs at the topmost points on either side of the equipment. The lower part of the outer framework is just sufficiently strong to bear the weight of the apparatus when standing on the laboratory bench.

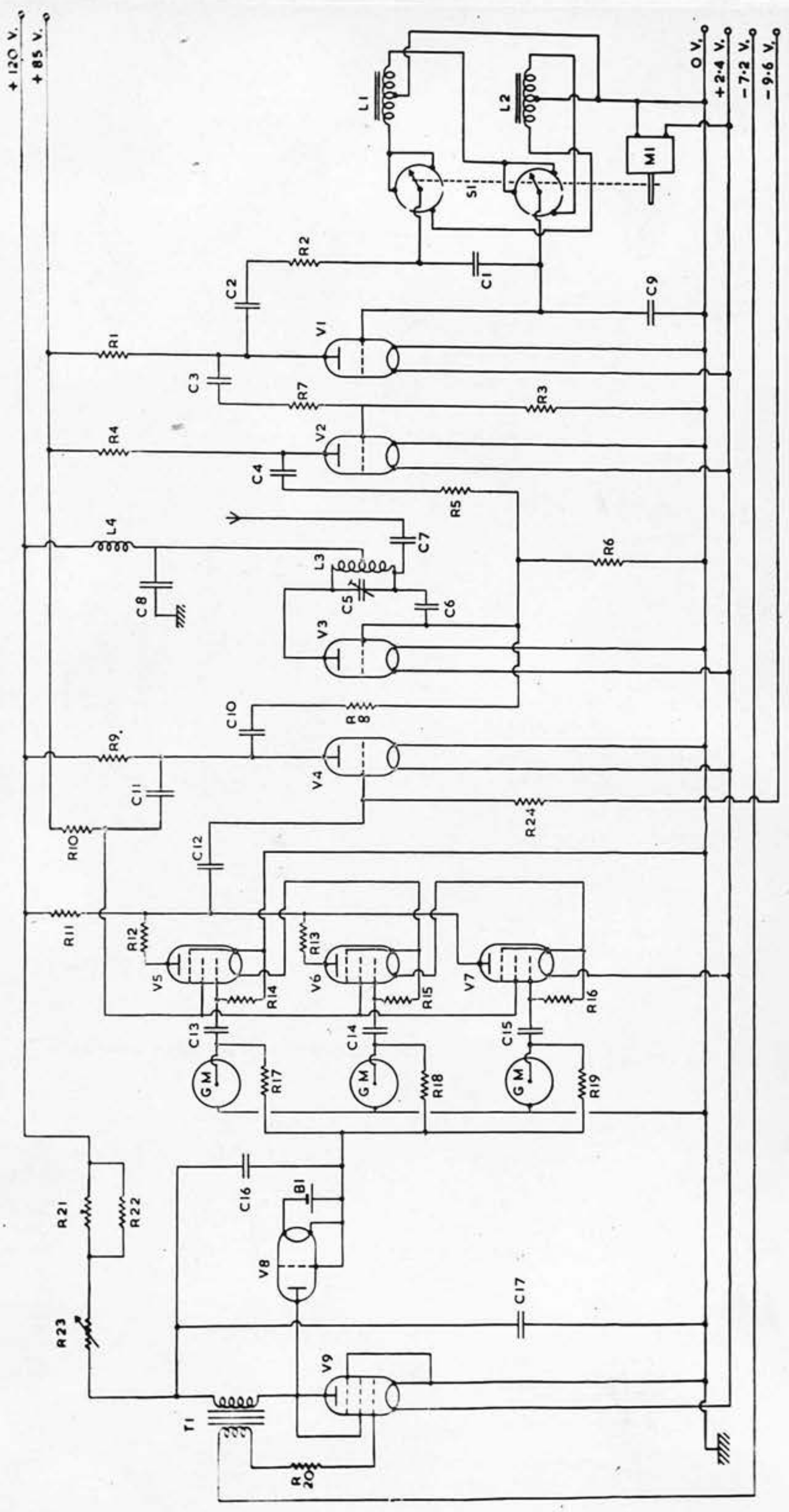

Figure 26. Complete circuit of transmitting equipment.

Components list overleaf.

Components list - Figures 1, 17, 22 and 26.

Resistor	Value (ohms)	Tolerance (%)	Rating (watts)
R1,2,5,6	22K	5	½
R3,4	47K	5	½
R7	Selected values about 1M.		¼
R8,9	100K	5	¼
R10	75K	5	¼
R11	1M	2	¼
R12,13	Selected values 5K-20K.		1/10
R14,15,16	68K matched to 1%.		1/10
R17,18,19	10M	10	1/10
R20	27K	10	1/10
R21	Brimistor, S.T.C. type CZ2 (F1-F3 only).		
R22	15K	10	¼
R23	10k variable, linear law.		3
R24	1M	10	¼

Valve	Maker	Type
V1,2,3,4,8	Mazda	HL23
V5,6,7	Hivac	XWO.75A
V9	Mazda	VP23

Capacitor	Value	Type	Tolerance (%)
C1	0.07μf	mica	3
C2	0.01μf	mica	15
C3,4	0.001μf	mica	15
C5	5-20pf	concentric air-spaced trimmer.	
C6	20pf	mica	10
C7	5pf	ceramic 350v.	5
C8	100pf	mica	15
C9	500pf	mica	15
C10,11	0.1μf	tubular 350v.	20
C12,17	0.5μf	tubular 350v.	20
C13,14,15	100pf	mica 2,250v.	10
C16	0.1μf	tubular 1,500v.	20

<u>Miscellaneous</u>.

L1	Pressure controlled inductor.
L2	Temperature controlled inductor.
L3	28 Mc./s. tank coil.
L4	R.F. choke, 30 microhenries.
B1	Ever Ready, U 11, 1.5 volt cell.
M1	Rev. Motors Electrotor type 240.
T1	4:1 ratio audio transformer (see text).
S1	Changeover switch (see text).
GM	Geiger-Mueller counters, Cintel type G.M.4.

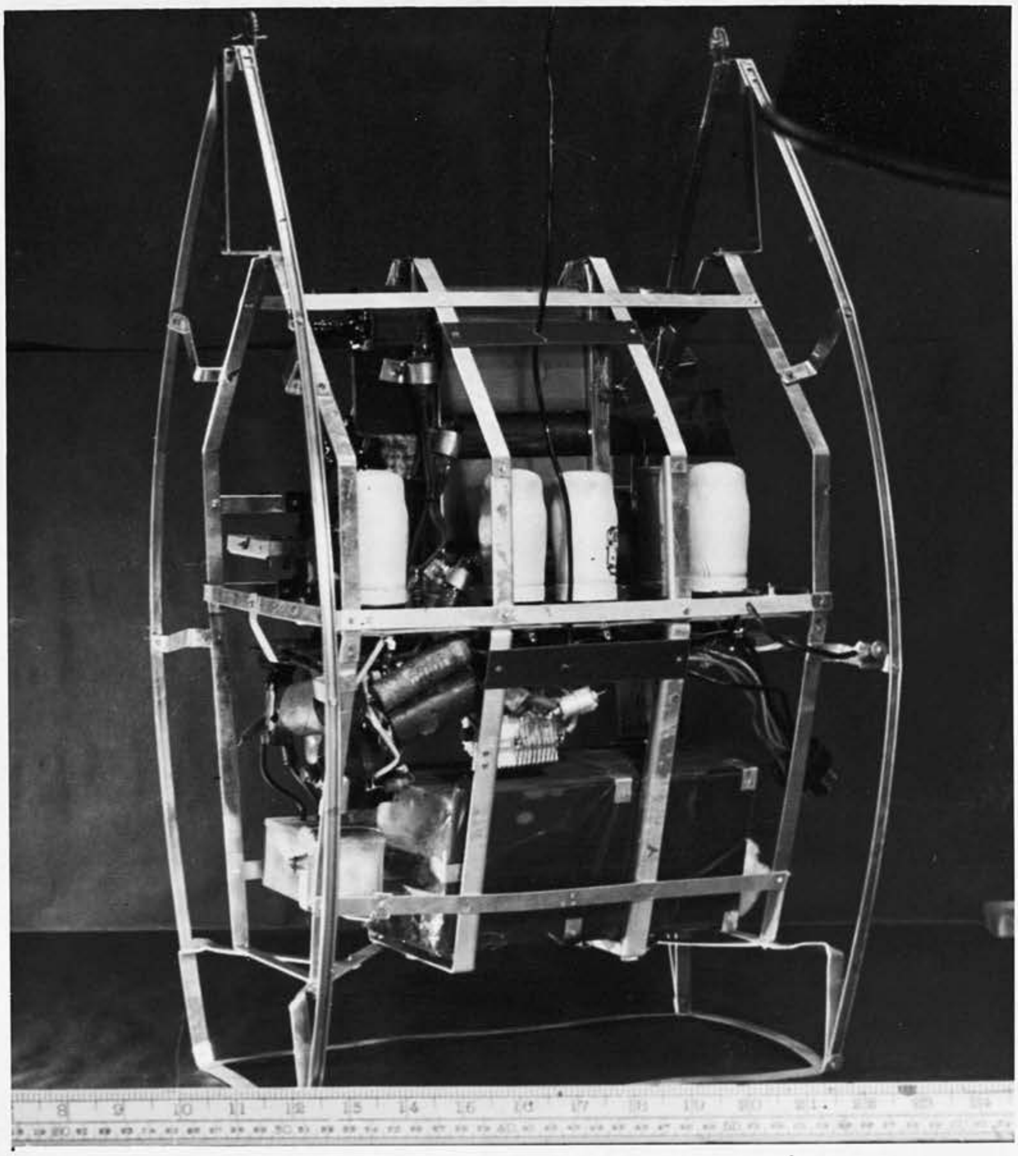

Figure 27. Transmitting equipment - front view.

Constructional details.

The radio sonde pressure and temperature units are visible in Figure 28, mounted symmetrically on either side of the centre. This arrangement was adopted so that the two elements would be at equal temperatures irrespective of the possible existence of a vertical temperature gradient within the gondola. Under these conditions the transmitted temperature data give the most accurate pressure frequency corrections.

The motor and switch unit is positioned below the pressure unit, while the main circuitry of the Kew radio sonde is built on a chassis formed by two narrow

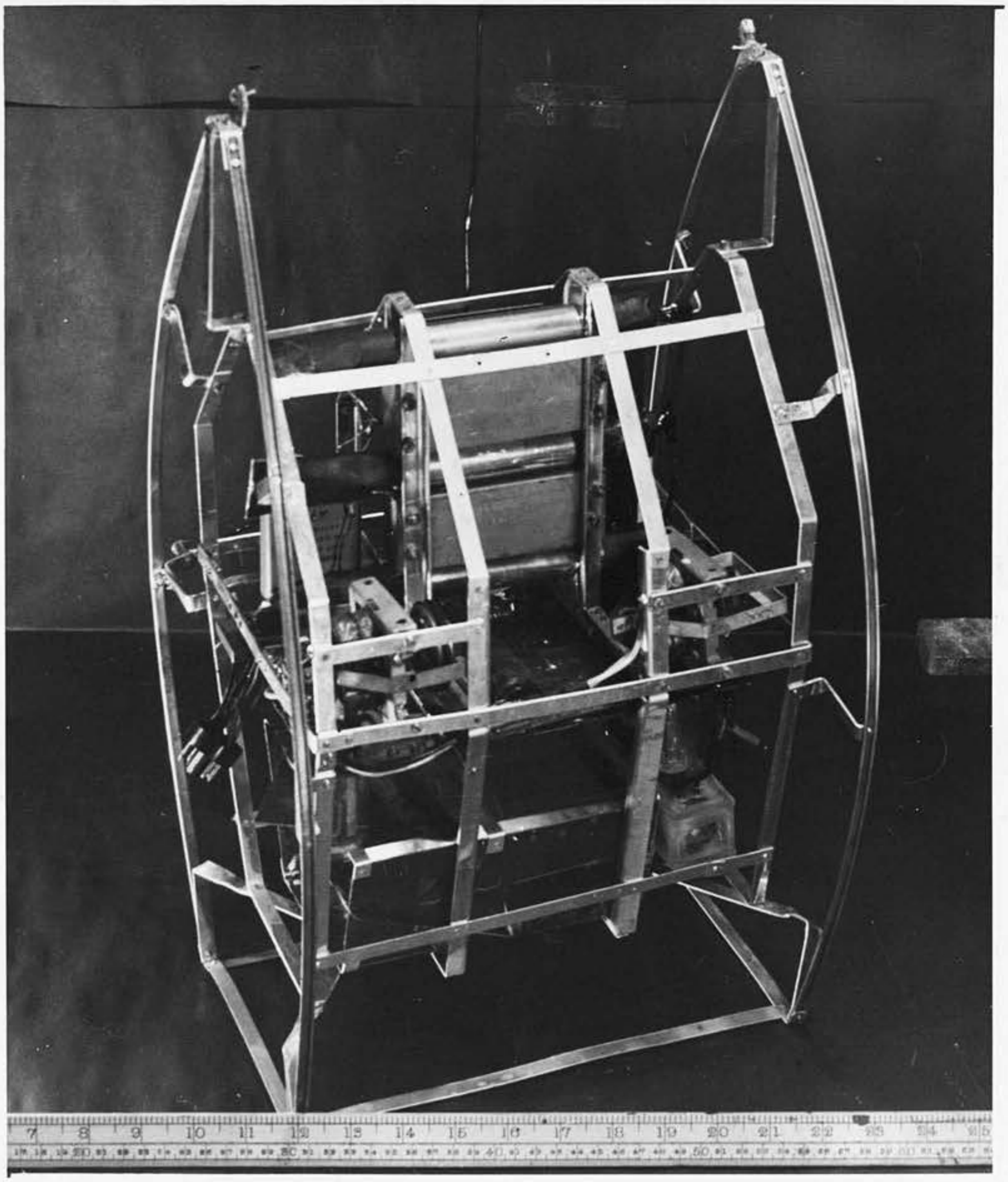

Figure 28. Transmitting equipment - rear view.

strips of aluminium. The four metallised valves in Figure 27 are, from the right, the A.F. oscillator, buffer stage, R.F. oscillator, and coincidence selector V4, respectively. The high frequency tank circuit is immediately below the R.F. valve, with sufficient clearance from surrounding components to avoid loss of radiated power.

A strip of paxolin which carries the subminiature valves of the Rossi circuit and also the blocking condensers C13, 14, 15 is bolted along the main strut behind the R.F. oscillator. The valves, each on a level with the corresponding counter, are visible in Figure 27. The high potential ends of the blocking condensers, the connections to the counter anodes, and the counter load resistors R17, 18, 19, are waxed over to suppress corona discharges.

The high voltage supply unit is mounted in the lower half of the apparatus, with the valves upside down. The smoothing condenser C16 is visible below the counters in Figure 28, which also shows, at the bottom right, the polystyrene box containing the filament battery for the rectifier V8.

The high and low tension batteries are contained in the paxolin box at the bottom of the inner framework.

Average weights for the transmitters used in the various series of flights are given below. These figures do not include the weight of batteries or rigging. In addition, up to 250 gm. of photographic emulsions were carried in flights F1-F8.

Flights	Average weight (gm.)
F1-F8	4,460 (including 2,100 gm. Pb.).
F9-F11	7,560 (" 4,725 " ").
F12-F16	4,660 (" 2,100 " ").
F17	2,165.

Counter telescopes.

The various geometrical arrangements of the counter telescopes, and the physical thicknesses of the lead blocks are shown in Figure 29. The absorbers were cast slightly oversize and then machined to the final dimensions. In all cases the blocks were of length 10.75 cm. which is 0.45 cm. longer than the greatest measured effective counter length. The absorber width was 2.15 cm., except in flights F9-F11 where a width of 4.35 cm. was required for complete screening of the two counters in each tray.

To keep the counter telescopes as nearly as possible vertical during a flight, the lead blocks were mounted centrally in the framework, being bolted to four sectioned aluminium struts. Bent out horizontally below the level of the lowest counter tray, these struts provided the main source of mechanical strength and carried most of the electronic components. The absorbers and struts held the counters in position sufficiently tightly to prevent any slipping, and, although no shock absorbing material was used to pad the mountings, very few counters were broken by the impact on landing at the end of a flight.

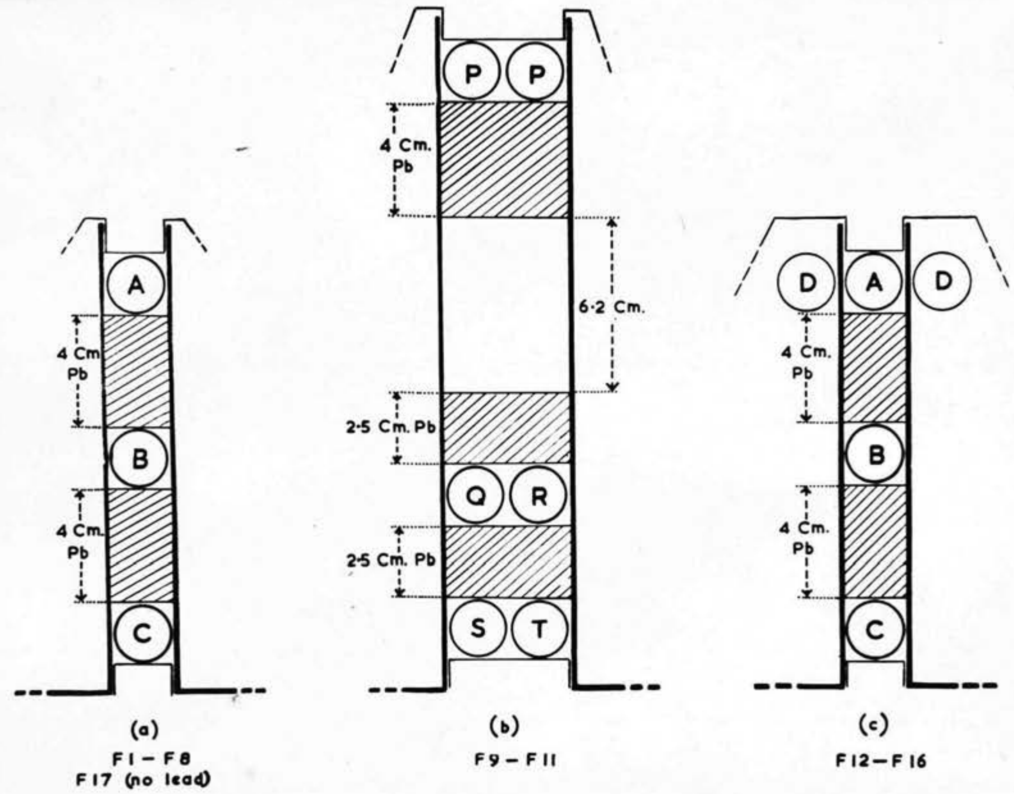

Figure 29. Construction of counter telescopes.

To reduce the effect on the coincidence rates of side showers created in the surrounding material, the counter telescopes were mounted high in the frameworks in relation to the other components. In the equipments used in flights F1-F8 and F12-F17 no major components were positioned above the level of the central counter B. So far as possible the transmitters used in these fourteen flights were identical in design. The additional parallel-connected counters D used in flights F12-F16 were mounted alongside the counters A of the simple threefold vertical telescopes by slipping them through light aluminium rings attached to the main struts. The separation at the closest points between the effective volumes of counter A and counters D was about 3 mm.

The lead blocks were not required in flight F17, but the sāme construction was used, the counters being held in position by light aluminium cross-pieces.

The additional length of the counter telescope in the other three flights F9-F11 made the overall height of the equipment, some 8 cm. greater, but no radical alteration in design was necessary. The framework had to be strengthened somewhat to support the greater weight of absorber.

Short cylinders of black paper were fitted over the anode ends of the counters, so that the anode terminals and connections thereto could be completely covered by pouring molten Apiezon wax "W" into the cylinders. The possibility of corona discharges occurring at these points was eliminated by this procedure, which also served to black-out the anode ends of the counters and to prevent surface leakages.

<u>Cellophane coverings</u>.

A fair measure of temperature constancy was maintained within the balloon-borne equipment by the usual method of covering the framework with a double layer of cellophane. The inner layer was fitted over the main framework of the equipment, and made as leak-proof as possible with adhesive cellophane tape. The outer curved aluminium strips seen in Figures 27 and 28 were cross-braced with thin steel wire, and the whole apparatus then covered by the other cellophane layer. The aerial wire and the negative L.T. connection protruded through both coverings, flaps being left in the cellophane to allow of testing, last-minute adjustments and insertion of the batteries. Transparent cellophane of thickness 0.001 inch and density 0.0034 gm./cm.^{2} was used.

For various reasons it is not possible to achieve an exact balance throughout a flight between heat losses from the gondola and the heat gained from the sun. The most suitable compromise for the present equipments was found by trial and error. In the first Test Flight, to increase the absorption of the sun's radiation, one-quarter of the outer surface area of the inner layer of cellophane was covered with black paper. The internal temperature on this occasion rose steeply after the uppermost cloud layer had been passed. The proportion of black paper was successively reduced in the following two flights, but in both cases the maximum temperatures were rather high. Part of the inner cellophane layer was then covered with aluminium foil to reduce the rate of absorption, the area of reflecting surface being increased until satisfactory results were obtained from flight F2 onward. The area of aluminium foil was then approximately one-sixth of the area of the outer cellophane layer, or just over one-quarter of the inner layer. The aluminium foil also served to prevent direct sunlight falling on either the temperature or the pressure unit.

Positioning of controls.

In designing the balloon-borne equipment provision had to be made for testing of operation during the interval between covering the framework with cellophane and take-off, and to allow of last-minute adjustments. The E.H.T. voltage control resistor R23, and, in later flights, the dropping resistor for the filaments of the Rossi valves had therefore to be accessible through flaps left temporarily in the cellophane. Checking operation of the pulse control circuitry introduced no complication in flights F1-F8 and F17, owing to the frequency of occurrence at ground level of the cosmic ray event under observation. In the remaining flights, however, the extremely low ground level counting rates made impracticable a direct test of correct operation. To reduce the possibility of releasing a faulty equipment in these flights the anodes of the Rossi valves were taken to the common anode load resistor via a terminal board accessible from outside. The anode current of each valve could then be checked, and, for testing purposes, by disconnecting the appropriate valves, simpler coincidences such as ABC and DBC in flights F12-F16 or PQS and PRT in flights F9-F11 could be transmitted.

(ix) Balloons and Rigging.

Balloons.

In routine meteorological soundings, the Kew radio sonde is carried aloft by a single rubber balloon of nominal weight 700 gm. and unstretched diameter about 5 feet. The balloon, inflated to lift about 3 Kgm. in addition to its own weight, provides a free lift of some 1,250 gm., and under these conditions a minimum pressure of 100 mb. is attained on a majority of occasions.

The performance of these 700 gm. balloons at a lesser inflation was investigated during the Test Flights. Two balloons per equipment were used, and in all three flights each balloon was inflated to carry 2 Kgm. The equipments weighed about 2,250 gm., which left a free lift of approximately 875 gm. per balloon. This gave a fairly linear ascent rate of 900-950 feet per minute, and the lowest pressures reached were as follows:

Test Flight 1	34 mb.	(77,000 feet)
" " 2	24 mb.	(84,000 feet)
" " 3	26 mb.	(80,000 feet)

The relative constancy of these figures indicates that they may be taken to represent the average performance of this type of balloon under the particular flight conditions employed. To carry an equipment weighing over 6 Kgm. to equivalent altitudes would therefore have required at least five balloons per flight. Further reduction of the inflation for the attainment of greater altitudes, again increasing the total number of balloons required, would have involved undesirable complexity of the rigging and the launching procedure, in addition to the greater possibility of including defective balloons. For these reasons the 700 gm. balloons were not considered suitable for use with heavy loads, and a more robust type was obtained. Balloons of this latter type have given very satisfactory performances, and have therefore been used in all flights. They are made of thicker rubber than the 700 gm. type; the unstretched diameter is about 6 feet, and the nominal weight is $4\frac{1}{4}$ Kgm.

Because of the combined effects of ultraviolet light from the sun, the intense cold, and atmospheric ozone, balloon rubber perishes rapidly at high levels in the atmosphere, and therefore the free lift given to the balloons on inflation must be sufficient to ensure a reasonably fast rate of ascent if great altitudes are to be attained. For the same reason, there is little to be gained by arranging the free lifts in relation to the load so that the equipment will float at a constant pressure level after the bursting of the first balloon. The duration of a flight, and therefore the statistical accuracy of the cosmic ray data, are decreased as the rates of ascent and descent are increased, but this was not considered to be of prime importance as the statistical accuracy could always be improved by repeating the flight with an identical equipment. The attainment of great altitudes was the first consideration in all flights.

The $4\frac{1}{4}$ Kgm. balloons have proved generally capable, when inflated with hydrogen to a free lift of about 1 Kgm., of carrying a load of 3 Kgm. per balloon to an altitude of over 90,000 feet (about 15 mb.). The rate of ascent is then 950 to 1,050 feet per minute. Two balloons were used in each of the flights F1-F8 and F12-F13, the transmitters weighing 5,740-6,532 gm., and in F17 with a transmitter weighing 3,493 gm. Three balloons were required in flights F9-F11 because of the greater load (about $9\frac{1}{2}$ Kgm.), and in flights F14-F16 owing to the importance of reaching the maximum possible altitude. Details of the loads, inflations, and balloon performances in each flight are given in tabular form in Chapter 4.

Parachute.

Owing to the high probability of all the balloons bursting at the point of maximum altitude, or of any surviving balloons being destroyed by perishing of the rubber during the early stages of the descent, it was necessary as a safety precaution to include a parachute in the balloon rigging. The sizes of the parachutes which were square or hexagonal in shape, were adjusted in accordance with the weight of the transmitter to provide an area of about 1 square foot per 100 gm. of load. On most occasions the velocity of descent by parachute, though rapid in the rarified atmosphere at high altitude, decreased exponentially to under 1,000 feet per minute before reaching ground level. This was satisfactory from the point of view of safety, a significant amount of cosmic ray data could be recorded during the descent, and the transmitter was generally recovered in fairly good condition.

General arrangement of rigging.

The lower part of the rigging was arranged as shown in Figure 30. The equipment is supported in flight by two cords, the lengths of which are adjusted to leave a small amount of slack on the aerial.

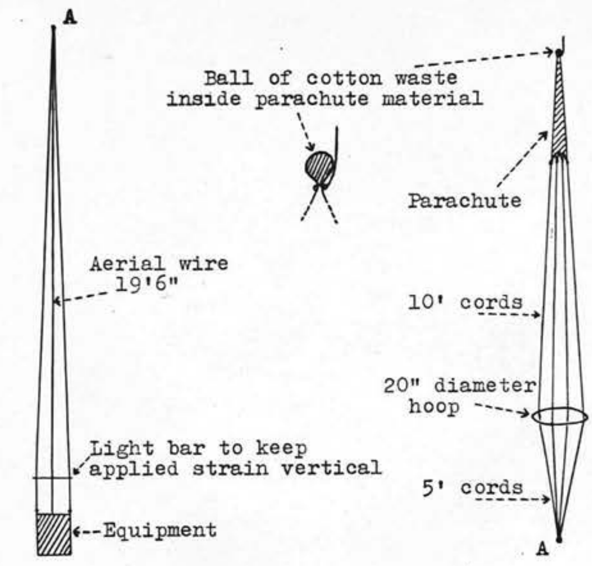

Figure 30. Lower part of rigging.

The top ends of these cords are attached to the parachute strings, which pass round a light hoop, and are tied one to each corner of the parachute. The hoop, 20 inches in diameter, is made of aluminium strip cross-braced with fine steel wire for increased rigidity. Its function is to facilitate opening of the parachute. The upward pull of the balloons is applied to the central point of the parachute in the manner shown in Figure 30.

The arrangements of the upper part of the rigging for a 2-balloon and 3-balloon flight are shown in Figure 31. Long connecting cords are used to reduce the angle of sway during a flight. The balloon

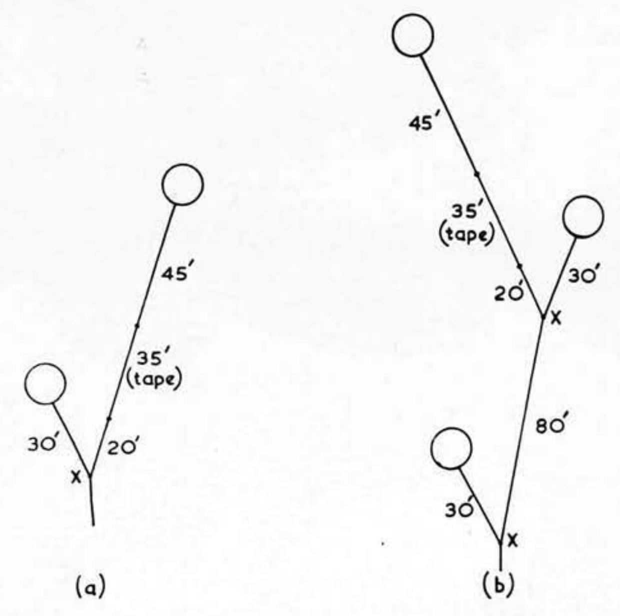

Figure 31. Upper part of rigging.

cords are mainly No. 1 gauge cotton string, but cotton tape, of softer texture than the string, is used where chafing between balloons and rigging may occur. The tape cannot safely withstand the combined pull of two balloons, and is not used to protect the lowest balloon in Figure 31(b). In practice, during the early stages of an ascent at least, it is noticeable that the lower balloons fly well clear of the cords attached to the upper balloons, so the use of tape may be quite an unnecessary precaution.

Release mechanisms.

From flight F11 onwards, release mechanisms designed to jettison the remains of burst balloons were included in the rigging. The need for some such device was apparent in flights F5 and F10 when all balloons burst at maximum altitude, and an abnormally rapid descent rate indicated failure of the parachute to open properly. Although observations in the Arctic[19] have shown that a rubber balloon tends to disintegrate completely rather than merely rip on bursting at high altitude, this failure may have been due to the drag on the centre of the parachute exerted by an unusually large mass of torn rubber adhering to the necks of the balloons.

Figure 32 shows the design of the release mechanisms. They were placed at the points marked "X" in Figure 31, the rigging being hooked together by fitting loops of brass wire attached to the balloon cords into slots cut in aluminium plates. The plates

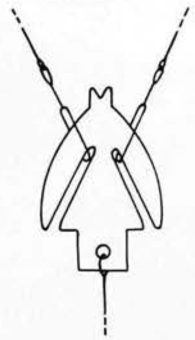

Figure 32. Release mechanism.

are shaped to allow the loops to slip off easily without entangling, on removal of the upward pull of the balloons, while the slots are sufficiently long to minimise the possibility of the balloons coming adrift while intact. The order of bursting of the balloons is immaterial, and so long as one balloon survives the other for a short time it is probable that the debris of the remainder will be jettisoned.

No direct evidence about the efficacy of these devices has been obtained. The danger attached to their use was shown in flight F17, when a balloon came adrift at take-off, but conditions on this occasion were not normal. This balloon, which had been recovered from the previous flight, was being re-used to give extra free lift. It had become stretched to well beyond its normal size, and in a moderate surface wind was not stable in flight.

CHAPTER 3.

THE GROUND STATION.

The ground station was located in the Natural Philosophy Department of Edinburgh University. This site was by no means ideal as regards freedom from electrical interference, and because of the confined nature of the only nearby launching area, a courtyard some 35 yards square surrounded by high buildings, a flight could be safely released only under very calm surface wind conditions. These disadvantages were outweighed, however, by the practical convenience of having the ground station permanently installed in the laboratory.

The receiving equipment is shown in Figure 33, and the various items may be identified from the block diagram in Figure 34 where the same layout is preserved.

The pressure and temperature frequencies transmitted by the radio sonde are measured by the standard method of applying the A.F. output of the receiver to one pair of deflector plates of a cathode ray oscillograph, while the output of a standard variable audio oscillator is fed to the other pair. When the two frequencies are equal a stationary loop appears on the oscillograph screen. During a flight, the transmitted signal alternates between pressure and temperature frequencies, which themselves are slowly varying. At short

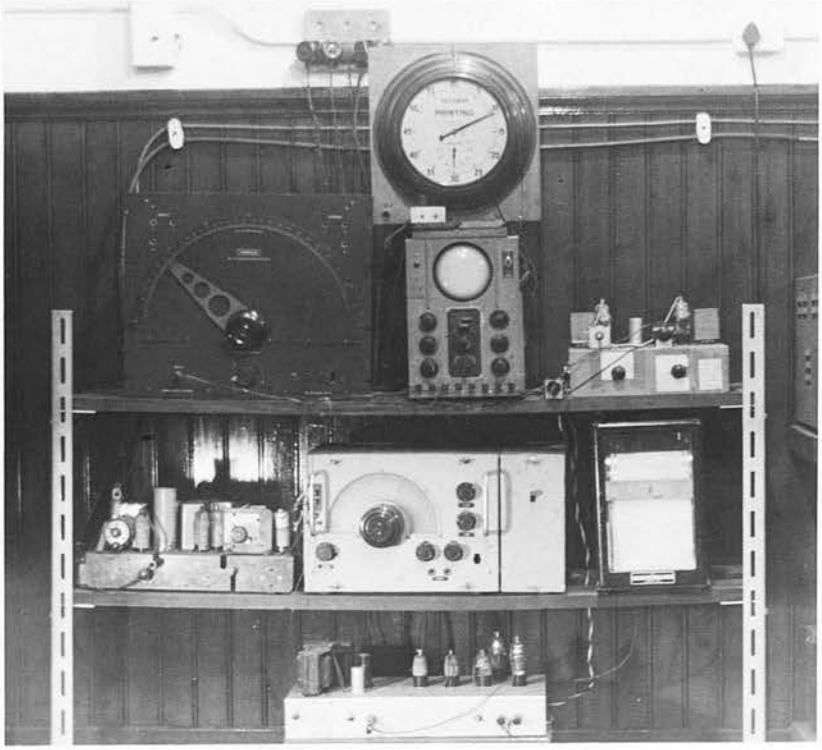

Figure 33. Ground station equipment.

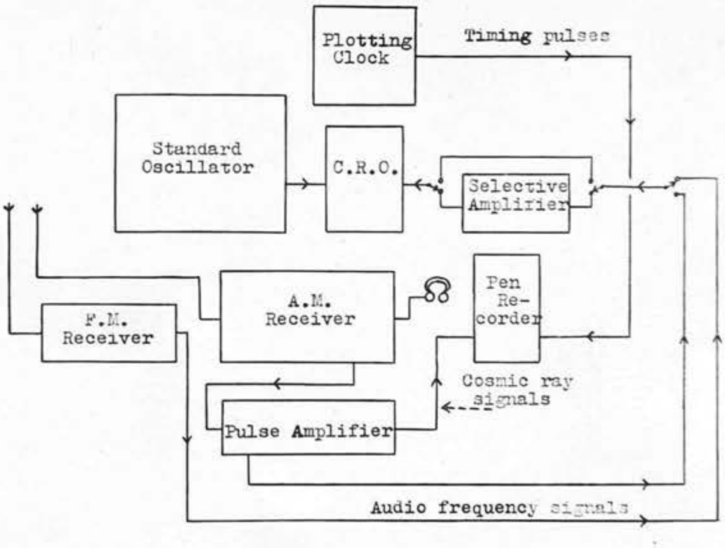

Figure 34. Ground station - block diagram.

time intervals each frequency is measured, to a reading accuracy of 0.1 c./s., by adjustment of the standard oscillator for a stationary loop on the oscillograph, and the pressure and temperature frequency records are manually plotted against time.

The standard oscillator (Muirhead R.C. Oscillator type D-207-A) is the same instrument used in the calibration of the transmitter pressure and temperature units, and therefore its absolute accuracy of frequency is less important than its frequency stability. The absolute accuracy was repeatedly checked by comparison of the oscillator output with the fundamental and harmonic frequencies of various tuning forks, and, with greater accuracy, by counting the peaks of the sinusoidal output waveform over a known interval of time on an electronic scaler. At no time during these tests was the oscillator calibration at any point in the range in error by more than 0.8 c./s., and the stability at all frequencies over a period of three years has been better than 0.3 c./s.

The cosmic ray signals are detected, amplified, and used to operate a pen recorder (Esterline-Angus Graphic Ammeter) which provides a permanent record of the counts. An electrical contact operated by the minute hand of the plotting clock actuates a relay in the pen recorder and produces on the paper chart a succession of timing marks at one minute intervals. This allows the cosmic ray data to be correlated to the pressure and temperature records.

Receiving aerials.

Owing to the orientation of the transmitter aerial during a flight, the transmitted signals are vertically polarized, and best reception on the ground is to be expected with a vertical receiving aerial. For maximum range of low angle pick-up, and minimum level of locally generated interference, the most attractive position for the receiving aerial was on the top of the tower of the Departmental building. This tower, 80 feet high, is surmounted by a 38 foot flagstaff to the top of which runs the heavy copper earth lead of a lightning conductor. Because of space restrictions, a vertical aerial mounted on the tower could not have been separated from the lightning conductor by more than about a quarter wavelength at the carrier frequency in use, and as a result would have possessed undesirable directional properties in a horizontal plane. This difficulty could only be avoided by using the lightning conductor itself as the aerial. A gap, left bridged except during a flight, was therefore cut in the conductor 19'6" from the top, and the isolated section adapted to form an end-fed half-wave dipole. The impedance of this aerial is about 3,000 ohms, and a step-down transformer was necessary to match it to the 80 ohm concentric cable used for the down-lead to the receiving equipment. An auto-transformer in a weather proof container was constructed for the purpose, and the optimum step-down ratio of about 6:1 found by experiment on a radio sonde signal.

The transmitter aerial radiates no power in an end-on direction, and therefore very poor signal strength is to be expected during a flight when the transmitter is almost directly above the ground station. The severity of this effect depends to some extent on the characteristics of the receiving aerial, and it is reduced to a minimum by the use of a receiving aerial which responds efficiently to high angle radiation. It was found during the Test Flights that the vertical dipole, though otherwise satisfactory, did not adequately fulfill this requirement, and a second aerial was therefore erected. This alternative aerial, a centre-fed horizontal half-wave dipole, positioned three-quarters of a wavelength above a flat roof, has maximum response in the vertical direction, and it was used when necessary to provide the high angle pick-up. In this connection its directional property in a horizontal plane is not a serious disadvantage. 80 ohm concentric cable was again used for the down-lead, no matching transformer being required since the aerial was centre-fed.

Receivers.

The main receiver was a sensitive commercial superheterodyne A.M. set, covering the range of frequencies 20-36 Mc./s. A low noise R.F., oscillator and mixer circuit is followed by four stages of I.F. amplification at a frequency of 5 Mc./s. The I.F. bandwidth, with each stage tuned to 5 Mc./s., is 16 Kc./s. at 6 db. down, which is ample for the reception of the 700-1,000 c./s. audio frequencies, and sufficient to preserve the shape of the cosmic ray pulses. The detector and output stages in the A.M. receiver were used only to operate the telephones.

Although the transmitted carrier frequency is primarily amplitude modulated, the simple Hartley R.F. oscillator in the transmitter is deviated in frequency to a marked extent by variations in its control grid bias, and as a result the R.F. output is also frequency modulated by the audio oscillator. This made it possible to use an F.M. superheterodyne set (constructed by Mr. I.M. Hunter, T.R.E.) as an auxiliary receiver. F.M. reception gives a better signal to noise ratio, and the auxiliary receiver was therefore used for measurement of the audio frequencies when external interference was severe. The sensitivity is no better than that of the A.M. set, however, and at low signal strength noise capture of the discriminator stage causes intermittent reception of the desired signal, and makes continual returning of the R.F. circuits necessary. For this reason the F.M. receiver was not used for detection of the cosmic ray signals.

Selective A.F. amplifier.

The audio frequency output of either the A.M. or the F.M. receiver could be passed to a selective amplifier designed to cover the required frequency range in five switched steps. The resonant frequency of the amplifier is determined by two tuned L.C. circuits,

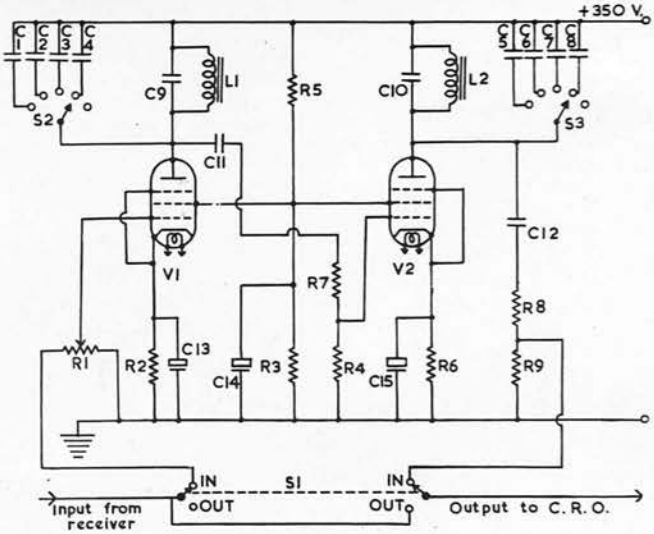

Figure 35. Selective audio amplifier circuit diagram.

various capacitors being connected across the fixed inductors L1 and L2 (Figure 35 *) in the different switch

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* For component values see page 119

positions. The bandwidth is about 130 c./s. for half response, and therefore five suitably spaced centre frequencies give adequate coverage of the important range 720-950 c./s. The response curves shown in Figure 36, in which a gain of unity is taken as the reference level (0 db.) show that a voltage amplification factor of at least 4 (12 db.) is available over the desired frequency range. The improvement to be expected from this amplification, and from the attenuation of all noise frequencies outside the bandwidth of the amplifier, is not entirely realised in practice. Without the selective amplifier, noise appears on the oscillograph trace in the usual form of "mush", and its appearance bears no relation to the audio frequency being measured. When

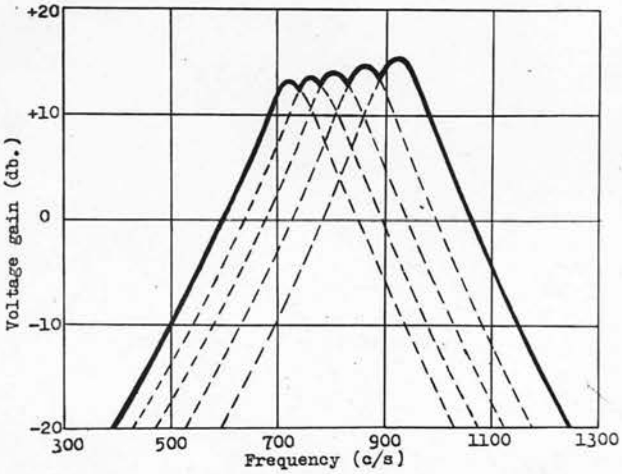

Figure 36. Selective A.F. amplifier response curves.

the amplifier is used, those components of the noise frequencies lying within its pass-band are amplified, and they combine with the output of the standard oscillator to produce moving Lissajous' figures, which make it difficult, at low signal strength, to identify the desired signal. In spite of this limitation on its efficiency under exceptionally noisy conditions, the selective amplifier does in general make an important contribution to the sensitivity of the ground station.

Pulse amplifier.

The function of the pulse amplifier is to detect and amplify the cosmic ray signals, and to pass them to the pen recorder. The detector in the A.M. receiver was found to be relatively insensitive to the quiescent periods in the carrier frequency, and a more efficient response was obtained by feeding the 5 Mc./s. output of the last I.F. stage to a leaky grid detector included in the pulse amplifier chassis. The control grid of this valve (V1 in Figure 37 *) is driven negative by the I.F. signal, and when this signal is quenched during a cosmic ray pulse the control grid rises momentarily to a more positive voltage. Proper choice of the time constant of R1, C1, gives the optimum amplitude of the positive pulse at the control grid, and therefore of the negative pulse at the anode of V1. For convenience the components R1 and C1 are mounted in the A.M.

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* For component values see page 120

receiver, and a short fly-lead carries the I.F. signal direct to the top-cap of V1 in the pulse amplifier immediately below.

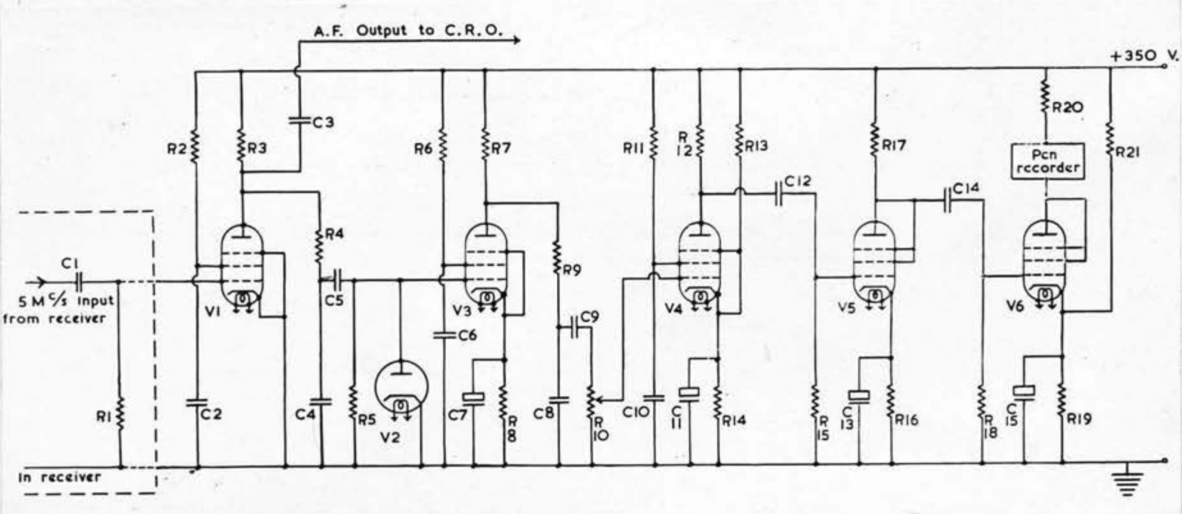

Figure 37. Pulse amplifier circuit diagram.

The negative pulses at V1 anode, of duration 30 milliseconds, must now be amplified, and the 700-1,000 c./s. audio frequency signals appearing at the same point filtered off. The signals are therefore fed through a low-pass filter R4, C4, C5, amplified by V3 which is normally conducting, and again fed through the filter R9, C8, C9. These filters remove the audio component without greatly affecting the pulse shape. The positive pulses from V3 anode are of sufficient amplitude to raise the bias on V4 which is normally cut-off. The value of this bias is the main factor in determining the sensitivity of the pulse amplifier, since it fixes the minimum amplitude of the pulses which are passed to V5 and V6 for further amplification. If the voltage is set too low interfering signals of small amplitude will be amplified and registered by the pen recorder. If the bias is too great the sensitivity to cosmic ray pulses at low signal strength may be seriously reduced. The values of the resistors R13 and R14 forming the cathode bias potentiometer are therefore critical, and are selected to give the best possible compromise. R10 is a pre-set gain control which can be used to reduce the sensitivity of the amplifier if interference is severe.

Suppression of electrical interference is greatly eased by the system adopted for the transmission of the cosmic ray pulses. On receipt of a cosmic ray signal a negative pulse appears at the anode of V1, whereas interfering signals drive V1 control grid more negative and produce positive pulses at V1 anode. When a positive pulse appears at this point, the diode V2 immediately conducts, and the signal is not passed on to V3. Interfering signals are still recorded if an individual pulse or a rapid succession of pulses is of sufficient amplitude to drive V1 control grid considerably below its static bias. After the burst of interference is over the control grid rises sharply to its normal bias, and the effect is equivalent to the onset of a cosmic ray signal. In practice the occurrence of heavy interference is infrequent in the early hours of the morning, when traffic on nearby streets is light, and, except when the transmitter is nearly out of range, the receiver gain can be reduced sufficiently to prevent undesired signals being registered. Any false pulses which do come through the filter circuits are usually of such a nature as to be easily recognisable on the pen recorder trace.

The negative pulses at V4 anode are not of sufficient amplitude to operate the pen recorder, and the inclusion of further stages V5 and V6 is necessary. V5 is normally conducting, and the positive pulses from its anode are fed to V6 which is normally cut-off. The pen recorder forms part of the anode load of V6. V6 is saturated by the positive pulses from V5, except at extremely low signal strength, and so the amplitude of swing of the pen recorder needle is nearly independent of the strength of the carrier signal, and depends mainly on the pulse duration. With the circuit arrangement shown in Figure 37 the recorder needle is deflected by about 3 cm. at each coincidence.

It was found during the Test Flights that operation of the ground equipment would be eased if the sensitivities of the audio frequency and pulse channels were balanced, so that both could be set to a suitable operating level by adjustment of the receiver gain control. When using the output stage in the A.M. receiver to feed the oscillograph, the audio sensitivity was too low, and a more suitable level was obtained by taking the audio frequency signal from the anode of V1 in the pulse amplifier.

Components list for selective audio amplifiers.

(Figure 35)

Code No.	Value (ohms)	Rating	Code No.	Value (μf.)	Type
R1	500K	3	C1	0.01	mica
R2	500	½	C2	0.02	"
R3	100K	1	C3	0.03	"
R4	100K	½	C4	0.05	"
R5	47K	½	C5	0.01	"
R6	500	½	C6	0.02	"
R7	1M	½	C7	0.03	"
R8	150K	½	C8	0.05	"
R9	18K	½	C9	0.07	" } 3%
V1	Brimar 6J7G		C10	0.07	" } tolerance
V2	"	"	C11	0.5	paper tubular
L1	0.36H } mumetal		C12	0.5	" "
L2	" } core		C13	50	electrolytic 12v
			C14	16	" 500v
			C15	50	" 12v

All fixed resistors are of carbon type, 20% tolerance.

Capacitors C1-C8 are of selected values within 20% tolerance range of stated capacitance.

Components list for pulse amplifier (Figure 37).

Code No.	Value (ohms)	Rating	Tolerance (%)	Code No.	Value	Type
R1	100K	½	5	C1	100pf	mica
R2	1.5M	½	20	C2	2µf	paper
R3	280K	½	10	C3	500pf	mica
R4	2M	½	20	C4	.01µf	paper tubular
R5	470K	½	20	C5	.05µf	ditto
R6	2M	½	20	C6	2µf	paper
R7	100K	1	20	C7	50µf	electrolytic
R8	600	½	20	C8	.005µf	mica
R9	470K	½	20	C9	.02µf	paper tubular
R10	2M	3	(var.)	C10	2µf	paper
R11	1.5M	½	20	C11	50µf	electrolytic
R12	100K	½	20	C12	.05µf	paper tubular
R13	30K	5	5(WW)	C13	50µf	electrolytic
R14	5K	1	5(WW)	C14	.05µf	paper tubular
R15	1.5M	½	20	C15	50µf	electrolytic
R16	1K	½	20	V1	Osram	KTZ 73M
R17	6K	1	20	V2	Mullard	EA 50
R18	470K	½	20	V3	Osram	KTZ 73M
R19	10K	1	5(WW)	V4	"	"
R20	50K	1	5(WW)	V5	Brimar	6K7G
R21	60K	3	5(WW)	V6	"	"

CHAPTER 4.

PRESENTATION OF RESULTS.

(i) Reduction of data.

At short intervals during each flight the transmitted pressure and temperature frequencies were measured and plotted against time, so that continuous frequency records could afterwards be drawn. The precision of each measurement was in general sufficiently good for the scatter in the readings to be negligible, and particularly in the case of pressure it was possible to draw a smooth frequency-time curve passing through the majority of the points.

Suitable time intervals having been selected, the necessary control correction was applied to the temperature frequency readings, and by reference to the calibration curve the data were resolved to produce a temperature-time curve for the duration of the flight. The form of this curve varies considerably with atmospheric conditions, but the record shown in Figure 38 exhibits typical features in the initial cooling until the transmitter has reached the clear atmosphere above the uppermost cloud layer, the steady rise in temperature until just after the point of maximum altitude, and the slow drop in temperature during the descent. The final rise in temperature, due to the equipment reaching the warmer

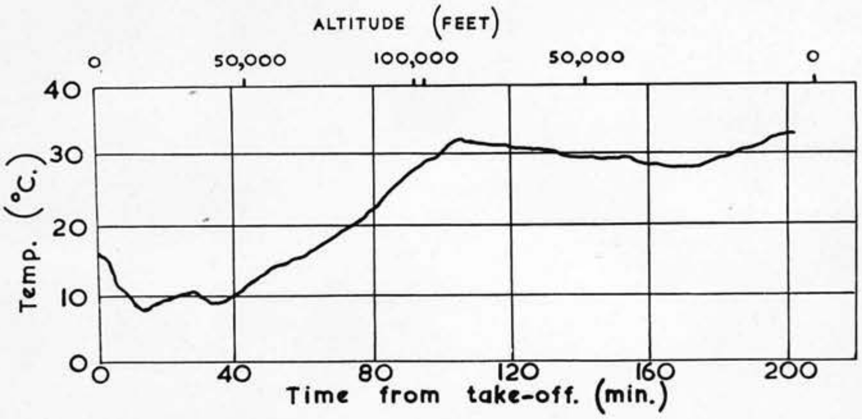

Figure 38. Temperature record flight F4.

air near ground level, is only marked when the descent is made in clear atmospheric conditions.

The pressure frequency record was first corrected for the effect of temperature variations as calculated from the temperature-time graph in conjunction with the temperature correction curves for the pressure unit in use, and then the appropriate control correction was applied. The pressure frequency-time record was then converted to pressure-time. A typical example of this latter curve is shown in Figure 39 (full line). A large-scale graph is required, particularly in the pressure range below 100 mb., to avoid loss of accuracy in the determination of the time spent within a given pressure interval.

Although not essential for the interpretation of the data, an altitude-time curve was drawn for each flight, since it provides an additional check on the consistency of pressure measurements. At the lowest pressures attained, a variation of 1 mb. corresponds to a change in altitude of about 5,000 feet, so any significant casual error in pressure measurement is likely to be detected as an unusual deviation from the normal linearity of the altitude-time curve in this region. Altitudes can be computed by division of the atmosphere (assumed dry) into selected pressure intervals, and calculation of the depth (d) of each of these layers from the relation

$$d = 18{,}400\ (1 + {}^{t}/_{273})\ \log_{10}\ {}^{p_1}/_{p_2}\ \text{metres},$$

where p_1 and p_2 define the pressure interval, and t (°C.) is the mean temperature of the layer. It was convenient however, to use for this purpose the Meteorological Office Aerological Form 2813 from which the depths of standard pressure intervals may be rapidly evaluated for

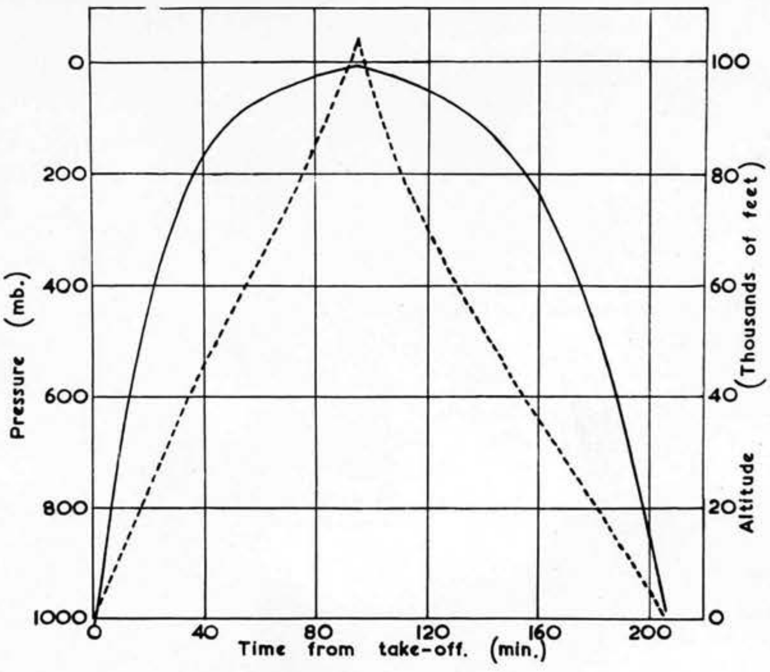

Figure 39. Pressure record (full line) and altitude record (broken line) flight F4.

a wide range of temperatures. The necessary atmospheric temperature information was obtained from the routine observations of the local weather station at Leuchars, with some rather arbitrary extrapolation at constant temperature in the pressure range below about 100 mb. The altitudes of the standard pressure levels, found by summation, were used to provide a pressure-altitude graph by means of which the pressure-time curve for the flight in question could be converted to altitude-time. The altitude record shown in Figure 39 (broken line) is typical of most in that the rate of ascent is linear from ground level until the tropopause is reached at about 200 mb. The ascentional velocity then drops slightly, but regains its former value in the later stages of the ascent.

When the possible error of ± 1 mb. in pressure measurement at high altitudes and the uncertainties in the atmospheric temperature in the same region are both taken into account, it is apparent that the maximum altitudes given later for each flight may be in error by 1,000 feet at 75,000 feet, 3,000 feet at 100,000 feet, or 6,000 feet at 125,000 feet.

Cosmic ray data.

During each flight the cosmic ray coincidences and the timing pulses were automatically recorded on the paper chart of the pen recorder, registration of the data being under practically continuous observation. If at any time electrical interference or fading of the signals became so severe as to make the cosmic ray record unreliable, the doubtful period was so marked on the chart, and afterwards discarded as "dead" time. Except during periods of poor signal strength, coincidences were audible in the telephones, and it was possible to detect aurally the occurrence of two or more counts within the period of swing of the pen recorder needle. By monitoring the cosmic ray record in this way the majority of spurious counts were eliminated, and it is estimated that fewer than 1 per cent of the coincidences recorded outside the discarded "dead" periods can be classified as doubtful. Sections of the cosmic ray record record in flight F5 are shown in Figure 40.

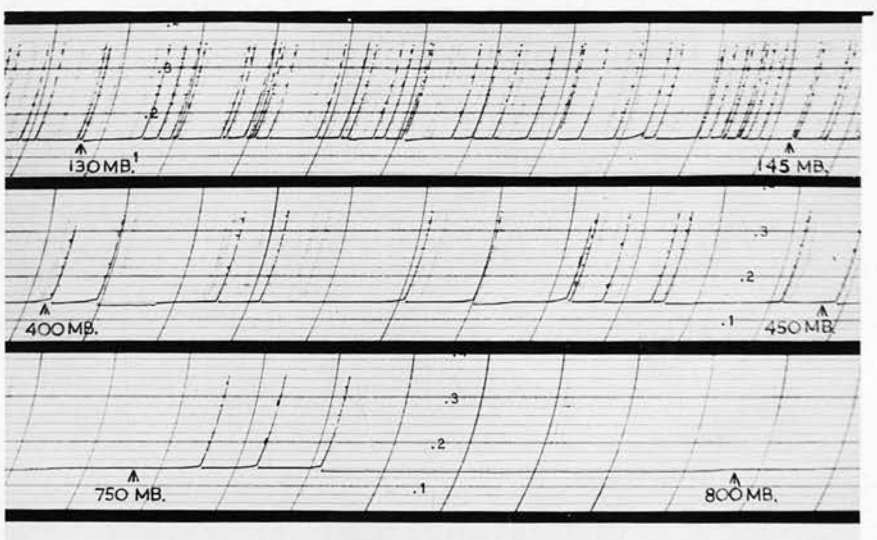

Figure 40. Sections of cosmic ray data record flight F5.

The slight smudging of the record, and the apparent "ghost" pulses which are actually on the reverse side of the chart, are due to the recorder being run at a fast rate and rewinding the paper before the ink is properly dry. The minute timing pulses are not shown in Figure 40, but the curved graduation lines correspond approximately to 15 second intervals.

On completion of a flight, the minute interval timing pulses were serially numbered from take-off, and by reference to the pressure-time curve for the flight in question, the cosmic ray record was divided into selected pressure intervals. The choice of these intervals was quite arbitrary. Equal intervals of altitude, and therefore nearly constant intervals of time, are most suitable for the statistical analysis of the results for a single flight, and correspond to approximately logarithmic intervals of pressure. However, when results extending over the unusually wide pressure range 3.6 - 1,000 mb. are presented graphically on a linear scale of pressure in conformity with normal practice, the distribution of pressure intervals is unsatisfactory, and leads either to a congestion of points in the low pressure region or to a dearth of points at higher pressures. In the present case, the variation in minimum pressures attained in each flight, and the distribution in pressure levels at which radio communication was lost, to a large extent prevent equal time intervals being obtained for the consolidated results of the series, and, in the results for flights F1-F8, since too much emphasis is thrown on flight F7 which reached the greatest altitude, the points at very low pressures have poor statistical weight. The pressure intervals were therefore chosen to give a reasonable distribution of points on the coincidence rate-pressure graphs when plotted linearly.

In the tables of cosmic ray data which follow, are given the number of counts in each pressure interval, and the corresponding effective counting times after deduction of any "dead" time. Except where otherwise stated loss of cosmic ray signals was due to the transmitter passing out of range.

No information was obtained in flight F3, take-off having been attempted in unusually boisterous surface wind conditions, and the aerial wire snapping near the tank coil end at the moment of release. This transmitter was recovered from Prestwick, Ayrshire. From the time of flight it is estimated that an altitude of at least 90,000 feet was attained.

(ii) Flights F1-F8.

Flight histories.

Flight	F1	F2	F3	F4
Date	30/3/49	21/6/49	8/7/49	23/7/49
Total load (gm.)	5,740	5,940	5,916	6,001
No. of balloons	2	2	2	2
Free lift per balloon (gm.)	1,000	980	992	1,000
Average rate of ascent (ft./min.)	1,000	1,000	-	1,090
Minimum pressure (mb.)	8	33	-	10
Maximum altitude (ft.)	101,000	77,000	-	105,000
Average rate of descent (ft./min.)	1,360	740	-	955
Descent by -	?	Balloon	Balloon	Balloon
Max. temp. (°C.)	48	34	-	33
Min. temp. (°C.)	13	14	-	8
Temp. at maximum altitude (°C.)	48	28	-	30
Pressure control correction (c./s.)	0.1	0.8	0.2	0.6

Flight	F5	F6	F7	F8
Date	23/8/49	27/9/49	11/10/49	1/3/50
Total load (gm.)	6,288	6,130	6,211	6,319
No. of balloons	2	2	2	2
Free lift per balloon (gm.)	856	885	845	790
Average* rate of ascent (ft./min.)	940	1,060	1,070	1,000
Minimum pressure (mb.)	16	10	3.6	45
Maximum altitude (ft.)	94,000	102,000	124,000	70,000
Average* rate of descent (ft./min.)	3,320	1,240	1,470	1,220
Descent by -	Parachute	Parachute	?	?
Max. temp. (°C)	28	32	36	19
Min. temp. (°C)	11	15	7	11
Temp. at maximum altitude (°C)	28	31	34	18
Pressure control correction (c./s.)	0.4	0.0	1.0	0.6

* Where no indication of any discontinuity is given, ascent and descent rates may be assumed approximately linear.

Cosmic ray data - flight F1.

Pressure interval (mb.)	Ascent Time* (min.)	Ascent Counts	Descent Time* (min.)	Descent Counts	Total Time* (min.)	Total Counts
1,000-900	2.50	1	-	-	2.50	1
900-800	3.33	3	-	-	3.33	3
800-700	3.50	6	-	-	3.50	6
700-600	3.67	8	-	-	3.67	8
600-500	4.08	12	-	-	4.08	12
500-400	4.58	21	-	-	4.58	21
400-350	2.50	5	-	-	2.50	5
350-300	3.00	21	-	-	3.00	21
300-250	3.25	22	-	-	3.25	22
250-218	3.00	26	-	-	3.00	26
			Ground level test		1,200	1,148

Transmission of cosmic ray data stopped 34.5 minutes after take-off, at a pressure of 218 mb., probably due to failure of the E.H.T. rectifier filament battery. Transmitter not recovered.

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* Times are calculated to nearest 5 sec. (0.083 min.).

Cosmic ray data - flight F2.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	2.50	4	-	-	2.50	4
900-800	2.92	3	-	-	2.92	3
800-700	3.58	7	-	-	3.58	7
700-600	3.58	16	-	-	3.58	16
600-500	3.92	15	-	-	3.92	15
500-400	4.58	27	-	-	4.58	27
400-350	2.50	16	-	-	2.50	16
350-300	2.75	14	-	-	2.75	14
300-250	2.83	21	-	-	2.83	21
250-200	3.67	35	-	-	3.67	35
200-150	5.67	78	-	-	5.67	78
150-100	9.67	161	-	-	9.67	161
100-80	5.42	81	-	-	5.42	81
80-60	7.42	129	-	-	7.42	129
60-43	5.83	100	-	-	5.83	100
			Ground level test		1,260	1,207

Transmission of cosmic ray data stopped 67.5 min. after take-off, at a pressure of 43 mb., due to failure of the E.H.T. rectifier filament battery.

Landing point - Cardrona, Peebleshire.

Cosmic ray data - flight F4.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	2.75	5	-	-	2.75	5
900-800	3.08	4	-	-	3.08	4
800-700	3.50	3	-	-	3.50	3
700-600	4.17	13	-	-	4.17	13
600-500	4.33	13	5.58	10	9.92	23
500-400	3.17	18	6.75	26	9.92	44
400-350	2.58	11	4.00	28	6.58	39
350-300	2.83	19	4.67	35	7.50	54
300-250	3.17	27	5.67	34	8.84	61
250-200	3.58	28	6.75	71	10.33	99
200-150	5.00	63	7.42	96	12.42	159
150-100	8.67	132	11.00	134	19.67	266
100-80	5.08	90	5.58	97	10.67	187
80-60	6.92	129	6.33	119	13.25	248
60-40	9.50	173	8.25	139	17.75	312
40-20	13.00	240	13.00	237	26.00	477
20-10	11.67	224	7.83	147	19.50	371
10-9.9	0.17	2	0.17	4	0.33	6
			Ground level test		1,401	1,341

Landing point - Duns, Berwickshire.

Cosmic ray data - flight F5.

Pressure interval (mb.)	Ascent Time (min.)	Counts	Descent Time (min.)	Counts	Total Time (min.)	Counts
1,000-900	3.33	4	-	-	3.33	4
900-800	3.25	3	-	-	3.25	3
800-700	3.58	4	-	-	3.58	4
700-600	3.92	10	-	-	3.92	10
600-500	4.25	13	-	-	4.25	13
500-400	4.67	23	-	-	4.67	23
400-350	2.50	17	-	-	2.50	17
350-300	2.67	19	-	-	2.67	19
300-250	2.92	22	-	-	2.92	22
250-200	2.58	22	-	-	2.58	22
200-150	4.83	47	-	-	4.83	47
150-100	8.17	144	-	-	8.17	144
100-80	4.75	88	-	-	4.75	88
80-60	4.92	92	-	-	4.92	92
60-40	4.00	93	-	-	4.00	93
40-20	-	-	-	-	-	-
20-16	6.17	129	-	-	6.17	129
			Ground level test		995	950

Reception was intermittent in the latter stages of the ascent, and the descent was too rapid for reliable pressure measurements.

Landing point - Balerno, Midlothian.

Cosmic ray data - flight F6.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	3.50	4	-	-	3.50	4
900-800	3.33	6	-	-	3.33	6
800-700	3.58	5	-	-	3.58	5
700-600	3.58	9	-	-	3.58	9
600-500	4.08	10	2.92	10	7.00	20
500-400	4.50	15	4.83	22	9.33	37
400-350	2.42	11	3.25	17	5.67	28
350-300	2.83	21	3.50	26	6.33	47
300-250	3.25	26	4.08	42	7.33	68
250-200	3.58	40	4.75	45	8.33	85
200-150	4.92	71	6.08	91	11.00	162
150-100	7.00	119	7.33	122	14.33	241
100-80	4.17	71	4.50	93	8.67	164
80-60	5.75	129	5.08	90	10.83	219
60-40	8.25	185	4.50	99	12.75	284
40-20	14.08	310	8.83	168	22.93	478
20-10	16.50	377	7.17	141	23.67	518
			Ground level test		1,190	1,123

Landing point - Chirnside, Berwickshire.

Cosmic ray data -flight F7.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	3.33	4	-	-	3.33	4
900-800	3.50	5	-	-	3.50	5
800-700	3.67	6	-	-	3.67	6
700-600	4.08	12	-	-	4.08	12
600-500	4.50	18	-	-	4.50	18
500-400	5.25	24	-	-	5.25	24
400-350	3.17	22	-	-	3.17	22
350-300	3.25	21	-	-	3.25	21
300-250	3.42	34	-	-	3.42	34
250-200	4.17	52	-	-	4.17	52
200-150	5.58	81	-	-	5.58	81
150-100	9.33	164	-	-	9.33	164
100-80	5.17	99	-	-	5.17	99
80-60	5.42	110	-	-	5.42	110
60-40	8.83	190	-	-	8.83	190
40-20	13.17	310	13.83	318	27.00	628
20-10	11.67	254	9.75	216	21.42	470
10-3.6	15.17	350	9.42	202	24.58	552
Ground level test					1,440	1,396

Transmitter not recovered.

Cosmic ray data - flight F8.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	3.33	4	-	-	3.33	4
900-800	3.42	3	-	-	3.42	3
800-700	3.75	7	-	-	3.75	7
700-600	4.17	14	-	-	4.17	14
600-500	4.42	14	-	-	4.42	14
500-400	5.08	25	-	-	5.08	25
400-350	2.83	14	2.42	14	5.25	28
350-300	2.83	22	2.25	15	5.08	37
300-250	3.17	29	3.42	38	6.58	67
250-200	3.67	52	4.33	53	8.00	105
200-150	5.75	65	5.17	61	10.93	126
150-100	8.33	154	6.00	107	14.33	261
100-80	5.67	114	3.08	68	8.75	182
80-60	6.17	120	4.17	87	10.33	207
60-45	7.67	166	3.17	60	10.83	226
Ground level test					1,170	1,117

Landing point - Allendale, Northumberland.

<u>Consolidated cosmic ray data - flights F1-F8.</u>

Pressure interval (mb.)	Ascents Time (min.)	Ascents Counts	Descents Time (min.)	Descents Counts	Total Time (min.)	Total Counts
1,000-900	21.25	26	-	-	21.25	26
900-800	22.83	27	-	-	22.83	27
800-700	25.17	38	-	-	25.17	38
700-600	27.17	82	-	-	27.17	82
600-500	29.58	95	8.50	20	38.08	115
500-400	31.83	153	11.58	48	43.42	201
400-350	18.50	96	9.67	59	28.17	155
350-300	20.17	137	10.42	76	30.58	213
300-250	22.00	181	13.17	114	35.17	295
250-200	24.25	255	15.83	169	40.08	424
200-150	31.75	405	18.67	248	50.42	653
150-100	51.17	874	24.33	363	75.50	1,237
100-80	30.25	543	13.17	258	43.42	801
80-60	36.58	709	15.58	296	52.17	1,005
60-40	44.08	907	15.92	298	60.00	1,205
40-20	40.25	860	35.67	723	75.92	1,583
20-10	46.00	984	24.75	504	70.75	1,488
10-3.6	15.33	352	9.58	206	24.92	558
Ground level tests					8,656	8,282

<u>Calculation of counting rates - flights F1-F8.</u>

In addition to the depression of the counting rates by a constant factor (shown to be just under 0.5 per cent for a triple coincidence telescope) due to the intrinsic inefficiency of the counters, three further corrections have to be considered in calculating the true counting rates from the observed data.

Firstly, allowance must be made for the loss of triple coincidences owing to the finite recovery time t_1 of the counters. This reduces their individual efficiencies by a factor $e^{-N_1 t_1}$, where N_1 is the background counting rate of a single counter. The magnitude of this correction varies with the intensity of the total omnidirectional cosmic radiation, which, in the 40 mb. pressure region, reaches a maximum value of some 200 times the ground level intensity. At ground level the counters in use have a background rate of about 25 counts per minute due to cosmic radiation, and so the maximum value of N_1 is about 5,000 counts per minute. The effective recovery time t_1 has been shown to be 75 microseconds, giving a maximum correction of just over 0.6 per cent per counter, and therefore of 1.9 per cent for the three counter telescope. In computing this correction for the various pressure intervals, the values of N_1 have been taken from the results obtained by Bowen, Millikan and

and Neher[20] at geomagnetic latitude 60°N.

The second correction, of opposite sign to all the others, takes into account the effect of accidental triple coincidences. As mentioned before, the rate of occurrence N_{123} of accidental triple coincidences is given sufficiently accurately by the relation

$$N_{123} = 3N_1N_2N_3t_2^2 ,$$

where N_1, N_2 and N_3 are the counting rates of the individual counters, and t_2 is the resolving time of the associated circuitry. Taking $N_1 = N_2 = N_3 = 5,000$ counts per minute as a maximum, and $t_2 = 5$ microseconds as found by experiment, the maximum rate of accidental coincidences is of the order of 1 count per 6 hours, so the contribution to the counting rates from this source is negligible.

The third correction is necessary to allow for counting losses occurring during the 30 millisecond period t_3 of the flip-flop cycle. This insensitive period reduces the coincidence rate N by a factor e^{-Nt_3}. In flights F1-F8 the value of N varied from just under 1 count per minute at ground level, to just over 22 counts per minute at the highest altitudes reached. The correction is therefore negligible at ground level, but increases to 1.1 per cent at low pressures.

In the table which follows are shown the consolidated counting rates for the seven effective flights of this series, together with the mean pressure levels in the selected intervals when weighted with respect to time. The standard statistical deviations and the total percentage correction to be added to each counting rate are also listed, and it will be observed that at low pressures these quantities are of the same order of magnitude.

The results, with corrections applied, are presented graphically in Figure 41.

Consolidated counting rates - flights F1-F8.

Pressure interval (mb.)	Mean weighted pressure (mb.)	Observed counting rate (counts/min.)	Standard statistical deviation (counts/min.)	Total Correction (%)
1,000-900	949	1.22	0.24	0.5
900-800	849	1.18	0.23	0.5
800-700	748	1.51	0.25	0.6
700-600	648	3.02	0.33	0.8
600-500	548	3.02	0.28	0.8
500-400	448	4.63	0.33	0.9
400-350	374	5.50	0.44	1.0
350-300	324	6.97	0.48	1.2
300-250	274	8.39	0.49	1.4
250-200	224	10.58	0.51	1.9
200-150	173	12.95	0.51	2.3
150-100	122.5	16.38	0.48	2.7
100-80	89.5	18.45	0.65	3.1
80-60	69.3	19.26	0.61	3.2
60-40	49.1	20.08	0.58	3.4
40-20	28.3	20.85	0.52	3.4
20-10	14.4	21.03	0.55	3.3
10-3.6	6.0	22.39	0.95	3.3
Ground level	1,007	0.957	0.011	0.5

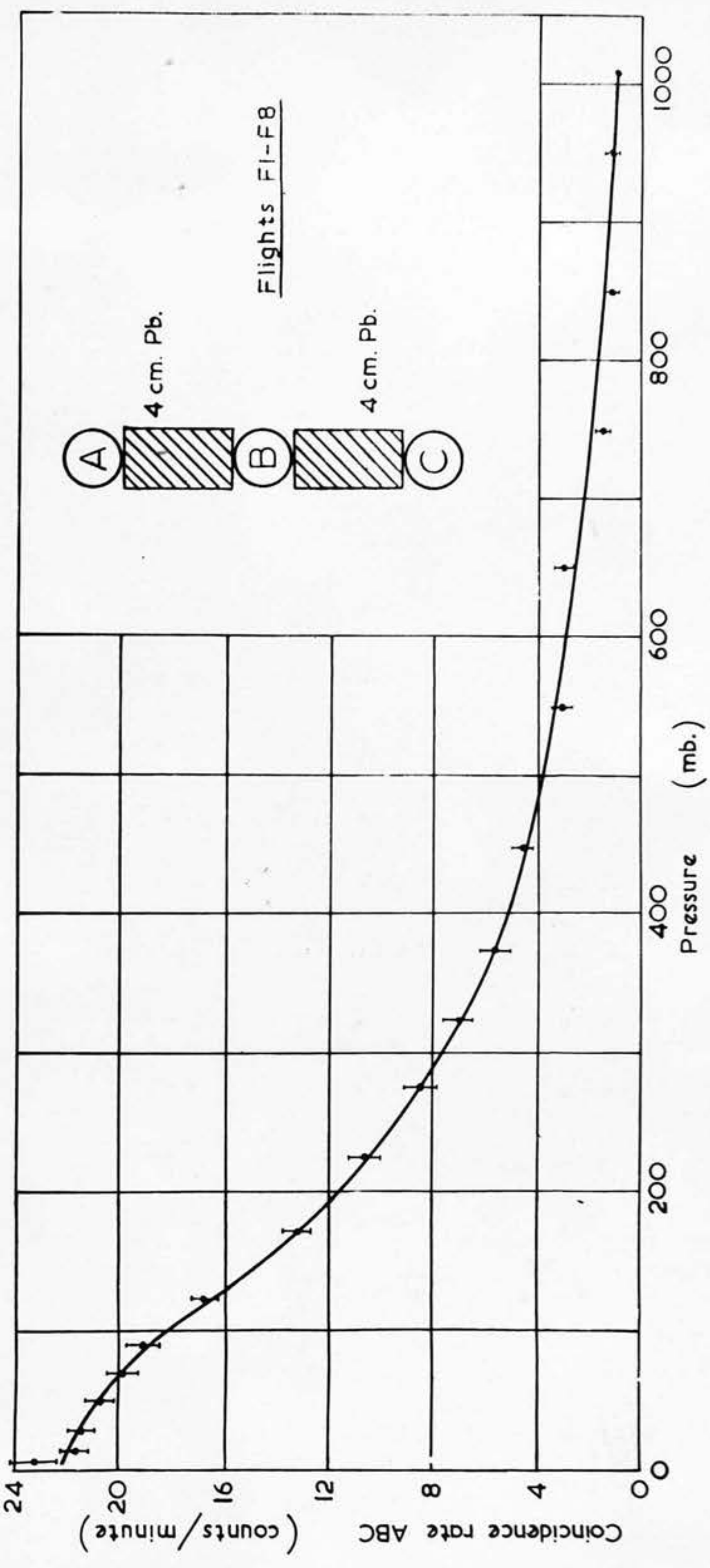

Figure 41. Coincidence rate-pressure curve, flights F1-F8.

(iii) Flights F9-F11.

Flight histories.

Flight	F9	F10	F11
Date	8 May 50	2 June 50	22 Oct 50
Total load (gm.)	9,447	9,578	9,493
Number of balloons	3	3	3
Free lift per balloon (gm.)	800	760	786
Average rate of ascent (ft./min.)	1,080	830	1,047
Minimum pressure (mb.)	8	16	7
Maximum altitude (ft.)	108,000	93,000	109,000
Average rate of descent (ft./min.)	1,153	2,770	1,400
Descent by -	?	Parachute	Balloon
Maximum temp. (°C.)	33	29	38
Minimum temp. (°C.)	10	6	7
Temp. at maximum altitude (°C.)	32	28	35
Pressure control correction (c./s.)	0.6	0.9	0.7

Cosmic ray data - flight F9.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	3.83	0	-	-	3.83	0
900-800	3.42	0	-	-	3.42	0
800-700	3.58	0	-	-	3.58	0
700-600	3.67	0	-	-	3.67	0
600-500	4.25	0	-	-	4.25	0
500-400	4.58	2	6.00	0	10.58	2
400-350	2.67	1	3.75	1	6.42	2
350-300	2.75	0	-	-	2.75	0
300-250	3.00	0	-	-	3.00	0
250-200	3.83	1	6.08	3	9.92	4
200-150	4.50	2	6.92	5	11.42	7
150-100	7.92	5	8.92	7	16.83	12
100-80	4.33	1	4.25	5	8.58	6
80-60	6.08	4	5.33	7	11.42	11
60-40	8.42	12	7.08	15	15.50	27
40-20	13.42	16	10.33	15	23.75	31
20-10	13.17	25	8.83	10	22.00	35
10-8	5.00	8	2.42	6	7.42	14

Landing point - Hurlford, Ayrshire.

Cosmic ray data - flight F10.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	3.33	0	-	-	3.33	0
900-800	3.25	0	-	-	3.25	0
800-700	3.58	0	-	-	3.58	0
700-600	3.75	0	2.50	0	6.25	0
600-500	4.42	0	2.92	0	7.33	0
500-400	5.67	2	3.00	0	8.67	2
400-350	2.92	2	1.50	0	4.42	2
350-300	3.17	0	1.75	1	4.92	1
300-250	3.75	0	2.00	0	5.75	0
250-200	5.00	2	2.08	2	7.08	4
200-150	7.42	2	2.42	1	9.83	3
150-100	12.00	9	2.67	3	14.67	12
100-80	3.67	1	1.08	0	4.75	1
80-60	10.67	19	1.67	4	12.33	23
60-40	10.83	17	2.00	2	12.83	19
40-20	20.17	40	2.83	7	23.00	47
20-16	8.17	18	-	-	8.17	18

Initial descent rate too rapid for reliable pressure measurements.

Landing point - Colinsburgh, Fife.

Cosmic ray data -flight F11.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	3.83	0	2.50	0	6.33	0
900-800	3.17	0	2.83	0	6.00	0
800-700	3.75	0	3.33	0	7.08	0
700-600	4.08	0	3.50	0	7.58	0
600-500	4.33	0	3.75	0	8.08	0
500-400	5.00	0	4.25	0	9.25	0
400-350	2.08	0	2.75	0	4.83	0
350-300	3.50	0	3.08	0	6.58	0
300-250	3.42	1	3.33	0	6.75	1
250-200	4.00	4	4.08	2	8.08	6
200-150	5.08	5	4.75	3	9.83	8
150-100	7.50	7	5.83	1	13.33	8
100-80	4.50	5	2.83	3	7.33	8
80-60	5.75	9	3.50	4	9.25	13
60-40	8.17	11	4.42	4	12.58	15
40-20	14.50	31	5.08	8	19.58	39
20-10	12.58	27	9.17	20	21.75	47
10-7	8.08	18	8.00	20	16.08	38

Initial descent on two balloons, second balloon bursting at 50 mb.

Transmitter picked up by trawler in Firth of Forth.

<u>Consolidated Cosmic ray data - flights F9-F11.</u>

Pressure interval (mb.)	Ascents Time (min.)	Ascents Counts	Descents Time (min.)	Descents Counts	Total Time (min.)	Total Counts
1,000-900	11.00	0	2.50	0	13.50	0
900-800	9.83	0	2.83	0	12.67	0
800-700	10.58	0	3.33	0	13.92	0
700-600	11.50	0	6.00	0	17.50	0
600-500	13.00	0	6.67	0	19.67	0
500-400	15.25	4	13.25	0	28.50	4
400-350	7.67	3	8.00	1	15.67	4
350-300	9.42	0	4.83	1	14.25	1
300-250	10.17	1	5.33	0	15.50	1
250-200	12.83	7	12.25	7	25.08	14
200-150	17.00	9	14.08	9	31.08	18
150-100	27.42	21	17.42	11	44.83	32
100-80	12.50	7	8.17	8	20.67	15
80-60	22.50	32	10.50	15	33.00	47
60-40	27.42	40	13.50	21	40.92	61
40-20	48.08	87	18.25	30	66.33	117
20-10	33.92	70	18.00	30	51.92	100
10-7	13.08	26	10.42	26	23.50	52
Ground level test - F11 equipment only					5,760	23

Calculation of counting rates - flights F9-F11.

Owing to the greater multiplicity of the genuine coincidences observed in this series of flights, the correction due to accidental counts is not significant.

Because of the low coincidence rate the loss of counts during the inactive period of the flip-flop cycle is never greater than 0.1 per cent.

The correction due to the inherent inefficiency of the counters is, to a first approximation, about 0.8 per cent. This correction, already negligible in view of the statistical uncertainties of the data, is probably too high since many of the observed events will have been large showers with several particles passing simultaneously through some of the counters.

The only appreciable correction is that required to offset the loss of coincidences during the counter recovery period. Calculated as before, the maximum loss of counts is about 3.1 per cent in the region of 40 mb. atmospheric pressure.

With the pressure intervals selected, the statistical deviations at high altitude are of the order of 10 per cent. The maximum total correction of 4 per cent is therefore barely significant.

The corrected results of flights F9-F11 are shown graphically in Figure 42.

Consolidated counting rates - flights F9-F11.

Pressure interval (mb.)	Mean Weighted pressure (mb.)	Observed counting rate (Counts/min.)	Standard statistical deviation (Counts/min.)	Total Correction(%)
1,000-900	949	0	-	0.8
900-800	849	0	-	0.8
800-700	748	0	-	0.9
700-600	648	0	-	0.9
600-500	548	0	-	1.0
500-400	448	0.14	0.07	1.1
400-350	374	0.25	0.13	1.3
350-300	324	0.07	0.07	1.5
300-250	274	0.07	0.07	1.7
250-200	224	0.56	0.15	2.0
200-150	173	0.58	0.14	2.4
150-100	122.5	0.71	0.13	3.0
100-80	89.5	0.73	0.19	3.5
80-60	69.3	1.42	0.21	3.8
60-40	49.1	1.49	0.19	3.9
40-20	28.3	1.76	0.16	4.0
20-10	14.7	1.93	0.19	3.9
10-7	8.7	2.21	0.31	3.8
Ground level	1,004	0.004	0.001	0.8

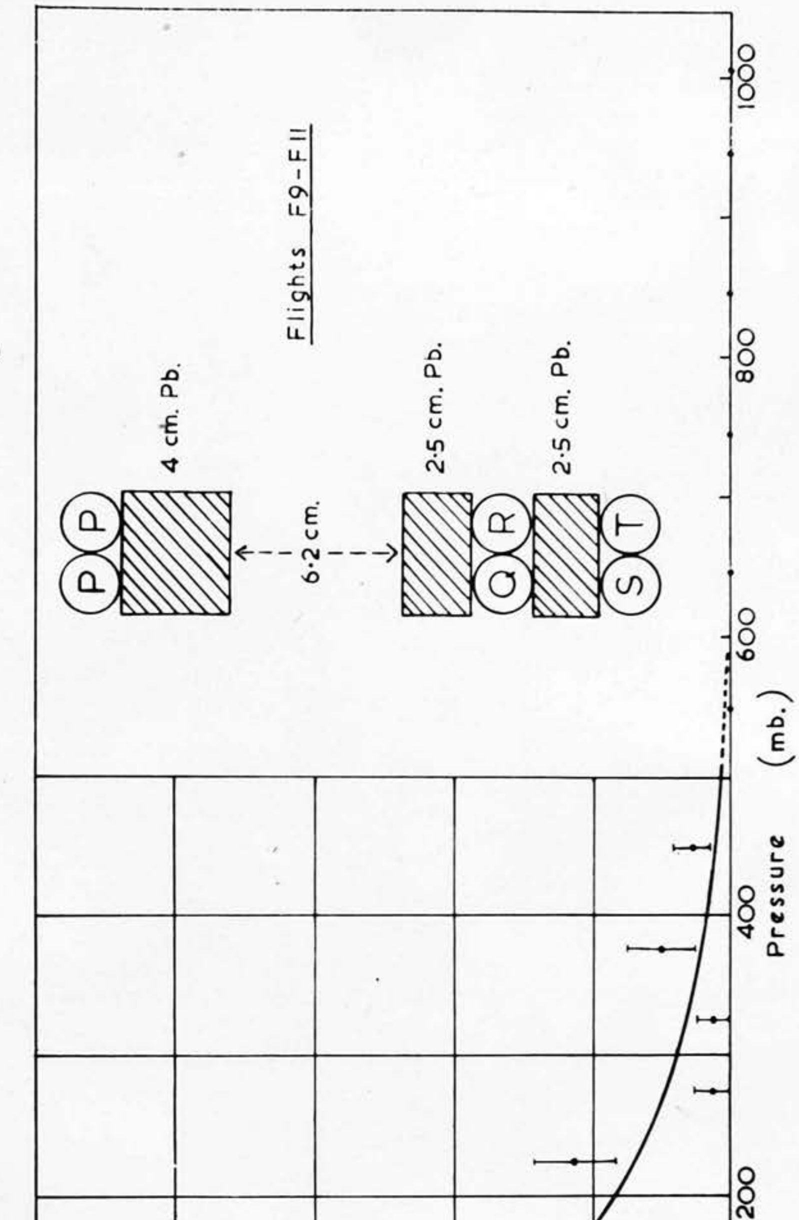

Figure 42. Coincidence rate – pressure curve, flights F9-F11.

(iv) Flights F12-F16.

Flight	F12	F13	F14
Date	25 Oct 50	28 Jan 51	1 Jun 51
Total load (gm.)	6,352	6,159	6,403
Number of balloons	2	2	3
Free lift per balloon (gm.)	874	870	866
Average rate of ascent (ft./min.)	1,032	1,000	525
Minimum pressure (mb.)	12	14	16
Maximum altitude (ft.)	98,000	94,000	92,000
Average rate of descent (ft./min.)	1,100	892	1,080
Descent by -	?	?	Balloon
Maximum temp. (°C.)	36	28	36
Minimum temp. (°C.)	5	4	8
Temp. at maximum altitude (°C.)	28	23	36
Pressure control correction (c./s.)	0.4	0.6	1.0

Flight	F15	F16
Date	9 Sep 51	13 Apr 52
Total load (gm.)	6,480	6,485
Number of balloons	3	3
Free lift per balloon (gm.)	840	1,540
Average rate of ascent (ft./min.)	610	930
Minimum pressure (mb.)	16	14
Maximum altitude (ft.)	91,000	95,000
Average rate of descent (ft./min.)	1,000	900
Descent by -	Balloon	Balloon
Maximum temp. (°C)	36	31
Minimum temp. (°C)	13	4
Temp. at maximum altitude (°C)	36	30
Pressure control correction (c./s.)	0.2	0.4

Cosmic ray data - flight F12.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	5.58	0	6.92	0	12.50	0
900-800	4.92	0	5.25	0	10.17	0
800-700	4.25	0	4.33	0	8.58	0
700-600	4.00	0	3.83	0	7.83	0
600-500	4.25	0	4.33	0	8.58	0
500-400	4.92	0	5.25	0	10.17	0
400-350	2.67	0	3.33	0	6.00	0
350-300	2.92	0	3.58	0	6.50	0
300-250	3.08	0	4.17	1	7.25	1
250-200	3.92	0	4.33	2	8.25	2
200-150	4.67	0	5.25	1	9.92	1
150-100	8.00	8	8.08	8	16.08	16
100-80	4.33	7	3.42	3	7.75	10
80-60	6.00	3	4.00	5	10.00	8
60-40	8.58	10	5.08	11	13.67	21
40-20	11.50	24	6.33	8	17.83	32
20-12	12.50	42	-	-	12.50	42

Data lost during early stages of descent due to rapid signal fading.

Transmitter not recovered.

Cosmic ray data - flight F13.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	3.33	0	-	-	3.33	0
900-800	3.58	0	-	-	3.58	0
800-700	3.25	0	-	-	3.25	0
700-600	3.75	0	-	-	3.75	0
600-500	4.08	0	-	-	4.08	0
500-400	4.75	1	6.75	1	11.50	2
400-350	2.75	0	4.25	0	7.00	0
350-300	3.25	0	4.67	0	7.92	0
300-250	4.00	1	5.17	0	9.17	1
250-200	4.25	2	6.08	1	10.33	3
200-150	6.00	4	8.08	3	14.08	7
150-100	9.42	2	10.00	7	19.42	9
100-80	5.00	7	5.25	11	10.25	18
80-60	6.58	11	6.33	7	12.92	18
60-40	9.08	16	8.92	8	18.00	24
40-20	12.42	22	13.33	29	25.75	51
20-14	6.67	16	5.67	19	12.33	35

Transmitter not recovered.

Cosmic ray data - flight F14.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	3.25	0	-	-	3.25	0
900-800	3.50	0	-	-	3.50	0
800-700	3.67	0	3.58	0	7.25	0
700-600	4.08	0	4.17	0	8.25	0
600-500	4.42	0	4.92	0	9.33	0
500-400	4.75	0	5.83	0	10.58	0
400-350	2.67	0	3.25	0	5.92	0
350-300	2.92	1	3.83	0	6.75	1
300-250	3.25	0	4.17	1	7.42	1
250-200	5.50	3	5.00	3	10.50	6
200-150	11.00	3	5.67	3	16.67	6
150-100	19.50	12	8.83	4	28.33	16
100-80	10.83	12	4.50	5	15.33	17
80-60	14.17	22	5.33	4	19.50	26
60-40	21.42	24	6.67	7	28.08	31
40-20	39.75	102	9.58	18	49.33	120
20-16	19.17	48	3.33	8	22.50	56

Ascent rate - 1060 feet/minute from 1,000 to 220 mb.
400 " " " 220 to 16 mb.

Landing point - Comrie, Perthshire.

Cosmic ray data - flight F15.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	3.75	0	-	-	3.75	0
900-800	3.75	0	-	-	3.75	0
800-700	4.08	0	-	-	4.08	0
700-600	4.42	0	-	-	4.42	0
600-500	4.50	0	-	-	4.50	0
500-400	5.33	0	-	-	5.33	0
400-350	2.83	0	-	-	2.83	0
350-300	3.08	1	-	-	3.08	1
300-250	3.33	1	-	-	3.33	1
250-200	5.58	3	-	-	5.58	3
200-150	10.92	6	-	-	10.92	6
150-100	17.83	16	-	-	17.83	16
100-80	9.25	4	-	-	9.25	4
80-60	12.67	17	-	-	12.67	17
60-40	19.50	36	-	-	19.50	36
40-23	21.75	40	-	-	21.75	40

Ascent rate - 1000 feet/minute from 1000to 220 mb.
470 " " " 220 to 16 mb.

Transmission of cosmic data stopped (137 minutes after take-off), at a pressure of 23 mb., probably due to failure of filament of V7.

Landing point - Blair Atholl, Perthshire.

Cosmic ray data - flight F16.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	2.92	0	-	-	2.92	0
900-800	2.67	0	-	-	2.67	0
800-700	3.17	0	-	-	3.17	0
700-600	3.50	1	-	-	3.50	1
600-500	4.17	0	5.83	0	10.00	0
500-400	4.58	0	6.33	0	10.92	0
400-350	2.33	0	3.83	0	6.17	0
350-300	2.75	0	4.17	1	6.92	1
300-250	3.50	1	4.92	0	8.42	1
250-200	4.25	0	5.92	3	10.17	3
200-150	5.58	4	7.92	2	13.50	6
150-100	8.50	8	9.25	3	17.75	11
100-80	5.42	8	4.58	1	10.00	9
80-60	7.33	10	5.92	6	13.25	16
60-40	9.67	15	7.82	9	17.50	24
40-20	18.33	32	15.00	38	33.33	70
20-14	13.67	42	7.50	16	21.17	58

Transmitter picked up by trawler off Fife Ness.

<u>Consolidated cosmic ray data - flights F12-F16</u>.

Pressure interval (mb.)	Ascents Time (min.)	Ascents Counts	Descents Time (min.)	Descents Counts	Total Time (min.)	Total Counts
1,000-900	18.83	0	6.92	0	25.75	0
900-800	18.42	0	5.25	0	23.67	0
800-700	18.42	0	7.92	0	26.33	0
700-600	19.75	1	8.00	0	27.75	1
600-500	21.42	0	15.08	0	36.50	0
500-400	24.33	1	24.17	1	48.50	2
400-350	13.25	0	14.67	0	27.92	0
350-300	14.92	2	16.26	1	31.17	3
300-250	17.17	3	18.42	2	35.58	5
250-200	23.50	8	21.33	9	44.83	17
200-150	38.17	17	26.92	9	65.08	26
150-100	63.25	46	36.17	22	99.42	68
100-80	34.83	38	17.75	20	52.35	58
80-60	46.75	63	21.58	22	68.33	85
60-40	68.25	101	28.50	35	96.75	136
40-20	103.75	220	44.25	93	148.00	313
20-12	52.00	148	16.50	43	68.50	191
Ground level test - F12 equipment only					4,520	68

<u>Consolidated counting rates - flights F12-F16.</u>

Pressure interval (mb.)	Mean weighted pressure (mb.)	Observed Counting rate (counts/min.)	Standard statistical deviation (counts/min.)	Total correction * (%)
1,000-900	949	0	-	0.7
900-800	849	0	-	0.7
800-700	748	0	-	0.8
700-600	648	0.04	0.04	0.8
600-500	548	0	-	0.9
500-400	448	0.04	0.03	1.0
400-350	374	0	-	1.2
350-300	324	0.10	0.05	1.4
300-250	274	0.14	0.06	1.6
250-200	224	0.38	0.09	1.8
200-150	173	0.40	0.08	2.3
150-100	122.5	0.68	0.08	2.8
100-80	89.5	1.11	0.14	3.2
80-60	69.3	1.24	0.13	3.4
60-40	49.1	1.41	0.12	3.6
40-20	28.3	2.11	0.12	3.7
20-12	16.8	2.79	0.20	3.5
Ground level	1,006	0.015	0.002	0.7

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* Similar to corrections for flights F9-F11 except one counter fewer.

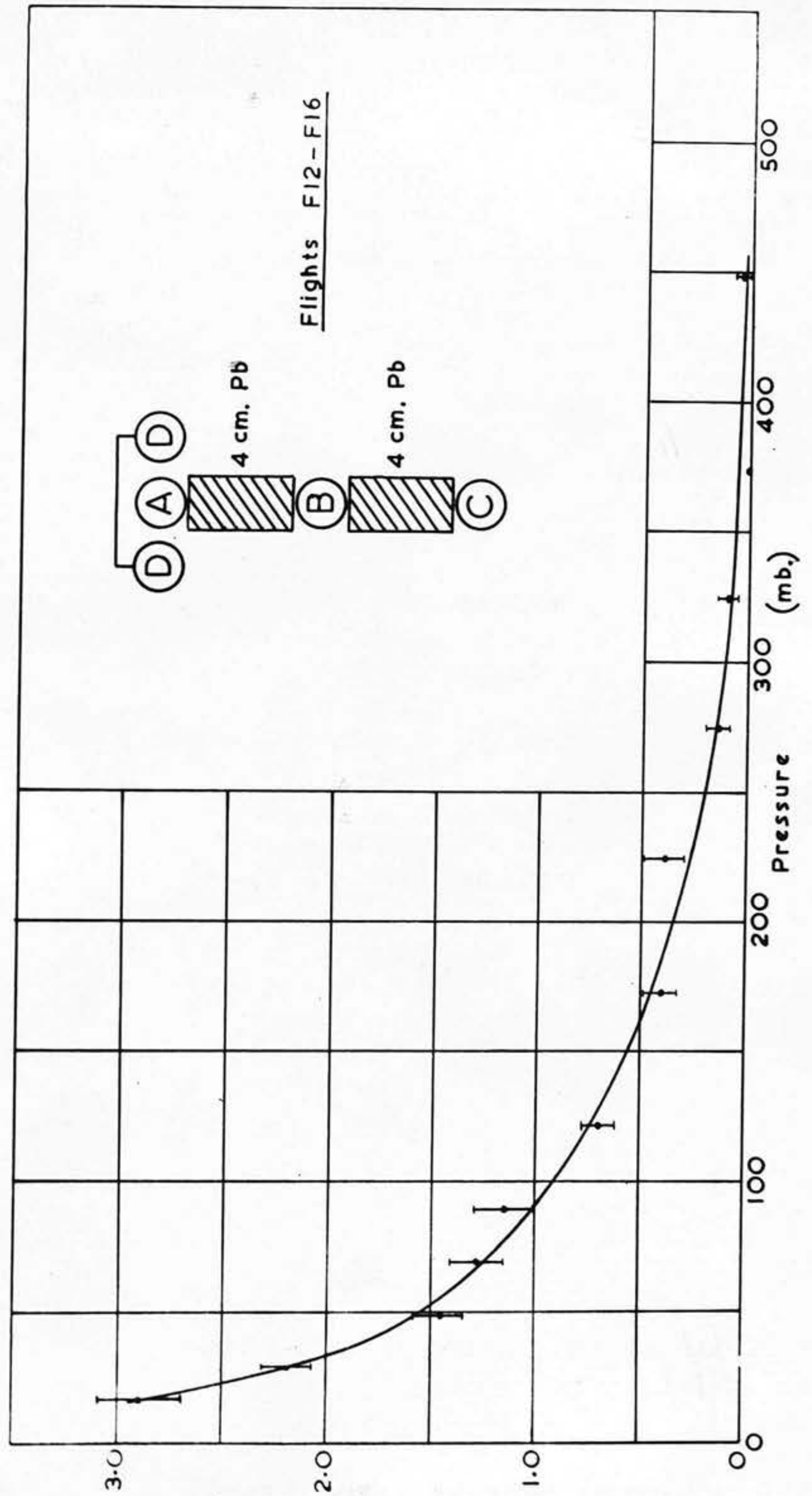

Figure 43. Coincidence rate - pressure curve , flights F12-F16.

(v) Flight F17.

Flight history.

Flight	F17
Date	7 Oct 51
Total load (gm.)	3,493
Number of balloons	1
Free lift per balloon (gm.)	200
Average rate of ascent (ft./min.)	680
Minimum pressure (mb.)	17
Maximum altitude (ft.)	92,000
Average rate of descent (ft./min.)	1,800
Descent by -	Parachute
Maximum temp. (°C)	40
Minimum temp. (°C)	15
Temp. at maximum altitude (°C)	40
Pressure control correction (c./s.)	1.7

Cosmic ray data - flight F17.

Pressure interval (mb.)	Ascent Time (min.)	Ascent Counts	Descent Time (min.)	Descent Counts	Total Time (min.)	Total Counts
1,000-900	5.33	11	-	-	5.33	11
900-800	6.00	7	-	-	6.00	7
800-700	5.17	17	-	-	5.17	17
700-600	11.83	43	-	-	11.83	43
600-500	7.50	47	2.83	25	10.33	72
500-400	6.17	56	4.17	60	10.33	116
400-350	3.25	48	2.08	34	5.33	82
350-300	3.83	66	1.83	39	5.67	105
300-250	4.25	107	-	-	4.25	107
250-200	2.67	75	-	-	2.67	75
200-140	5.67	238	-	-	5.67	238
140-100	10.58	502	-	-	10.58	502
100-80	7.17	377	1.50	86	8.67	463
80-60	9.33	461	2.33	89	11.67	550
60-40	10.00	393	-	-	10.00	393
40-28	10.17	399	0.67	16	10.83	415
28-20	10.83	401	1.50	38	12.33	439
20-17	6.50	198	0.92	33	7.42	231
			Ground level test		1,740	2,225

Reception intermittent during descent owing to radio interference.

Landing point - Inverarity, Angus.

Counting rates - flight F17.

Pressure interval (mb.)	Mean weighted pressure (mb.)	Observed counting rate (counts/min.)	Standard statistical deviation (counts/min.)	Total correction * (%)
1,000-900	949	2.06	0.62	0.5
900-800	849	1.17	0.44	0.5
800-700	748	3.30	0.80	0.6
700-600	648	3.64	0.55	0.7
600-500	548	6.97	0.82	0.8
500-400	448	11.23	1.04	1.0
400-350	374	15.38	1.70	1.3
350-300	324	18.52	1.81	1.6
300-250	274	25.18	2.43	1.9
250-200	224	28.09	3.24	2.4
200-140	167	41.98	2.72	2.9
140-100	118.3	47.44	2.12	3.4
100-80	89.5	53.40	2.48	3.9
80-60	69.3	47.13	2.01	3.8
60-40	49.1	39.30	1.98	3.7
40-28	33.5	38.32	1.88	3.6
28-20	23.7	35.61	1.70	3.4
20-17	18.4	31.13	2.05	3.2
Ground level	1005	1.279	0.027	0.5

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* Owing to reduction of period of flip-flop cycle, corrections almost identical to those in flights F1-F8

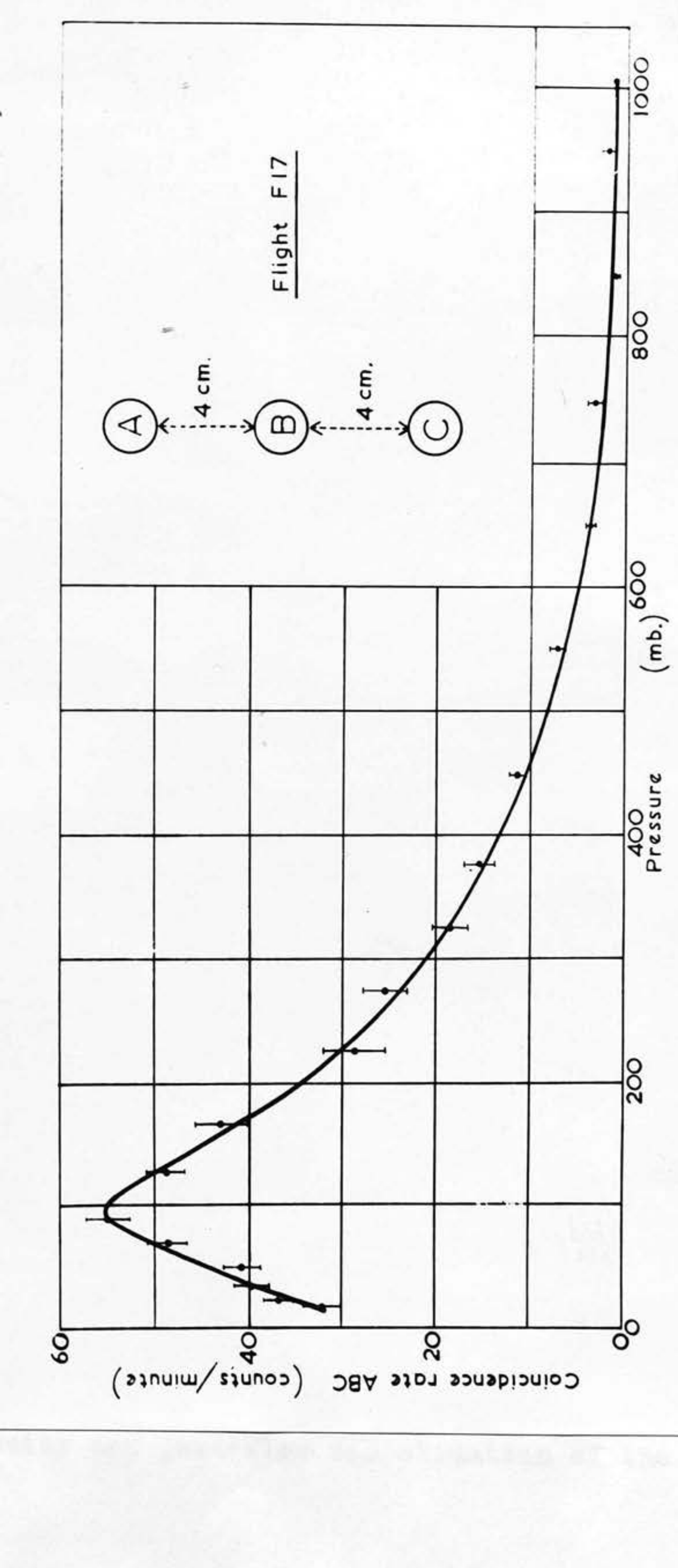

Figure 44. Coincidence rate - pressure curve, flight F17.

CHAPTER 5

DISCUSSION OF RESULTS.

(i) Flights F1-F8 and F17.

The consolidated results of flights F1-F8 (Figure 41, page 142) indicate a continuous smooth increase with altitude in the vertical intensity of the penetrating component at latitude 59^{o}N. Above about the 50 mb. level the rate of change of intensity is slow, but there is no indication of a maximum within the range of atmospheric pressure 3.6 to 1,000 mb. The data from individual flights show no significant departures from the composite result, experimental points from each flight in general agreeing with the mean counting rate in the appropriate pressure interval to within standard deviation. At ground level the coincidence rates of the telescopes were matched to within 3 per cent. At high altitude, in the pressure interval centred on 122 mb. for example, all experimental points lie within 15 per cent of the average value, and all except one within 5 per cent. At 69 mb. and at 14 mb. no point differs from the mean counting rate by more than 10 per cent. Also the ascent data are consistent with the descent data. This general agreement indicates the absence of any marked time variation of intensity and justifies consolidation of the data.

Extrapolation to zero pressure, which is not greatly in doubt since only about 3.6 gm./cm.^{2} of the atmosphere remains above the highest altitude reached, shows an increase in the coincidence rate ABC by a factor of 23 over the average ground rate of 0.957±0.011 counts per minute.

The results of flight F17 are shown in Figure 44, page 164. After a rapid increase from ground level, the vertical total intensity passed through the expected maximum in the region of 100 mb., the coincidence rate there reaching its peak value of about 43 times the ground counting rate of 1.279±0.026 counts per minute.

At any given latitude the earth's magnetic field sets a lower energy limit for vertical incidence of the primary cosmic ray particles. At 59°N. the critical energy for protons, which are known to form the major part of the primary flux, is calculated[21] to be about 0.5×10^9e.v. From balloon flight data obtained at many latitudes it is shown by Neher[22] assuming only protons, that the average energy of the incoming particles is much higher than this figure. To penetrate 8 cm. of lead a proton requires a minimum energy of 2.8×10^8e.v. It may therefore be expected that most of the primary particles will be capable of penetrating this thickness of absorber, and hence that the curves representing the vertical penetrating and total intensities will converge at the limit of the atmosphere.

In view of the fact that only one flight was made with no lead absorber, and that the statistical uncertainties in the total intensity data are therefore large, agreement between the counting rates with and without absorber extrapolated to zero pressure is quite good. Exact convergence of the two curves depends on several factors. The total intensity observed at high altitudes with a vertical telescope may be increased relative to the penetrating intensity by the presence of an appreciable flux of soft upward moving or re-entrant radiation. At the same time the penetrating intensity may also be relatively increased by a contribution due to extensive showers occurring in the lead blocks where the parent particle is moving outside the solid angle of the telescope, or it may be diminished by absorption of primary and secondary particles in the lead and by scattering of radiation out of the telescope. The rate of change of total intensity observed in flight F17 above the 100 mb. level is too rapid for extrapolation to be sufficiently reliable to establish or rule out the existence of a small discrepancy in counting rates at zero pressure due to a combination of the above effects. The total intensity may be in excess of the penetrating intensity, but the difference is not likely to amount to more than 20 per cent.

In comparing these measurements with those of other workers it must be remembered that the possible correction for the effect of side showers has not yet been considered. Since this may vary with the geometry of the telescope employed, a direct comparison of the uncorrected results may not be valid. However, in view of the fact that previous side shower measurements indicated a negligible effect, and that the data from flights F12-F16 will be discussed later at some length, the comparison will be made now.

Comparison of vertical penetrating intensity measurements.

Mention was made in Chapter 1 of the measurements of the altitude variation of the vertical intensity of the penetrating component which were reported before this research commenced. Of these early results only the data obtained by Schein et al (6) in their second series of flights show the continuous increase in intensity to extreme altitude and are therefore in qualitative agreement with the present observations. A more exact comparison with these results is made impossible by the lack of published experimental detail.

During the last few years, however, several high altitude balloon flights with shielded vertical telescopes have been reported, and attention can mainly be directed to those which were conducted at geomagnetic latitudes between 50°N. and 60°N., and in which thicknesses of lead absorber comparable with 8 cm. were disposed between counters.

In 1949, Pomerantz[23, 24] published the results of an extensive series of flights at latitude 52°N., in which vertical four-fold coincidence telescopes containing various thicknesses of lead or carbon absorber were used. Contrary to the results of Schein et al.[6] the coincidence rate except at extreme altitude was found to vary markedly with absorber thickness in the range 4-7.5 cm. of lead. Because of this variation the data from only one flight, with 7.5 cm. of lead, can be used for comparison with flights F1-F8.

Also in 1949, Winckler et al.[25, 26] reported the completion of a series of flights at latitude 56°N. Triple coincidence telescopes containing different absorber thicknesses and inclined at various zenith angles were used. Two flights of the series included a vertical telescope with 7.6 cm. of lead interposed between counters.

When the results obtained in these flights by Pomerantz and by Winckler et al. are compared with the consolidated data from flights F1-F8, it is found that all coincidence rate-pressure curves are very similar in general form. In no case does the intensity pass through a maximum at high altitude. Sufficient experimental detail is provided to make possible a more quantitative comparison, and this is given later. One further set of data will first be considered.

After a preliminary report(27), Vidale and Schein, in 1951, published a detailed account(28) of a series of flights with vertical four-fold telescopes at various latitudes. 7.5 cm. and 12 cm. of lead absorber were used in two separate flights at 55°N. In each case the coincidence rate is considered to pass through a very flat maximum in the region of 60 mb. On examination of the published data, however, it is evident that the assumption of a maximum on the curves obtained at 55°N. is barely justified on the data from these flights alone. This is particularly the case in the flight with 7.5 cm. of lead, where the maximum depends on a single experimental point of low statistical weight. Both Pomerantz and Winckler find that the maximum on the total vertical intensity curve disappears with lead absorber thicknesses greater than 4 cm. The balance of experimental evidence at high latitudes is therefore in favour of regarding the maxima found at 55°N. by Vidale and Schein as due to statistical fluctuations rather than to instrumental differences or geomagnetic effects. An explanation in terms of side showers is considered later. The authors' interpretation is supported by their observations at latitudes 28°N. and 41°N. where similar maxima were observed. Confirmation of this result at low latitudes comes from the work of the Bombay group[29] close to the geomagnetic equator. The composite results of five flights at Bangalore, latitude 3°N., with four-fold telescopes containing 10 cm. of lead show a well defined maximum at 120 mb.

Present evidence therefore indicates that the vertical penetrating component increases continuously in intensity with altitude at latitudes above about 50°N. At lower latitudes it is probable that a maximum appears which becomes more marked and occurs at a slightly increasing pressure on nearing the magnetic equator. An effect of this sort must be connected with the increased average energy of the primary particles at low latitudes or else be due to meteorological conditions. It can be interpreted as showing that the multiplicity of meson production varies rather rapidly with the energy of the parent particle.

A convenient method of comparing data obtained with different telescopes which has frequently been used in the past, is simply to normalise the counting rate to a common scale at some particular pressure level and then to consider the adjusted curves. This procedure can, however, be considerably in error, and although agreement at one point, usually ground level pressure, is assured in arbitrary fashion, consistency of the normalised coincidence rates throughout the atmosphere does not necessarily result. This is partly due to the altitude variation of the directional intensity of cosmic radiation, in conjunction with the finite but probably dissimilar solid angles of the telescopes in use.

The distribution of the intensity of the hard component with zenith angle θ has been shown[30] to follow closely a $\cos^2\theta$ dependence at ground level. Various values of the exponent have been reported, but the departures from the cosine squared law are small enough to be neglected here. From the absence of any large regular time variations of intensity it is assumed that the primary distribution is isotropic outside the sphere of influence of the earth's magnetic field, and there is experimental evidence[26, 31] at high latitudes for the region of isotropic distribution extending down to the extreme altitudes reached in free balloon flights. Hence, the relative multiplication of the counting rates of different counter telescopes with increasing altitude will depend on the effective angular apertures of the various arrangements, and even when the geometries are known the coincidence rates can only be precisely compared at those pressure levels where the zenithal distribution of the radiation is well established. At these points the observed coincidence rates can be converted into absolute intensities, which, being independent of the type of telescope employed, form a proper basis of comparison.

Taking into account all significant end corrections due to the cylindrical shapes of the counters, the absolute vertical intensity I of downward radiation is given in terms of the observed coincidence rate N of a particular vertical telescope by the following relations[24, 30],

Isotropic distribution:

$$N = I d^2 \left[\frac{\ell}{a} \arctan \frac{\ell}{a} + \frac{\pi d}{4a} \left\{ 1 - \frac{a^2}{a^2+\ell^2} \right\} \right],$$

cos θ distribution:

$$N = I \frac{2d^2}{3} \left[\frac{2(a^2+\ell^2)^{\frac{1}{2}}}{a} - 1 - \frac{a}{(a^2+\ell^2)^{\frac{1}{2}}} + \frac{\pi d}{4a} \left\{ 1 - \left(\frac{a^2}{a^2+\ell^2} \right)^{3/2} \right\} \right],$$

$\cos^2\theta$ distribution:

$$N = I \frac{d^2}{4} \left[\frac{3\ell}{a} \arctan \frac{\ell}{a} + \frac{\ell^2}{a^2+\ell^2} + \frac{\pi d}{2a} \left\{ 1 - \left(\frac{a^2}{a^2+\ell^2} \right)^2 \right\} \right],$$

where d is the effective counter diameter, ℓ the effective counter length, and a the perpendicular distance between axes of extreme counters. If N is expressed in counts per minute, I is obtained in units of particles per $cm.^2 min.$ steradian. In Table 1 the appropriate dimensions have been substituted in the above relations, and the resulting values of the conversion factors $^N/_I$ refer to the telescopes used in the flights mentioned above.

TABLE 1

	Conversion factor $^N/_I$		
	(1) Isotropic case	(2) cosθ case	(3) $\cos^2\theta$ case
Telescope ABC	2.27	2.17	2.08
Pomerantz	1.45	1.29	1.23
Winckler et al.	1.84	1.80	1.75
Vidale and Schein	1.15	1.13	1.11

Comparison is first made at high altitude, assuming an isotropic distribution. The factors shown in Table 1, column (1), are divided into the appropriate coincidence rates at 15 mb., this pressure level being

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For telescope ABC, d = 1.95 cm., l = 10.0 cm., a = 12.4 cm.

chosen to avoid the necessity of extrapolation. The resulting values of the absolute vertical intensity at 15 mb., which are shown in Table 2, column (2), are in very close agreement.

TABLE 2.

-	(1) Observed counting rate at 15 mb. (counts/min.)	(2) Absolute intensity at 15 mb. (Particles/cm.^{2} min. steradian)
Telescope ABC (8 cm. Pb.)	22.2 ± 0.3	9.8 ± 0.2
Pomerantz (7.5 cm. Pb.)	14.7 ± 0.3	10.1 ± 0.2
Winckler et al. (7.6 cm. Pb.)	approx. 17.4	approx. 9.5
Vidale and Schein (7.5 cm. Pb.)	12.0 ± 0.2	10.4 ± 0.2

It should be noted that these figures relate to the vertical intensity at 15 mb. when the radiation is filtered through 85-95 gm./cm.^{2} of lead. They would only refer to the primary intensity if the coincidence rate at this point were shown to be independent of the presence of the absorber. Estimates of the primary vertical intensity, somewhat higher than the values shown in Table 2, have been published by Winckler et al.[26] and by Vidale and Schein[28]. They are obtained from the coincidence rate at high altitude without absorber.

A similar comparison of the coincidence rates at a lower altitude using the conversion factors in Table 1, column (2), requires a knowledge of the pressure level at which the zenithal distribution of the penetrating intensity follows a cosθ law. Measurements by Jenkins[32] in aeroplane flights at latitude 43°N. provide some evidence that this occurs in the region of 250 mb. This finding is fairly well confirmed at 56°N. by Winckler et al.[26]. Using the appropriate conversion factors the agreement in absolute rates at 250 mb. is found to be within 10 per cent. This comparison, however, loses much of its value because of the statistical uncertainties of some of the data at lower altitudes. A discrepancy of this order of magnitude lies well within the combined experimental errors around 250 mb. Indeed, as may be expected from the consistency of the absolute rates at 15 mb. and the general similarity of the data at lower altitudes, these other measurements show very little variation from the present results throughout the upper part of the atmosphere. Apart possibly from the data of Vidale and Schein in the region of 60 mb., allowance for solid angle effects brings all discrepancies well within probable statistical fluctuations.

The calibration data obtained near sea

level can be compared using the conversion factors shown in Table 1, column (3). Absolute values of the vertical intensity so obtained are given in Table 3, column (2). The interesting point which emerges is that the

TABLE 3.

	(1) Observed ground counting rate * (Counts/min.)	(2) Absolute intensity (Particles/cm.^{2} min. steradian)
Telescope ABC (8 cm. Pb.)	0.957 ± 0.011	0.460 ± 0.005
Pomerantz (7.5 cm. Pb.)	0.672 ± 0.014	0.547 ± 0.011
Vidale and Schein (7.5 cm. Pb.)	0.567 ± 0.020	0.511 ± 0.018

percentage differences in absolute rates near sea level are greater than at maximum altitude. The figures relating to the telescope used by Vidale and Schein may be reduced by about 5 per cent to allow for a difference in altitude, but otherwise the calibration data appears to have been obtained under very similar conditions with only a light protective covering over the telescope. The remaining discrepancies cannot be entirely explained

* Ground counting rate with absorber in position not stated by Winckler et al.

in terms of different absorber thicknesses. They may be due to a true variation in intensity resulting perhaps from geomagnetic effects, or else to the influence of showers occurring in the lead blocks. Since various dispositions of absorber were used these showers may have affected the lower counters to a different degree.

<u>Comparison of total vertical intensity measurements.</u>

The various series of flights by Pomerantz, by Winckler et al., and by Vidale and Schein each included a determination of the altitude variation of the total vertical intensity with telescopes containing no lead but of the same geometrical patterns as before. The data from these flights can be compared with the results of flight F17.

In all cases a pronounced intensity maximum, lying within 10 mb. of the 100 mb. level, was obtained. Agreement is not so satisfactory, however, concerning the multiplication of intensity at the maximum. From the data obtained by Winckler et al. with inclined telescopes at 56°N. it appears that the zenithal distribution of the total radiation at zenith angles less than 60° must pass through isotropism very close to the 100 mb. level. This conflicts with the earlier measurements by Swann(33) in which isotropism was observed at about 250 mb., but a tentative comparison of coincidence rates using the conversion factors for an isotropic distribution can be made. Estimated maximum counting rates converted to absolute vertical intensities, together with the minimum counter wall thickness to be penetrated by a particle discharging all counters, are given for each telescope in Table 4.

TABLE 4.

	Latitude °N	Counter wall thickness (gm./cm.^{2})	Absolute intensity (Particles/cm.^{2} min. steradian)
Telescope ABC	59	1.7	24.2
Pomerantz	52	4.2	25.5
Winckler et al.	56	3.3	17.6
Vidale and Schein	55	5.0	20.9

The figures obtained by this procedure are in doubt because of the variation between telescopes in the minimum energy required for penetration of the counter walls. The radiation is observed by Winckler to be isotropic over a range of zenith angles greater than the angular opening of any telescope, but this finding is not necessarily independent of the low energy instrumental cut-off. The distribution of very low energy radiation may not be isotropic. Greisen[30] has shown at sea level that measurement of the total intensity is greatly affected by absorption in the counter walls. From the absorption curves obtained by Pomerantz(24) it may be expected that this effect will increase with altitude. It has also been reported(34) that the total vertical intensity at high altitudes varies markedly with time. In these circumstances, and in view of the statistical uncertainties of all data near 100 mb., the agreement in absolute vertical rates at the point of maximum intensity is probably as good as can be expected.

From the rapid decrease in total intensity observed in flight F17 above the 100 mb. level it seems likely that the inclusion of up to 8 cm. of lead absorber in the telescope ABC does not reduce the coincidence rate at extreme altitude by more than 20 per cent. This is in agreement with the results of Pomerantz and of Winckler et al. with comparable quantities of absorber, though Winckler finds appreciable absorption of the primary radiation with 16.7 cm. of lead. On the other hand, in the results of Vidale and Schein at 55°N., even with only 7.5 cm. of lead, the counting rates with and without absorber do not extrapolate to a common point. This same feature appears in their observations at lower latitudes, but this time it is not confirmed by the experiments of the Bombay group at 3°N.

It is of interest to compare the ground counting rates of the telescopes used in these total intensity measurements. The figures given in Table 5, column (2), have been obtained assuming a $\cos^2\theta$ distribution. Allowance can be made for a more rapid[30] decrease in intensity of the soft component with zenith angle, but since only about one-quarter of the total intensity is affected and the error is in the same sense for all telescopes, the change in the relative values of the total absolute rates at ground level is hardly significant. Discrepancies of the order of 20-30 per cent remain, which do not bear a simple relationship to counter wall thicknesses, and cannot be completely resolved in terms of known differences in calibration conditions.

TABLE 5.

	Observed ground counting rate without lead (Counts/min.)	Absolute intensity at ground level (Particles/cm.^{2} min. steradian)
Telescope ABC	1.279 ± 0.027	0.615 ± 0.013
Pomerantz	0.917 ± 0.007	0.745 ± 0.006
Winckler et al.	0.944 ± 0.015	0.539 ± 0.009
Vidale and Schein	0.700 ± 0.020	0.631 ± 0.018

So far as this research is concerned the main importance of this variation in ground counting rates, both with and without absorber, is to emphasize the danger of comparing different measurements by simple normalisation. The error introduced by normalising independent sets of calibration data may be much greater than that due to the change with altitude in the zenithal distribution of radiation. In the measurements considered above, normalising the ground rates would hide the anomalies at that point, but the discrepancies in counting rates would reappear at higher altitudes, where, in the penetrating intensity curves at least, agreement is actually good. Normalisation at 15 mb. would be preferable here, but in this case the scale, if linear, would be such as to mask the differences in ground rates.

(ii) Flights F9-F11.

The object of this series of flights was to investigate the altitude dependence of penetrating showers occurring in a block of lead mounted in the telescope. The arrangement of counters and absorber is shown in Figure 29, five-fold coincidences PQRST being recorded.

The desired event was one in which a single incident ionizing particle discharged a counter P and produced in the top lead block (4 cm. thick) a shower of penetrating secondaries. This type of event was considered to be the most probable cause of five-fold coincidences, at least two secondary particles being required to discharge counters Q, R, S and T. For maximum sensitivity to showers of small angular divergence the counters in each of the two lower trays were placed in physical contact. Hard showers occurring in the air above the telescope may also be recorded, but for particle energies less than about 5 x 10^9 e.v. the probability of vertical electron showers penetrating the absorber is small. The arrangement of counters discriminates strongly against the possibility of a large proportion of the coincidences observed at high altitudes being due to knock-on events since a double knock-on is required, and five-fold coincidences due to the parent particle and decay products of mesons stopping in the lead are improbable.

The consolidated results of the three flights with this type of telescope are shown in Figure 42, page 150. The statistical errors of the data from each individual flight are large, but substantially the same result was obtained on each occasion. Few coincidences were observed below the 200 mb. level, but at greater altitude the counting rate rose sharply. At 7 mb., the lowest pressure reached, the coincidence rate was about 2.3 counts per minute.

From the absence of a maximum on the counting rate curve, it is probable that the shower producing radiation is part of, or is very closely connected with, the primary cosmic ray flux. Also, those primary particles giving rise to recorded showers are likely to be travelling at small zenith angles. If the direction of motion of the primaries is limited to the solid angle defined by the extreme counter trays, the average amount of matter traversed in passage through the atmosphere is less than 5 per cent greater than for vertical incidence. The intensity of shower primaries incident on the telescope may then be regarded as varying with atmospheric pressure in accordance with the simple exponential absorption law,

$$I_{(x)} = I_{(o)} e^{-\frac{x}{\lambda_A}}$$

where $I_{(x)}$ is the vertical intensity at atmospheric depth x gm./cm.^{2}, $I_{(o)}$ the primary vertical intensity, and λ_A the attenuation length* of the shower producing particles in air.

If x_a is the thickness of lead absorber provided, and λ_I the interaction mean free path* in lead of the shower primaries, then a constant fraction $\left[1-e^{-\frac{x_a}{\lambda_I}}\right]$ of the incident radiation will suffer collision in the absorber. Hence, with decreasing atmospheric pressure the rate of occurrence of these local events may be expected to follow the exponential increase in intensity of the primary radiation. The upper lead block of thickness 45 gm./cm.^{2} represents an appreciable fraction of the interaction mean free path of the known primary particles. At low altitudes Cocconi[35, 36] has obtained a value of $\lambda_I(\text{lead}) = 160$ gm./cm.^{2} for the charged nucleonic primaries of penetrating showers; this is consistent with the value calculated from the geometric cross section, and with the results of other workers (37, 38). At high altitudes this figure may effectively be reduced by the presence of an appreciable flux of heavier nuclei, but this will serve only to increase the fraction of the primary flux colliding in the absorber. In the top lead block alone, about 25 per cent of

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* For definition of these terms see reference 46.

vertically incident primary protons and a larger fraction of any heavier primaries must cause interactions. Thus if comparable reactions occur in air and in lead, the contribution to the coincidence rate PQRST due to air showers is likely to be negligible in comparison with the contribution due to local showers in the lead. In this case, provided the nature of the local showers does not vary greatly with altitude, the coincidence rate PQRST should increase exponentially with decreasing residual atmospheric pressure.

When plotted to a logarithmic scale of counting rate, as shown in Figure 45 (full line), it is found that the data can be fitted quite well to the exponential absorption of primary radiation with $\lambda_A = 115 \pm 15$ gm./cm.^{2} This is in agreement with the results obtained by Vidale and Schein(28) in balloon flights at latitudes 28°N. and 55°N., and with the aeroplane observations by Tinlot(39, 40) at 53°N. A comprehensive list of references to other experimental findings, mainly consistent with this result, is published elsewhere(41).

The present results constitute strong evidence that the shower producing radiation is part of the primary flux, but do not necessarily indicate that the charged shower primaries are of purely protonic nature. It has been shown(42, 43, 44) that at least 20 per cent

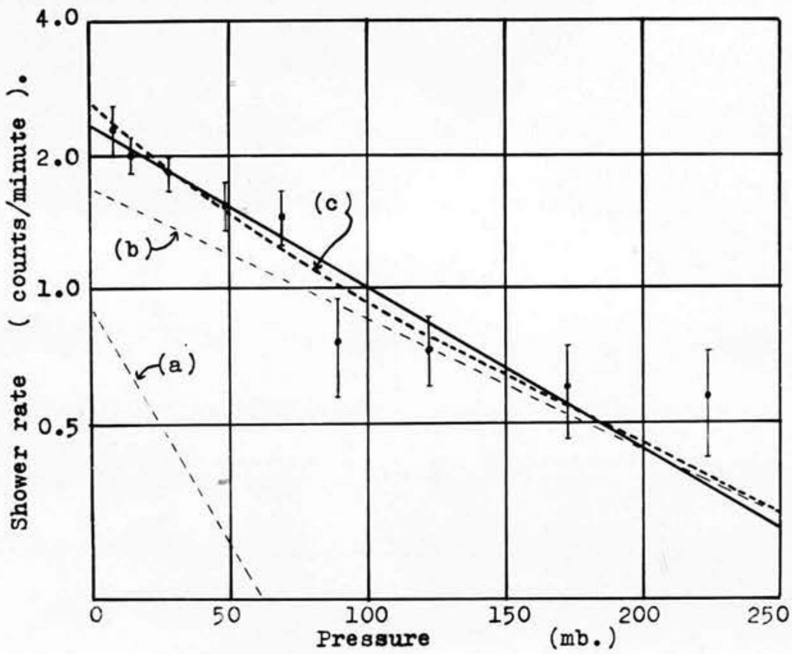

Figure 45. Absorption curves for shower producing radiation.
Full line - Primary particles of λ_A=115 gm./cm.
Broken lines - (a) α-particles λ_A=45 gm./cm.
(b) Protons λ_A=140 gm./cm.
(c) Sum of (a) and (b).

of the primary beam consists of α-particles, with a small proportion of still heavier nuclei. Since penetrating showers initiated by heavy nuclei have frequently been observed in photographic emulsions, it is possible that a significant fraction of the events recorded at high altitude in the present flights are due to α-particles. Since these particles are more rapidly absorbed than protons the presence of an appreciable contribution to the coincidence rate from this source should be detected through a certain non-linearity of the curve in Figure 45 at the low pressure end. Investigating from this point of view, it is found that the accuracy of the data is inadequate to establish whether or not showers due to heavy nuclei were recorded. If an attenuation length greater than 115 gm./cm.^{2} is assigned to the protonic component a contribution due to α-particles becomes possible. For example, as shown by the broken lines in Figure 45, the data can be interpreted equally well in terms of the absorption of a proton component of $\lambda_A(\text{air}) = 140$ gm./cm.^{2} plus an α-particle component of $\lambda_A(\text{air}) = 45$ gm./cm.^{2} At extreme altitude about one-third of the penetrating showers may be due to α-particles. The attenuation length for protons is then compatible with the value obtained by Walsh and Piccioni[45] in aeroplane flights, and on the assumption of catastrophic interactions the attenuation length for α-particles is consistent with the interaction mean free path measured by Bradt and Peters[42].

Whether particles heavier than protons play an important part in the production of the showers recorded in these flights could be decided if the absorption coefficient for the protonic component could be precisely determined from the experimental points in the region of 200 mb. Unfortunately the statistical accuracy here is insufficient for this purpose. Also, the calibration data can only be regarded as an upper limit to the penetrating shower rate at ground level, and may not safely be used to fix the slope of the absorption curve for protons. In the laboratory, a period of 96 hours counting gave only 23 coincidences, while on removal of the top lead block 21 coincidences occurred in a further period of 96 hours. It is probable therefore that a large part of the counting rate observed at ground level is due to anomalous effects such as air showers and knock-on events in the two lower lead blocks.

The following data give some idea of the quantitative relationship between the intensity of particles vertically incident on the telescope and the rate of recorded showers. At ground level when the two counters in each tray are connected in parallel, the rate of three-fold coincidences P, QR, ST, is 1.30±0.04 counts per minute. By relating the geometry of the telescope to the known increase in the vertical absolute intensity it is calculated that at maximum altitude the three-fold coincidence rate would be about 30 counts per minute. The observed shower rate PQRST of 2.3 counts per minute at 7 mb. indicates that a five-fold coincidence is recorded in only about 1 in 13 of these occasions, although roughly 40 per cent of vertically incident primary particles should interact in the lead above the two lower counter trays.

It is impossible, from this information alone, to reach any firm conclusion about the multiplicity of meson production in the average event, but the results of other workers with different counter arrangements may be taken into consideration. Vidale and Schein(28) performed similar experiments in balloon flights reaching the 15 mb. level at latitudes 55°N. and 28°N. For a shower to be recorded in their apparatus at least three particles were required to emerge from a lead block 12 cm. thick. In spite of this extra requirement the observed shower rate at high altitude, when considered in relation to the solid angle of the telescope, was very similar to that in the present experiments. While differences in geometry make the validity of a direct comparison of these data doubtful, the results indicate that although the average number of penetrating particles produced per absorbed primary is probably small, an important fraction of events must occur in lead in which mesons are created in rather high multiplicity. This conclusion is consistent with the results obtained by Tinlot(39, 40). He interprets penetrating shower measurements with dissimilar apparatus at aeroplane altitude in favour of large multiplicity and large angular divergence of the recorded events.

(iii) Flights F12-F16.

In this series of flights it was intended to investigate whether the previous vertical penetrating intensity measurements were influenced to any significant extent by lateral showers - i.e. events in which a minimum of three shower particles come in from the side and discharge all counters simultaneously. Any contribution to the coincidence rate ABC from this source should be deducted from the results of flights F1-F8 to get the true vertical penetrating intensity.

The correction could, in principle, have been measured with the same telescope as before, either by moving counter B just out of line with A and C, or else by screening any of the original counters with further coincidence-connected counters. From the results of flights F9-F11 it was known, however, that either arrangement might record bursts occurring in the absorber in addition to side showers. To get over this difficulty the second method had to be adopted, the police counters being mounted above the level of the upper lead block. Two parallel-connected counters D were placed one on either side of counter A, and four-fold coincidences ABCD were recorded.

A negligible amount of material remained above and to the side of counters A and D, so showers produced

Addendum.

In a preliminary communication about these experiments (Phil. Mag. 42, 663, 1951) the results of flights F12-F16 were interpreted in terms of side showers. Further consideration has shown, however, that this explanation is unlikely to be correct.

in the material of the transmitter should have been eliminated. In spite of this the coincidence rate ABCD was by no means insignificant throughout the atmosphere as had been expected. Substantially the same result was obtained in each of the five flights, the consolidated data from which are shown in Figure 43, page 160. Again a sharp rise in counting rate was observed in the top 200 gm./cm.^{2} of atmosphere, the maximum rate occurring at the minimum pressure reached (12 mb.), and amounting to nearly 3 counts per minute or close on 15 per cent of the corresponding rate ABC.

This was a most surprising result. If it is attributed to the effect of side showers, and the apparent correction applied to the data from flights F1-F8, it is found, as shown in Figure 46, that the true vertical intensity represented by the difference curve, curve 3, exhibits a sharp maximum in the neighbourhood of 35 mb. due to the production of penetrating secondary particles by the primary beam. In addition to this important modification of the results of flights F1-F8, some doubt arises as to the type of event observed in flights F9-F11, since only three particles from the side are required to give a coincidence PQRST.

If, however, coincidences ABCD are not mainly due to side showers, the results of flights F12-F16 do not represent a direct correction to the data from

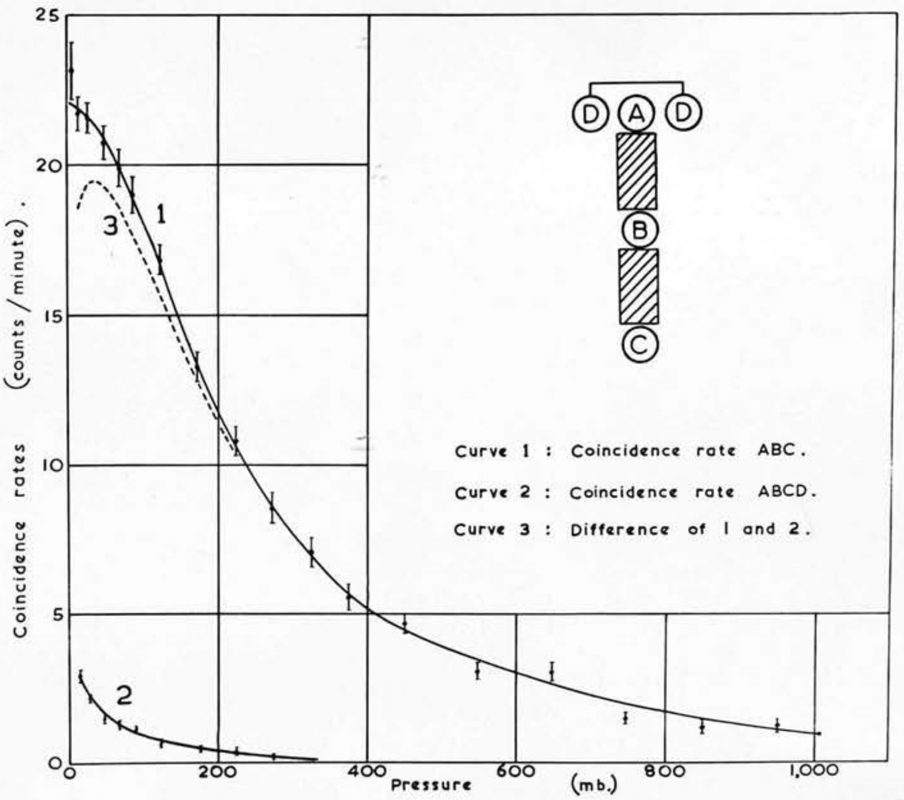

Figure 46. Effect of applying side shower correction to results of flights F1-F8.

flights F1-F8, and significant modification of the previous measurements may not be required. Thus the implication of the results of flights F12-F16 depends to a large extent on the direction of motion of the showers recorded in these flights. The data must be interpreted with care, and all possible explanations of the experimental results must be considered.

Possible types of recorded event.

Various distinct types of cosmic ray event can give rise to a coincidence ABCD. The following are the most obvious causes:

(a) Side showers containing three or more charged particles of any type.

(b) Vertical air showers of two or more charged particles containing at least one penetrating particle.

Consideration has also been given to the further possibilities which are discussed below.

(c) A coincidence ABCD can be due to a nuclear explosion in the upper lead block. If, for example, the initiating particle is charged and passes through counter A, shower particles may discharge counters B and C while radiation ejected backwards discharges a counter D. The observations of Lord and Schein[47] show that over 90 per cent of extensive stars occurring in photographic emulsions exposed at high altitude are due to charged particles. Hence, on the majority of occasions the back radiation need only discharge one counter in the top tray to complete the coincidence.

From a study of the published photographs of events of this type it is apparent that the production of penetrating particles together with an appreciable amount of backward radiation is characteristic chiefly of the very high energy disintegrations, in which the penetrating particles are mainly confined to the forward direction. The telescope ABCD will be most sensitive to these showers when the direction of motion of the primary particle is aligned with the axis of the telescope. In general a relatively small number of particles is ejected backwards, so, from considerations of solid angle, the probability of a counter D being discharged is not high. Also, the back radiation is largely composed of low energy particles which are likely to be absorbed before re-emerging from the lead. In view of the inefficiency of the recording arrangement for this type of event a very high proportion of explosive disintegrations would be required to explain the relative frequencies of coincidences ABC and ABCD at high altitude. This would be quite inconsistent with the frequency-size distribution of stars in photographic plates exposed at high altitudes by Lord and Schein[47] and by Camerini et al.[48] in which large events are quite rare. Explosive disintegrations may be more common in lead, but the results of flights F9-F11 give no evidence of any radical change towards more extensive showers. While a contribution from this source is possible, it is considered unlikely that a major part of the coincidence rate ABCD is due to interactions occurring in the absorber.

(d) Local showers may be created in the material of the gondola above the telescope. As mentioned above, this possibility was reduced to a minimum. Excluding the top counter walls, but including cellophane, aluminium foil and framework, the average thickness of material above counters A and D is less than 0.02 gm./cm.^{2} In terms of the interaction mean free paths of the primary particles this is quite negligible.

(e) At high altitudes there is known to exist an appreciable flux of upward moving radiation. The possibility arises of coincidences ABCD being due to showers created in the lead by particles entering at the lower end of the telescope. Even at extreme altitude events of this sort must be rare, however, since the observations of Lord and Schein[47] at 95,000 feet show the proportion of penetrating showers in which the parent particle is travelling at zenith angles greater than 120° to be extremely small.

Direct evidence about the type of event responsible for the rapid rise in the coincidence rate at high altitude might have been obtained if it had been possible to extend the range of observations to about 5 mb. It was for this reason that measurements with the telescope ABCD were continued after the general form of the experimental curve had been established in the first two flights. The extreme altitude data could be used to distinguish between possible types of event in the following manner. Consider first the response of the telescope to vertical showers created in the air by the primary cosmic ray flux. In the telescope ABCD, unlike the previous arrangement PQRST, there is no local artificial source of showers. Only events occurring in the atmosphere above the telescope can be recorded. Again a layer of atmosphere of given thickness in gm./cm.^{2} acting as absorber will remove by collision a constant fraction of the primary beam, but here the physical depth of the layer will vary with altitude. Although the coincidence rate ABCD will increase with diminishing residual atmospheric pressure on account of the greater intensity of shower producing radiation, it will decrease on account of the greater spacial separation between events as the atmosphere becomes more rarefied, and must tend to zero at the limit of the atmosphere owing to the infinite separation between collisions. Hence the coincidence rate, if due to vertical showers, must pass through a maximum at some point which the experimental data show to lie above the 15 mb. level. This may be compared with the probable response of the telescope to events such as (c) and (d) above. For events of this nature the coincidence rate depends only on the intensity of the shower producing radiation, and may well increase continuously to the limit of the atmosphere. The position with regard to side showers is more uncertain. To a large extent the same reasoning as for vertical showers applies, and again the coincidence rate must tend to zero at zero pressure, but it seems less probable that maximum counting rate will occur at accessible altitude. A sharp fall in the coincidence rate ABCD due to side showers near the top of the atmosphere should be accompanied by a corresponding drop in the coincidence rate ABC in flights F1-F8. Certainly at pressures greater than 5 mb. the data from these latter flights show no such apparent decrease in the vertical penetrating intensity. For consistency the effect of side showers must therefore remain very appreciable at least up to the 5 mb. level.

No further information on the possible existence of a maximum on the experimental curve was obtained in flights F14-F16 and the data at present available indicate a continuous increase in the shower rate throughout the range of observations. The form of the curve is most easily reconciled with the effect of such phenomena as explosive disintegrations in the absorber, but events of this nature do not appear adequate to provide more than a very minor contribution to the coincidence rate. Further discussion is therefore confined to consideration of the experimental data in terms of lateral and vertical showers occurring in the air around the telescope.

(a) Side Showers.

Showers occurring in the atmosphere may be regarded as being made up of three types - high energy events in which penetrating particles are produced, low energy evaporation stars, and the electron-photon cascades of the soft component. Showers of the first type are more likely to be recorded by the telescope ABCD when moving in the vertical direction, and of the other two types only the electron cascades occur in sufficient abundance and have the particle density required to produce an appreciable coincidence rate due to lateral showers.

Some idea of the altitude dependence of the vertical intensity of the soft component may be obtained from the present experiments by subtracting the curve for the vertical penetrating intensity from that for the vertical total intensity. The result so obtained is based on the arbitrary criterion of absorption in a given thickness of absorber. A better approach to the problem of resolving the vertical flux into its electronic and non-electronic components is that of Pomerantz[23,24] based on observations with telescopes containing different quantities of absorber. It is shown that the quickly absorbed radiation reaches its maximum intensity near the 100 mb. level. The curve is reproduced in Figure 47(a). This, of course, refers only to particles

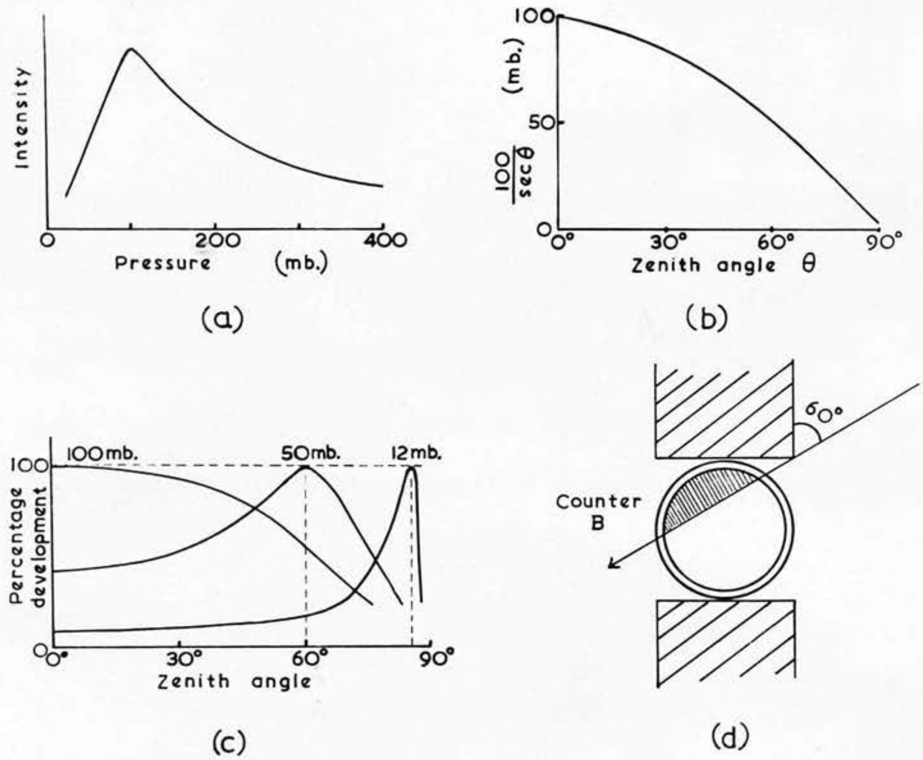

Figure 47. (a). Altitude variation of vertical intensity of soft component.
(b). Secant law corrected for curvature of earth.
(c). Zenithal distribution of soft radiation at various pressures.
(d). Screening of counter by absorber in telescope ABCD.

the exact form of the soft vertical intensity curve, is the marked collimation at very high altitudes of radiation at large zenith angles.

Individual counters of the telescope ABCD are partially screened from soft radiation coming from all directions except close to the horizontal by the adjacent lead blocks. The present problem is to decide whether the observed variation in the four-fold coincidence rate can be explained in terms of the greater intensity of soft low angle radiation at high altitudes, and the larger effective counter areas visible from directions close to the horizontal.

It is clearly impossible to do more than to assess the relative effect of side showers on the coincidence rate at different heights. In particular the pressure levels 50 and 12 mb. will be considered. The coincidence rate ABCD increases by close on 100 per cent in this interval.

To make progress with a strict analysis it would first be necessary to make some very arbitrary assumptions about the nature of an individual cascade shower and the penetrating power of its constituent particles. A solution obtained in this manner without sufficient experimental foundation could not be regarded as satisfactory. It is preferred to consider a most favourable case by making two tentative assumptions, both almost certainly incorrect, but each of which has the effect of making probable a rapid increase in the side shower counting rate at high altitudes. The first assumption is that all side shower coincidences are due to radiation which is at full development. This simplifies matters since the shower size distribution of cascades incident on the telescope can then be regarded as independent of altitude. The general effect of the assumption is apparent from Figure 47(c). When the telescope is at 12 mb., a very large proportion of the soft radiation is incident from a fairly limited range of zenith angles centred on 85°, the zenith angle of the radiation at full development. On the other hand, at 50 mb. where radiation from 60° reaches its maximum intensity, cascade showers from a much wider band of zenith angles are of comparable development. Hence, the neglect of incompletely developed radiation must lead to very considerable underestimate of the relative effect at 50 mb. The second assumption is that while individual cascades have a lateral spread large in comparison with the dimensions of the telescope, all shower counts are due to events in which only one particle passes through each counter. This gives maximum effect to the screening of the counters by the lead blocks; the counters can be considered as plane rectangular areas, and the sensitivity of the telescope to side showers will vary in proportion to the visible cross-section of each counter.

By considering the finer geometric details of the telescope, in the manner shown in Figure 47(d), it is found that 28 per cent of the area of counters B and C are affected by screening from zenith angle 60°, whereas the entire sensitive counter cross-sections are exposed to soft radiation from zenith angle 85°. Since two counters are affected, the greatest fractional decrease in the coincidence rate which could be expected under the assumptions above on going from 12 mb. to 50 mb. is 48 per cent. This requires that the shower particles are completely stopped even by the corners of the lead blocks. From the absorption curves for the total radiation at high altitudes obtained by Pomerantz[23] it is possible to make fairly accurate allowance for penetration of the lead blocks by the soft radiation from a fixed zenith angle. When this is done the effective reduction by screening of the areas of counters B and C at 50 mb. is found to be only 10 per cent. Hence the coincidence rate at 12 mb. should not exceed that at 50 mb. by more than 19 per cent. Two relatively unimportant factors which have been neglected so far, the end effect of the cylindrical shape of the counters on the screening by the lead blocks, and the variation with zenith angle in the projected spacing between extreme counters, both tend to reduce this figure of 19 per cent. One other factor, the slightly incomplete coverage of the sensitive area of counter A by the counters D for radiation from 60°, will tend in the other direction. The effect of this is small, however, since at least 85 per cent of the radiation passing through counter A from zenith angle 60° must pass through a counter D as well.

It would appear, therefore, that even in the most favourable case no satisfactory explanation of the experimental data can be obtained in this manner. Indeed, on applying the same reasoning to other pressure intervals, and on considering the probable effect of the major assumptions above, any increase due to side showers in the coincidence rate ABCD above approximately the 50 mb. level seems most unlikely.

In obtaining this result several important factors have been overlooked, and the treatment above has certainly presented an over-simplified picture of the cascade processes at high altitude. Some modification of the conclusion may be required for either of two reasons. Firstly, in postulating that all coincidences are due to electronic radiation which is at full development, and then assuming the type of radiation falling on the telescope to be independent of altitude, any possible effect of changing meteorological conditions and atmospheric density on the lateral spread of the showers was disregarded. A change in shower type giving an increased counting rate at extreme altitude might also arise if soft showers initiated by the decay of μ-mesons in flight were of particularly high particle density and were relatively more abundant at high level. It is considered unlikely, however, that such effects could be of sufficient importance to explain the rapid increase in the observed coincidence rate above the 50 mb. level. Secondly, it is possible that in the region of 12 mb. the intensity of soft low-angle radiation is greater than expected. This would most probably be due to the effect of the earth's magnetic field on the paths of the primary or secondary particles. However, if the intensity of soft low-angle radiation is in excess of expectations, then, no matter from what cause it arises, the effect should be observed in balloon flight measurements with tilted telescopes.

Such experiments have been performed by Winckler et al.[26] and by Vernov and Kulikov[49]. Winckler, referring to the total and penetrating intensity data at zenith angles $22\frac{1}{2}^{\circ}$ and 45°, reports that the observations in the vertical direction are duplicated at altitudes increased almost exactly in accordance with the secant law. At $67\frac{1}{2}^{\circ}$ the penetrating intensity at all altitudes is lower than expected, a result attributed to the decay of mesons in flight. The soft radiation at $67\frac{1}{2}^{\circ}$ reaches its maximum intensity in the region of 60 mb., a pressure rather greater than Figure 47(b) indicates, while the peak soft intensity does not differ significantly from that for the vertical direction. It is unfortunate that anomalous results were obtained with the original horizontal telescope, and that in the redetermination of the horizontal total intensity by Shanley[26] the observations only extended to 28 mb. where the coincidence rate may not have reached its maximum value. It must be remembered that in measuring the horizontal intensity in this manner, geomagnetic effects apart, radiation may enter equally from either end of the telescope, and a considerable excess of the horizontal maximum intensity over the vertical maximum intensity at a lower altitude does not necessarily indicate a departure from the secant law. At 28 mb., the horizontal soft intensity observed by Shanley is actually considerably lower than the maximum vertical soft intensity.

Vernov and Kulikov performed an experiment in which a simple triple coincidence telescope without lead was continuously rotated between zenith angles 0° and 90°. It was found, when the data was correlated with zenith angle, that the horizontal total intensity became appreciable only above 22 Km. (40 mb.). In the angular interval 0° to 70° from the vertical the secant law was obeyed with an accuracy of better than 10 per cent, the observations extending to 26 Km. (21 mb.).

There is no evidence from either experiment of an unexpectedly large concentration of low-angle soft radiation. The indications are that the collimation of soft radiation at high altitudes shown in Figure 47(c) is to some extent smeared out during the development of the cascades, with the result that the soft radiation does not reach the same maximum intensity at large zenith angles as in the vertical direction. Hence, the conclusion that the experimental data can not be interpreted in terms of side showers is further strengthened.

(b) Vertical showers.

If the events observed in flights F12-F16 are mainly vertical showers created in the atmosphere above the telescope, it is reasonable to assume from the form of the experimental curve that they must result directly from the rapid absorption of some component of the primary cosmic ray flux. If the absorption is exponential, an upper limit for the attenuation length for production of the showers may be obtained from the slope of the curve in the pressure range 15-200 mb., by disregarding the variation with altitude of atmospheric density and assuming that all recorded events occur close to the telescope in a layer of air of given depth. In analogy with the interpretation of the results of flights F9-F11, a logarithmic plot of the experimental data shows that the attenuation length in air, λ_A, is less than 80 gm./cm.^{2}

The actual value of λ_A must be considerably lower than this figure, but it is difficult to make accurate allowance for the effect of altitude variation in the density of the atmosphere above the telescope since this controls not only the relative frequency of collisions between primary particles and atmospheric nuclei in the neighbourhood of the telescope but also the geometric range of the secondary particles. A reduction in the number of collisions occurring within a fixed distance above the telescope, due to a decrease in density, is partially compensated by the increased proportion of secondary radiation capable of reaching the telescope. The nature of the secondary particles must therefore be taken into account when the data are analysed in terms of vertical showers. By considering the response of the counter arrangement to the products of disintegrations occurring in a volume of defined shape above the telescope, various attempts have been made to interpret the experimental data on the basis of extensive showers produced by a rapidly absorbed primary radiation. It is found, however, that the effective range of the secondary particles plays as important a part as the rate of absorption of the primaries in determining how the coincidence rate should vary with altitude. The greater the range of the secondaries the less probable is a rapid increase in the counting rate at very high altitude.

From directions close to the vertical, a minimum of two particles is required for a coincidence. They may both be mesons, but no satisfactory explanation of the present results has been obtained in terms of sufficiently long-range secondaries. It may be that in general only one penetrating particle is concerned in each coincidence, the out-of-line counters being discharged by comparatively short-range radiation produced in the same disintegration. In this case, assuming that the coincidence rate passes through a maximum close to the 15 mb. level, the experimental data may be consistent with the effect of showers due to primary radiation of attenuation length about 40 gm./cm.^{2} Such findings are, however, treated with considerable reserve because of the uncertainties of the calculations, which reach prohibitive complexity unless many simplifying assumptions are made.

Other considerations support the view that if the recorded showers are moving close to the vertical the out-of-line counters in the top tray must usually be discharged by relatively soft radiation. If this were not the case it is difficult to see how the results of flights F12-F16 can be interpreted consistently with the data from flights F9-F11. Extensive air showers of small angular divergence are required to give an appreciable coincidence rate ABCD at the 15 mb. level, where a 500 metre layer of atmosphere is only 1 gm./cm.^{2} thick. Except if very different interactions occur in lead, the presence of the primary radiation responsible for such events should be detected with much more efficiency in flights F9-F11 because of the greatly increased proportion of local events in the telescope PQRST. In spite of this, the coincidence rate ABCD at 15 mb. is higher than the rate PQRST at considerably greater altitude. Even though allowance is made for geometric differences, the results of the two series of flights seem quite incompatible with one another unless in the normal event the police counters in flights F12-F16 are discharged by radiation incapable of penetrating the absorber.

An objection to the vertical shower theory, more fundamental than the form of the experimental curve, concerns the frequency with which coincidences ABCD are recorded at high altitude in relation to the corresponding rate ABC from flights F1-F8. Taking the primary abundance ratio as 80 per cent protons to 20 per cent α-particles, with interaction mean free paths of 70 gm./cm.^{2} and 45 gm./cm.^{2} respectively, it is found that almost 80 per cent of the total primary flux should pass through the uppermost 15 gm./cm.^{2} of air without interacting with atmospheric nuclei. The results of flights F1-F8, if extrapolation to zero pressure is permissible, show little variation in the vertical intensity of particles capable of penetrating 8 cm. of lead over the pressure range 0-15 mb. Also the energy lost in traversing 15 gm./cm.^{2} of air is small compared with the average primary energy, so not much more than 20 per cent of coincidences ABC at 15 mb. can be due to penetrating particles associated with a disintegration at higher level. To explain the 15 per cent ratio of coincidences ABCD to ABC at 15 mb. would therefore require that a four-fold coincidence is registered on a large fraction of the occasions that the in-line counters are discharged by a penetrating shower particle. With only about 1 per cent of the primary flux interacting within 500 metres above the telescope, this could only be the case if the bulk of the secondary radiation near the "top of the atmosphere" were produced in events of very high multiplicity, the particles travelling in well collimated showers over air paths of great length.

There have been reported isolated instances of very large stars occurring in photographic emulsions, many of which are due to primary heavy nuclei. However, the observations of Lord and Schein[(47)] at 95,000 feet, where most of the disintegrations must be due to primary particles, and those of Camerini et al.[(50)] at 68,000 feet, show that the vast majority of showers are too small and the constituent particles too widely divergent to be detected over great distances in the present experiments.

Shower radiation incident on the telescope need not necessarily all be created in the same catastrophic event, since the particle density may be built up in successive interactions of the shower particles, but in this case it is difficult to see how the maximum counting rate can occur with less than 15 gm./cm.^{2} of air above the telescope. Secondary processes have little chance of development in this small quantity of matter. It is probable that a large part of the electronic radiation originates from the decay of neutral mesons emitted in the high energy interactions of the primary flux, and some increase in the shower multiplicity may come from this source. It has been estimated (50,51), however, that the average ratio per event of neutral to charged mesons is less than unity, the proportion decreasing with increasing shower size, and no important development of the resulting cascades above the telescope in less than half a radiation length of air is to be expected.

Thus the evidence obtained in photographic plates indicates that individual events of the requisite size are relatively too infrequent to account for the present results. A higher probability of an appreciable contribution to the coincidence rate ABCD from vertical showers will exist if the known trend towards a larger proportion of high energy events with increasing altitude becomes more marked above the 100,000 feet level, or if the production of short-lived non-ionising secondary radiation is more frequent than at present estimated. These factors would increase the possibility of recording individual events. The main requirement, however, is for a much larger fraction of the penetrating intensity at small atmospheric depths to be of secondary origin. Since the results of flights F1-F8 determine the vertical intensity of particles capable of penetrating 8 cm. of lead at any altitude, this can only come about if the interaction mean free paths of the primary protons and α-particles are much shorter than those assumed above, or if the relative abundance of incoming nuclei heavier than α-particles is much greater than is at present believed. Otherwise it is difficult to reconcile the frequency with which showers are recorded at high altitude with the effect of events occurring in the air above the telescope.

Experimental evidence.

The experimental evidence which is discussed below comes mainly from previous attempts to measure the influence of showers on the counting rate of a vertical telescope in the upper atmosphere. Comparison with the present data is difficult because in all other experiments (apart from some by Schein[34] and by Vidale and Schein[28] the results of which remain unpublished) the out-of-line counters were positioned below absorber level with the resulting possibility of recording local events.

In their 1941 report, Schein et al.[6] indicate that shower corrections were measured by the inclusion of additional counters alongside the main telescope. The position of these police counters was such that a high probability of shower detection was to be expected. However, the results showed that up to the 27 mb. level only a "few per cent" of particles traversing the main telescope were accompanied by shower counts. Because of the limited data provided and important differences in geometry no accurate comparison with the present results is possible.

Winckler et al.[25, 26] used extra counters to detect shower events, and by employing a multi-channel system of radio transmission were able to detect those particles passing through the main telescope which were accompanied by shower radiation. The few such events observed occurred at pressures greater than 200 mb. Screening of the central counter of the main telescope by the absorber may have largely excluded soft side showers, but it is difficult to understand why bursts in the lead were not detected. It seems probable, as the authors suggest, that the radio channels carrying the shower signals may have failed

Pomerantz[23, 24] measured the side shower effect in a separate flight in which one counter was moved just out of line with the other three in a telescope containing 4 cm. of lead. His highest out-of-line rate was about 5 per cent of the corresponding in-line rate. Though not specifically stated, this presumably occurred at 17 mb. the lowest pressure reached in this particular flight. At similar pressure the coincidence rate ABCD is about 15 per cent of the rate ABC. From the point of view of side showers this difference could be due to the extra particle required to give a coincidence in the four-fold telescope used by Pomerantz. In this case, however, unless the effect is masked by showers created in the absorber, the in-line intensity measured by Pomerantz should correspond more closely to the difference curve, curve 3 Figure 46, than to curve 1. This is clearly not the case. If, on the other hand, the events recorded by each telescope are mainly vertical air showers, a discrepancy of this nature in the observed shower rates is to be expected because of the relatively greater sensitive area presented to the shower particles by the out-of-line counters in the telescope ABCD. Further, the agreement between measurements of the absolute vertical intensity of the penetrating component at 15 mb. can only be regarded as fortuitous if 15 per cent of the coincidences ABC and only 5 per cent of the four-fold coincidences observed by Pomerantz are due to side showers.

Though not confirmed by Pomerantz' data, the maximum appearing on the vertical penetrating intensity curves published by Vidale and Schein(28) can be interpreted in favour of the side shower theory. Their measurements at latitude 55°N. with a four-fold telescope containing 7.5 cm. of lead bear some resemblance to curve 3, Figure 46. To explain this in terms of side showers again assumes a lower sensitivity to these events for the four-counter telescope. The objections are that the maximum observed by Vidale and Schein is much flatter than that on curve 3, and that it occurs at about 65 mb. as opposed to 35 mb. Also, if the three-fold telescope is the more sensitive to side showers, the absolute intensity at 15 mb. calculated from the coincidence rate ABC should be greater than that calculated from the data of Vidale and Schein. Although any latitude effect would tend in the same direction, the data show that this is not the case.

Several experiments relevant to the present problem have been performed by Russian workers. They are interesting because significant shower effects were observed, but in most cases it is difficult to correlate the findings with the results discussed above. For example, Baradzei et al.[52] found that about 25 per cent of the penetrating particles observed at high altitudes with a telescope containing 8 cm. of lead were associated with showers detected by an out-of-line counter, while on removal of the lead the number of such shower counts was small. This means that the effect of side showers and vertical air showers was relatively small compared with that of events occurring in the lead. Unless the efficiency of this type of shower recording arrangement depends critically on small differences in the disposition of absorber in relation to the position of the out-of-line counter, the frequency with which shower events were recorded in this experiment seems inconsistent with the observations of Pomerantz and Schein et al. In another experiment, by Alekseeva and Vernov (53), three counters separated by 4 cm. of lead were surrounded by eight police counters all in parallel, the police counters effectively screening the two lower counters of the main telescope though positioned out of line. At the minimum pressure reached, about 15 mb., approximately 33 per cent of three-fold coincidences were accompanied by discharge of the police counter arrangement. To account for the frequency of the shower events it seems probable that a contribution from some source other than wide-angle showers in the absorber is required. This might come from side showers or from vertical air showers. If it is the latter, an effect relatively larger than that observed in the present experiments may be expected from the increased police counter area. The contribution from side showers at very high altitude, where most of the soft radiation is moving at large zenith angles, should be recorded with similar efficiency by each telescope.

Conclusions.

The present interpretation of the results of flights F12-F16, so far as they affect the previous vertical penetrating intensity measurements, is necessarily based mainly on the rather indirect experimental evidence discussed above.

Using vertical four-fold coincidence telescopes, either with one counter displaced out of line or with suitably disposed police counters, Pomerantz and Schein et al. detected less than 5 per cent of the coincidences recorded at high altitude as being due to shower events. This figure includes an unknown contribution from bursts occurring in the absorber. In the present experiments, although precautions were taken against local disturbing effects, a considerably greater proportion of shower events was observed. It has been shown that no consistency among the various vertical penetrating intensity measurements results from assuming the showers recorded by all telescopes to be incident from the side, their influence being determined by the number of particles required to produce a coincidence. Apparently, therefore, the multiple events must be detected by the arrangement of counters ABCD with greater efficiency than was the case in previous experiments. There is no reason to believe that in the telescope used by Schein et al. the police counters gave any less adequate coverage of the shielded counter to radiation moving at large zenith angles than in the present experiments, or that the sensitivity to side showers of a vertical telescope, as used by Pomerantz, is significantly reduced by a small displacement of one counter. The greater response of the telescope ABCD can only be attributed, by reason of the position and the relatively larger effective cross-section of the police counters, to an increased sensitivity towards showers moving at small zenith angles. Much better consistency among the experimental results is obtained on the basis of vertical motion of the shower particles.

Consideration of the data from flights F12-F16 in terms of side showers has shown the improbability of a rapid increase in the coincidence rate ABCD up to the 15 mb. level due to this type of event. The observed variation of the coincidence rate with decreasing atmospheric pressure is more compatible with the response of the telescope to showers produced at higher altitude by the interactions of the primary flux. To explain the experimental results in this manner requires that the average interaction mean free path in air of the primary particles be shorter, and that the average event be of much higher multiplicity than is indicated by the data obtained in photographic plates. These difficulties are formidable, but they may be resolved when it becomes possible to expose emulsions over long periods at still greater heights.

Although the coincidences recorded in flights F12-F16 are attributed mainly to showers moving close to the vertical direction, some modification of the vertical penetrating intensity measurements may still be required. In addition to single particle coincidences and those due to side showers, the latter being defined as requiring a minimum of three charged particles, the results of flights F1-F8 will include a contribution from events in which two adjacent counters of the telescope ABC are discharged by one particle while the other counter is actuated by a second particle. Coincidences of this nature are caused by radiation moving outside the angular aperture of the three-fold telescope but inside the solid angle defined by two adjacent counters. The geometry of the telescope ABCD is such that the majority of these events will be recorded as a four-fold coincidence in flights F12-F16 provided the shower particles are moving along nearly parallel paths. In the most probable cases a single penetrating particle will traverse the counters D, B and C while associated radiation discharges counter A. The relative importance of events of this type may be estimated from the ground level counting rates. At this point the coincidence rate DBC is just under one-third of the rate ABC. Only this fraction of the four-fold rate ABCD can be regarded as a correction to the three-fold rate ABC at corresponding level. The maximum correction of about 5 per cent at high altitude is barely significant in view of the statistical uncertainties of the data.

It is unfortunate that deterioration of balloon performance made it impossible to extend the range of observations in flights F12-F16 at least to the maximum altitudes attained in previous flights. On the other hand, it is doubtful whether the information obtained in a single successful flight reaching, say, the 5 mb. level, would have been of sufficient accuracy to simplify greatly the interpretation of the experimental data. As an alternative to the attainment of extreme altitude, discrimination between events through various modifications to the telescope was considered. The difficulty is to devise a simple counter arrangement which would give unambiguous results. Owing to the low counting rates many more flights would have been required to obtain the necessary accuracy of information. The present equipment, designed with a single channel of radio transmission for the measurement of single particle intensities, is not suited to the study of multiple events. Further investigation by counter technique into the characteristics of air showers and disintegrations in absorbers at very high altitude is obviously necessary, but this type of work requires more complex telescopes and the simultaneous recording of coincidences between different combinations of counters.

ACKNOWLEDGEMENTS.

It is with pleasure that acknowledgement is made of the valuable assistance received from many quarters during the progress of these experiments.

Thanks are due in particular to Professor N. Feather, F.R.S. for extending the facilities of his laboratory, and to Mr. E.G. Dymond, M.A., who supervised this research, for his guidance and active participation in all phases of the work.

The assistance of many members of the staff and research students of the Natural Philosophy Department and other friends during the launching operations in the early hours of the morning was greatly appreciated.

Weather forecasts and information about the prevailing wind conditions in the upper atmosphere were made readily available through the kind co-operation of the Meteorological Officer and his staff at Pitreavie, Fife.

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