Dissertation

on

STUDIES IN COSMIC RAYS

"The Study of the Daily Variation of Low and High Energy & Mesons"

and

"The Study of the Correlated Changes of Anisotropy and Mean Intensity of Cosmic Rays"

presented

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STATEMENT

The work presented in the thesis was carried out by the author, at the Physical Research Laboratory, Ahmedabad, under the guidance of Professor Vikram A. Sarabhai, and is a part of an extensive research programme undertaken by the laboratory for the study of cosmic ray time variations.

Till 1950, such studies were generally made with ionisation chambers of omnidirectional sensitivity and counter telescopes of wide apertures. Daily variation of intensity of amplitude of the order of about 0.2 % was observed in such experiments. In the study described in Chapter III of the present thesis, the author has made an attempt to reduce the aperture of a counter telescope to what might be considered a lower limit. The study revealed, what was independently discovered by Sekido and his co-workers, that the daily variation of \$\mu\$ meson intensity observed by a narrow angle telescope shows a diurnal variation of large amplitude of about 2.2 \pm 0.5 %. This has led to more elaborate studies of time variations with narrow angle telescopes.

The experiment which made use of a magnetised iron core for deflecting low energy μ mesons, has also made possible for the first time a separate study of the daily variations of positive and negatively charged low energy μ mesons in the momentum range 400 to 3000 Mev/c, and high energy μ mesons of momenta in excess of 3000 Mev/c.

The second experiment described in Chapter IV deals with an attempt made by the author to study with narrow angle telescopes the types of daily variations that occur on individual days. The correlated day to day changes of anisotropy and of mean intensity of cosmic rays have also been examined. This is the first study of its kind, and while the conclusions are based only on data extending for 11 months, and therefore are tentative, they indicate that cosmic ray mean intensity changes are not only decreases but there are significant increases on some days.

The results and the conclusions derived from both the experiments are summarised in Chapter V. The author has included at the end of the thesis a list of references to original papers published in different parts of the world. The thesis mentions the specific information derived from each of them.

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W.

P. D. Bhavsar

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CHAPTER I

INTRODUCTION

It is a well established fact that the intensity of cosmic radiation is not constant, but changes with time. The review by ELLIOT (1952) and the more recent one by SARABHAI and NERURKAR (1956) trace the development of experimental knowledge and the interpretation of the variations of cosmic rays in light of the work published upto 1956.

Most early workers, who observed cosmic ray intensity variations, tried to explain them in terms of atmospheric and geomagnetic variations. Through the important contributions of DUPERTER (1944, 1949, 1951), BARRETT et al. (1952), OLBERT (1953), TREFALL (1953a, 1955a, 1955b, 1955c), MAEDA and WADA (1954), WADA and KUDO (1954), WAYAKAWA et al. (1955), and several other workers, the changes in the intensity due to the changes in the atmospheric conditions are now well understood. After applying correction for atmospheric variations there still remain residual significant variations. These are often correlated with geomagnetic changes, but closer study has

revealed that in many cases there is no causal relationship between the magnetic changes and the changes of cosmic radiation. In consequence, attempts have been made to explain these variations as arising from extraterristrial causes.

In the past, various workers have studied intensively the different types of variations, but there is as yet comparatively little that we know about the relationship between the different types. Thus a distinction is often made between types of variations, which probably have a common physical basis. It seems now necessary to make a more detailed examination, than hitherto, of the interrelationship between the types of variations classified on phenomenological considerations.

1. Variations of Atmospheric Origin.

The role of the changes of atmospheric conditions in producing changes in cosmic ray intensity is now more or less well understood. This is of particular significance for the meson component measured at low levels in the atmosphere and enables corrections to be made for variations of atmospheric origin. By partial correlation analysis of day to day changes, DUPERIER (1949) was able to derive a regression equation

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$$\frac{\delta I}{I} = \alpha_B \delta B + \alpha_H \delta H + \alpha_T \delta T$$

connecting the per cent change of meson intensity with the

change of barometric pressure &B, the change of height of the 100 mb. level &H and the change of temperature of atmosphere between the 100 mb. and 200 mb. levels. Duperier interpreted the barometer coefficient $lpha_{
m B}$ as arising from a mass absorption effect, the decay coefficient AH as arising from the change of survival probability of ju mesons when the mean height of meson formation alters, and the positive temperature coefficient T as arising from competition between the processes of π - μ decay and the nuclear capture of π mesons which depends on the density of the atmosphere near the level of creation of μ mesons. This equation and the physical meaning ascribed to the coefficients has met with two major difficulties. It was found that the values of the coefficients experimentally determined were not constant. They varied from period to period for the same instrument and they differed according to whether day to day or seasonal changes were considered.

The differences in the estimates of $\alpha_{\rm H}$ and $\alpha_{\rm T}$ when meteorological changes of a day to day and seasonal character are considered, have been examined by a number of workers. Neglecting π - μ decay, and with a production spectrum of μ mesons as given by SANDS (1950), OLBERT (1953) has studied the change of survival probability of μ mesons. He has pointed out that even if the mean height of meson formation remains constant, the survival probability of the mesons depends on the distribution of mass along their path.

If there is a proportionately greater mass encountered towards the end of the range, there is correspondingly a reduced ionisation loss and degradation of energy during the earlier part of the path of the meson, thus increasing the survival probability in the atmosphere. Olbert has further demonstrated that when one considers a regression equation connecting δI with δH and δB only, neglecting the role of δT , the contribution of δT gets included in the term containing δH . As the relationship between δH and δT differs in seasonal and day to day changes, he was able to reconcile the apparent differences in the values of ∞_H when two different types of variations were considered by ELLIOT and DOLBEAR (1951).

TREFALL (1955c) has recently pointed out that the survival probability of μ mesons would alter with change of pressure due to ionisation loss. This loss would make a contribution to the barometric coefficient α_B just as Olbert had shown earlier that it would make a contribution to the temperature coefficient α_T . Thus the interpretation of α_B as being due to a pure mass absorption effect requires modification. Trefall estimates that up to a third of this coefficient may arise from the change of survival probability.

It is evident now that the regression equation of the type used by Duperier is inadequate to describe fully the atmospheric effects. In physical terms, his coefficient α_B includes effects due to mass absorption

and μ -e decay, the coefficient α_H relates to μ -è decay while α_T relates to π - μ decay as well as to μ -e decay. WADA and KUDO (1954) have suggested that by taking the height H to represent the difference between the height of mean level of meson production and an isobaric level near the ground, the mean temperature of the lower atmosphere is taken care of. Moreover this H is independent of sea level pressure. Using this H and a mean atmospheric mass temperature in conjunction with an appropriate temperature coefficient, a satisfactory modification to the original regression equation can be derived.

The relative contributions of these processes to the secondaries of different momenta is of great interest in understanding the role of atmospheric effects to measurements of intensity within ranges of momenta measured in a particular experiment. HAYAKAWA et al.(1955) by considering the effect of nucleonic cascades on the production of μ mesons have studied the change of the temperature coefficient α_T with increasing energy of the μ mesons. Fig. 1 shows the relationship as calculated by them, which broadly agrees with observations made underground by BARRETT et al.(1954) and SHERMAN (1954). It would be observed that the positive temperature effect which includes the contribution arising from process of π-μ decay as well as the survival probability of the μ mesons, increases markedly from ~0.03% per degree C. to

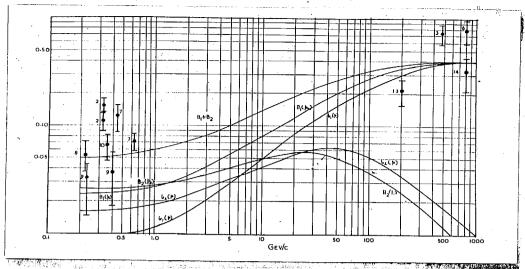


Fig. 1. Positive temperature coefficients. b₁ and b₂ are the coefficients for the differential intensity of μ mesons at sea level. B₁ and B₂ are the corresponding ones for the integral intensity. Figures attached on the experimental values indicate the reference numbers in the original paper. [HAYAKAWA et al.(1955)].

~ 0.27% per degree C. with change of momenta of secondary mesons observed at sea level from 1 to 100 Gev/c. The process of ionisation loss does not change substantially for momenta of μ mesons in excess of about 0.1 Gev/c.

The correction of the daily variation of meson intensity for the removal of the effects of atmospheric origin has been considered by several workers. SARABHAI et al. (1953, 1955) have discussed the expected contributions due to daily variation of pressure, of heights of isobaric levels and of temperatures of various levels in the atmosphere. Except at very high altitudes the diurnal heating of the atmosphere is important only up to about 2 Km. above the ground. Near the mean level of meson production there is nonsignificant and small diurnal change

of temperature or of the height of isobaric levels. The amplitude of the semidiurnal oscillation of the atmosphere at this level does not exceed a few meters even at the equator. Thus in the daily variation there is expected to be little contribution of the change of height of isobaric levels or of upper air temperature. MAEDA (1953) has also examined this problem from a number of different aspects. He concludes that there is a small diurnal variation of amplitude about 0.05% with maximum at 1400 hours which he considers to be of atmospheric origin. This is in addition to the contribution of the barometric pressure.

The appropriateness of using only a barometric coefficient for correcting the principal atmospheric effects in the daily variation of the hard component intensity has been borne out by experimental results. For instance, when the daily variation studied at two different stations which have markedly different daily variations of meteorological element are corrected on this basis, the resulting residual variations show similar characteristics and changes with time. However, no experimental data are available of the contributions of atmospheric effects on the daily variation of secondary μ mesons having momenta in the range from 0.4 to about 3.0 GeV/c and in the range extending from about 3.0 GeV/c to infinity.

2. Changes of Extraterrestrial Origin.

The residual changes which are observed in the

intensity of cosmic radiation after appropriate corrections are made to remove the effects of atmospheric origin can broadly be classified in terms of changes of intensity and changes of anisotropy. It has been found that many of these changes exhibit remarkable solar and terrestrial relationships. The important characteristics of the observed changes are described here.

- 2.1 Changes of intensity.
- 2.11 Long term changes of intensity and "knee":

Changes of total intensity. - One of the most remarkable variations that has been discovered recently is the change of general intensity of cosmic radiation correlated with the change of solar activity of sunspot numbers. This change of 12 month mean intensity measured by the Carnegie Institution stations was shown by FORBUSH (1954) and by GLOKOVA (1953), to be of the order of four per cent between sunspot minimum and sunspot maximum and to be present to almost an equal degree in all four stations ranging in latitude from the equator to 80°N. Fig. 2 taken from Forbush demonstrates this change. Forbush has separated his data for magnetically quiet and disturbed days and shows that the change of intensity is present almost equally in both the groups. This is indicative of the fact that the change is not produced in a simple way by a series of magnetic storm type decreases occuring with varying frequency during different periods of the solar cycle.

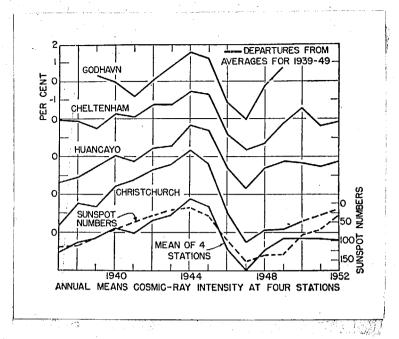


Fig. 2 Annual mean cosmic ray intensity at four stations [FORBUSH (1954)].

Evidence of similar changes at high altitudes is provided by balloon experiments conducted by NEHER (1955). Corresponding to the change of only four per cent observed at sea level, Neher shows that at the latitude of 35° to 35°N. there was a change in total ionisation of about 50 per cent at an altitude of 70,000 feet from the sunspot maximum year of 1937 to the sunspot minimum year of 1954.

MEYER and SIMPSON (1955) in aeroplane flights at 30,000 feet have reported a change of 13 per cent in intensity measured by neutron monitors from 1948 to 1957 compared to a 1 per cent change observed at sea level.

Change of "knee" of the latitude effect. — NEHER (1952) has summarised experimental data extending up to 1950 concerning the measurement of the latitude effect of cosmic rays at various altitudes. A most remarkable

feature that emerged from these studies was the absence of a low energy component of primary cosmic radiation. The "knee" in the latitude effect indicates that beyond a latitude of about 55° there is no further change in the total cosmic ray intensity even at the highest altitudes. This indicates a sharp cut-off in the primary spectrum at 0.8 Gev (for protons).

Fig. 3 from Neher shows the "knee" of the intensity versus latitude curves for an atmospheric depth of 15 gm./cm2 during 1937, 1951, and 1954. The figure illustrates clearly the shift of the "knee" to higher latitudes from 1937 to 1951. The low energy cut off for protons at 0.8 Gev during 1951 is absent during 1954 when a very large intensity of soft particles down to energies of 0.15 Gev for protons is measured and there is no evidence of a "knee". MEYER and SIMPSON (1955) have reported that from 1948 to 1951, the "knee" of the latitude effect has shifted by 3° from 55 to 58°N. Simpson did not observe much change between 1951 and 1954, but since the results of NEHER et al. (1953, 1955) show that this change was almost entirely due to the influence of particles, if protons, between 0.15 and 0.8 Gev, it is to be expected that these would produce little effect at 30,000 feet altitude where Simpson's observations were carried out.

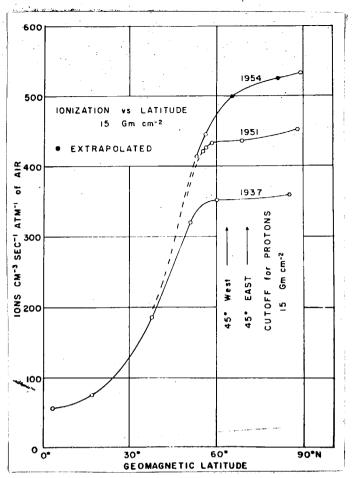


Fig. 3. Long term change of latitude effect at 15 gm./cm.2 atmospheric depth [NEHER (1955)]

2.12 Short term changes of intensity:

Day to day changes of intensity: The day to day changes of intensity, some of which are of the 27 day recurring type, have been extensively studied in recent years. Early work related to small changes noticed in ionisation chambers, but a significant step forward was possible with data from Simpson's neutron monitors in which it was quite obvious that large and significant changes of intensity of a few per cent in amplitude were occurring almost continuously from day to day. SIMPSON et al. (1952)

showed the association of the increases with the central meridian passage of active solar regions, and particularly of regions of green coronal emission on the sun. These increases were often seen to be followed within two to three days by increased geomagnetic activity. Recently SIMPSON et al. (1955) have shown the close association of the central meridian passage of unipolar UM regions with cosmic ray increases during 1953. These regions as well as the increases of intensity persisted for several solar rotations.

Several workers have now demonstrated that the day to day changes are worldwide in character. FONGER (1953) has found that changes in the neutron monitor at Climax are similar to simultaneous changes observed in the ion chamber at Freiburg, but on the average are five times greater in amplitude. NEHER and FORBUSH (1952) have demonstrated the correlated changes occurring in the ion chambers at Huancayo and Cheltenham, the neutron monitor at Climax and the ionisation at 70,000 feet over Bismarck. These are shown in Fig. 4 which reveals the difference in amplitude of changes in each case. NEHER et al. (1953) have demonstrated that the changes at high altitude over Bismarck and near the north geomagnetic pole are correlated amongst themselves and with changes in an ion chamber at ground level. van HEERDAN and THAMBYAHPILLAI (1955) have recently investigated the correlated changes measured with a neutron monitor and a counter telescope at London. In the study of

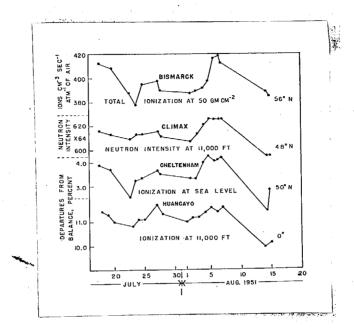


Fig. 4. Correlated day to day changes of cosmic ray intensity [NEHER and FORBUSH (1952)] .

the 27 day recurrence of these changes, they find a decrease of mean intensity connected with the increase of amplitude of the fluctuations. They have thus come to the conclusion that the changes represent decreases of intensity. MEYER and SIMPSON (1954) have studied the 27 day recurrence tendency in the ion chamber data of Huancayo and the neutron monitor at Climax, and have demonstrated that the recurrence tendency is altered during the solar cycle. It is more pronounced during sunspot maxima, when incidentally the general intensity is low, and is weak at sunspot minimum when the general intensity is maximum.

MEREDITH et al. (1955) have made rocket measurements with a single counter capable of responding to radiation of

intensity as low as 20 MeV. They find that on many days during 1954 there is, at an altitude above 40 km., a large intensity of radiation of energy between 20 MeV and 140 MeV. It is of course debatable whether radiation of this type can legitimately be classed in cosmic radiation. But the observations show that just like the day to day variations of high energy radiation, there is also a day to day variation of large magnitude occurring in much softer radiation which can only be observed at very high altitudes.

Magnetic storm type changes. - Large worldwide decreases of cosmic ray intensity associated with magnetic storms have been reported in the past. These decreases have several remarkable features. All magnetic storms are not associated with decrease of cosmic ray intensity, and when effective storms take place, the ratio of change of magnetic field strength to the change of cosmic ray intensity is not constant from event to event. In storms such as the large storm on March 1, 1942, there is almost no latitude effect observable in the magnitude of the decrease at different stations extending from the equator to high latitudes. On the other hand in some storms, the low energy component of the primary cosmic radiation appears to be disturbed more than the high energy component. NEHER and FORBUSH (1952) have compared a storm type decrease observed at 70,000 feet over Texas with the decrease in the ion chamber at Mt. Wilson and have showed that the effect was

about four times more pronounced in the former case.

During the past three years, further work has been done in studying the solar and terrestrial relationships of magnetic storm type decreases in cosmic ray intensity. CHASSON (1954) has shown that decreases of intensity occurred on two occasions an appreciable time before measurable geomegnetic disturbances. TREFALL (1953b) has concluded that magnetic storms with a dominent positive peak and a negative peak which is small or absent, produce no change of intensity. TRUMPY (1953) and KITAMURA (1954) have examined the characteristics of some magnetic storms. SEKIDO et al. (1955a) have studied the solar relationship of cosmic ray effective and noneffective magnetic storms, which they designate as S and M type storms respectively. have found that the frequency of S type storms varies in step with the 11 year cycle of solar activity, but this is not the case with M type storms which they associate with the supposed M regions on the sun. There is correlation between the occurrence of S type storms and the central meridian passage of large sunspot groups. This feature is absent for M type storms. The 27 day recurrence tendency as seen with Chree diagrams, shows sharp peaks for M type storms but sinusoidal change for S type storms. The authors conclude that 3 type storms are caused by wide corpuscular clouds ejected from sunspot groups, but the M type storms are caused by narrow corpuscular beams from M regions.

2.13 Solar flare type increases :

The large solar flare type of increase of intensity is of rather rare occurrence. Its characteristics during the four recorded occurrences prior to 1950 have been described in detail by ELLIOT (1952). However considerable fresh knowledge has been obtained from the latest occurrence on February 23, 1956, which was observed by a number of stations scattered in different part of the Elliot and Gold have made a compilation of the data relating to this interesting event. The remarkable feature about the recent event was that the general cosmic ray intensity was steadily diminishing from \sim 10 days prior to the onset of the flare. The increase of intensity was observed not only at middle and high latitude stations as during the earlier events but was recorded at equatorial stations as well. The increase was observed at all longitudes, though the time of onset, the per cent increase, as well as the time of recovery differed according to local time, latitude of the station and type of detector. The event is strongly suggestive of the existence of a storage mechanism in the solar system in which solar particles ejected during the flare are trapped and re-emitted under approximately isotropic conditions. Further interpretation on these lines has been discussed by MEYER et al. (1956) and by PFOTZER (1956).

2.2 Changes of solar anisotropy:

2.21 Long term changes :

Large worldwide changes of the 12 month mean daily variation of meson intensity have been discovered by SARABHAI and KANE (19534). By an examination of data from 1937 to 1946 of LANGE and FORBUSH (1948) they drew attention to correlated changes of amplitude and of time of maximum of the diurnal component of the daily variation at Christchurch, Cheltenham, and Huancayo. They pointed out the relationship of these changes with the 11 year cycle of solar activity and with the magnetic character figure, and showed that correlations improved during sunspot minimum.

THAMBYAHPILLAI and ELLIOT (1953) have confined attention to the time of maximum of the diurnal component of the daily variation. After showing the correlated changes occurring in it at the Carnegie Institution stations, they have combined data from various sources to study the trend of change from 1932 to 1952. They were led to a general conclusion that the change probably followed a 22 year cycle of solar activity.

STEINMAURER and GHERI (1955) have recently compared data taken over groups of years over the past 23 years. They show that during sunspot minimum in 1933, the time of maximum of the diurnal component was at about 0700 hours, comparable with the time of maximum about 20 years

later in 1953-54, but was earlier than the time of maximum 11 years later in 1944. This indicates again a relationship with the 22 year cycle of solar activity. It is noteworthy that a maximum as early as 0200 hours in 1954, has never before been observed.

SARABHAI et al. (1954) have extended their earlier analysis of changes at the Carnegie Institution stations by examining further unpublished data from 1946 to 1953 supplied by Forbush. They find that while changes of amplitude at the different stations are not correlated in the new sofar cycle, the changes of time of maximum continue to exhibit worldwide characteristics.

SARABHAI et al. (1955a) have demonstrated that in addition to long term changes in the diurnal component of the daily variation, significant changes also take place in the semidiurnal component. When the daily variation is considered as a whole instead of in terms of its harmonic components, a very remarkable sequence of changes is revealed as shown in Fig. 5. At Huancayo, the 12 month mean daily variation which exhibits one maximum near noon from 1937 to 1943, changes over by 1952 to a variation exhibiting one maximum early in the morning. In the intervening period, there is clear evidence of the progressive increase of the early morning maximum followed by a decrease of the noon maximum. During the period 1945 to 1950 the daily variation therefore exhibits two maxima instead of one. Sarabhai and co-workers thus conclude that

variation, it is clearly necessary to discard individual consideration of only the diurnal component of the variation. The most appropriate manner of studying the changes is by examination of the daily variation unresolved into its harmonic components. As shown in Fig. 5, only half the cycle of change appears to be completed in 11 years. This is again indicative of a 22 year cycle of change of the anisotropy.

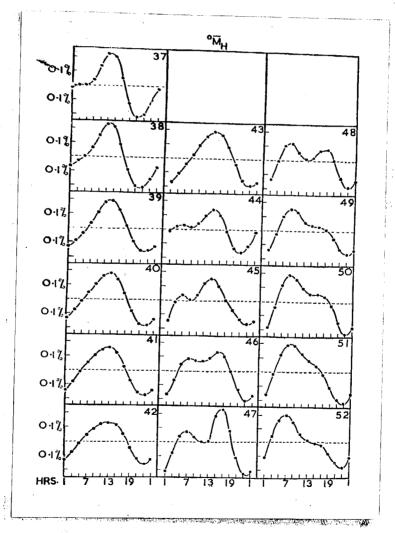


Fig. 5. The 12-month mean daily variation of meson intensity at Huancayo, during different years [SARABHAI et al. (1955)].

SARABHAI et al. (1955a) have suggested that changes of the daily variation could be considered in terms of the contributions of two distinct types of variations. Both have one principal maximum. For the 'd' contribution the maximum occurs near noon and for the 'n' contribution at about 0300 hours. It has been shown by them that the pattern of addition or subtraction of the day and night contributions of the daily variation is worldwide in character and can satisfactorily explain the observed changes from year to year at Huancayo as well as at Cheltenham. The activity of the two contributions is closely related to the solar cycle of activity. In general, the day and the night contributions are simultaneously added or attenuated. However, just preceding sunspot minimum, there is a brief period when only the day contribution appears to be active. This is immediately followed by an equally brief period when only the night contribution is active. The pattern of addition and attenuation of the contributions appears to be reversed after 11 years.

2.22 Short term changes :

The change of the diurnal component of the daily variation of cosmic rays during magnetically disturbed days has been studied by several workers [SEKIDO and YOSHIDA (1950), ELLIOT and DOLBEAR (1951), EHMERT and SITTKUS (1951), SEKIDO and KODAMA (1952), SEKIDO et al. (1952), TRUMPY (1953), FIROR et al. (1954), SANDSTROM (1955), and YAGI and UENO (1956)]. It is found that on days with high Kp, the amplitude of the

diurnal component increases and its time of maximum becomes earlier. SEKIDO and KODAMA (1952) have shown that this effect is present to a greater degree in measurements made with narrow angle telescopes than with instruments with wider directional sensitivity. SEKIDO and YOSHIDA (1951) have moreover demonstrated that the semi-diurnal component which is normally present to a greater extent in the daily variation measured with narrow angle telescopes than with telescopes of large semiangle, gets reduced on magnetically disturbed days.

of the mean storm type vector representing the difference in the diurnal components of the disturbed period daily variation and the quiet period daily variation during each year. They have shown that the disturbance vector representing a storm type anisotropy points on the average towards the radially outwards direction from the sun, and undergoes a long period change from year to year, broadly in step with the 11 year cycle of solar activity.

Following the discovery of long term changes in the anisotropy of the primary radiation as revealed by changes in the 12 month mean daily variation of cosmic ray intensity, various attempts have been made to study the short term changes of the anisotropy, not necessarily connected with magnetic disturbances. FIROR et al.(1954) have pointed out that the daily variation of the nucleonic component as revealed by the neutron monitor is highly variable in

character. They found groups of days on which there was a large diurnal variation with a maximum during the day. There were other days on which there was no appreciable daily variation, and indeed on others, the daily variation appeared to have a maximum in the night. SITTKUS (1955) has looked at the amplitude of the diurnal variation measured by an ion chamber on individual days and he has noticed the tendency for a variation of large amplitude with a maximum near noon to occur during groups of days. He has found 27 day recurrence tendency for these groups but compared to the rest of the days, the days with large noon time amplitude are not associated with a significantly different magnetic character figure. REMY and SITTKUS (1955) have shown that during 1954, the occurrence of days on which there was a large day time maximum of intensity was rarer than in 1953. They have moreover noticed a great variability of the time of maximum of the diurnal component of the daily variation.

Weighty evidence concerning the change of anisotropy from day to day comes from the investigations with narrow angle telescopes reported by SARABHAI and NERURKAR (1955). With telescopes having semiangles of 2.5° and of 5° in the E-W plane, the combined data for each type of telescope for every day were examined.

On about 75 per cent of the total days the daily variation exhibited only one maximum. For these days they

have found, as shown in Fig. 6, a marked tendency for the diurnal maximum during the year 1954 to occur either at 1200 noon or in the early morning at about 0300 hours

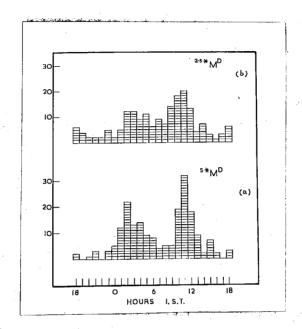


Fig. 6. The distribution of occurrence of the diurnal maxima for each of 24 hours of a day. The upper and the lower histograms refer to telescopes of 2.50 and 50 semiangles respectively in the E-W plane [SARABHAI and NERURKAR (1955)].

local time. On the basis of a phenomenological classification of days according to whether they exhibit a maximum during the day, a maximum during the night or they exhibit two maxima instead of one, the days have been designated as 'd', 'n' and 's' respectively. The three types of daiby variations obtained for data averaged for days of each type are shown in Fig. 7. The results indicate that there are at least two preferred orientations of the anisotropy and that on any particular day which does not belong to the 's' type, there is present either one of these two types of orientations.

The amplitude of the daily variation occurring on each of these types of days is large and is of the order of 1.5% to 2.0% as observed with a narrow angle telescope at low latitudes. These days, particularly of the 'd' type, have a 27 day recurrence tendency and usually occur in groups as observed by Sittkus.

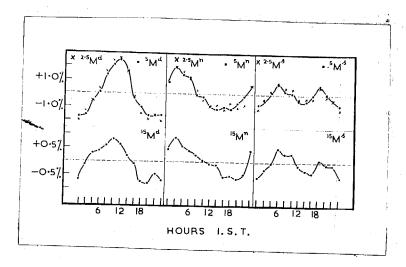


Fig. 7. The average daily variation of meson intensity measured with telescopes of 2.50,50 and 150 semiangles on 'd', 'n' and 's' type days [SARABHAI and NERURKAR (1955)].

The recurrence tendency of the anisotropy observed in the ion chamber data at Huancayo has been studied by YOSHIDA and KONDO (1954). They found a strong recurrence tendency, extending to two solar rotations, which was more marked than the recurrence tendency in either the general cosmic ray intensity or in the magnetic character figure during the same period. KANE (1955) has studied the recurrence tendency in the daily variation measured by neutron monitors at several stations and by the Freiburg ion chamber for the years 1951, 1952, and 1953. He has shown

that the recurrence tendency in the daily variation, unlike the tendency in the general intensity, remains almost unaltered during the three years.

3. Dependence of Variations on Energy and Type of Instrument.

SARABHAI and NERURKAR (1956) have attempted to summarise data, obtained by several workers with different types of instruments, as shown in Table 1 (page 26). will be noticed that the long term changes of intensity, the magnetic storm type decreases and the day to day changes of intensity exhibit certain common features. The amplitude of variations studied with omnidirectional instruments is generally smaller than with counter telescopes where the amplitude becomes progressively larger with a diminution of angle of opening of the telescope. There is often a larger change of intensity of particles of energy less than 10 Gev than of those above it. The ratio, however, of the changes observed in the two cases is variable. Moreover, there are occasions when, as shown by Neher, the reverse is true, and there can be increase of intensity at intermediate energies without corresponding change at low energies. It is remarkable that the fluctuations are not as latitude dependent as a comparison of the neutron monitor studies with charged particle detectors at the same latitude would seem to suggest. appears that the difference between the semiangles of the meson detector, which is usually an ion chamber or a wide

Table 1

Katio of Amplitudes of Various Types of Changes Recorded by Wifferent Recorders*

Reference	FOLDUSH (1954)	NEHER (1955)	(1661) MOSEMITS	FOREIGH (1954)	FOREMSH et al. (1950)	SEKIDO et al. (1950)	SARABHAI and KANE (1953b)	NGHER and FORBUSH (1952)	FONGER (1953)	NEHER and FORBUSH (1952)	NEHER and FORBUSH (1952)	FINOR et al. (1954)	SARABHAE and RANE (1953a)	SALABHAI and KANE (1953b)	SEKIDO et al. (1950)	SARABHAI et al. (1955b)	
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	IC 43°S sea level				IC 80°N sea level	C1 (+350)	33				Ic 16S			រ័			
	17 100 1t	1000 ft	IC LOOM	1000 ft	IC 500M sea level	CT(土400) 250世	10 4,00 M	IC sea level	IC 490M Sea Level	IC 50°N sea level	11000 ft	11000 ft	IC 500N Sea level	IC 490M	CE (±40°)	CT (±150)	
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change	10 4 5 10 10 10 10 10 10 10 10 10 10 10 10 10 1		Magnetic storm	change					de de la constant de			raria-	704				
	A:B or A:B:C	To 500N TO 103 IC 430S 1:1:1 FORBUSH (IC 50°N IC 1°S IC 4,3°S 1:1:1 FORBUSH (Sea level 11000 ft sea level (199000 ft 11000 ft 110	IC 50°N TO 1°S IC 43°S 1:1:1 FORBUSH (Sea Level 11000 ft sea level 12:1 NEHER (19 90000 ft sea level 5:1 SIMPSON (11000 ft sea level 5:1 SIMPSON (IC 500N IC 10S IC 430S I:1:1 FORBUSH Sea level IIO00 ft Sea level III NEHER	IC 500N IC 10S IC 430S 1:1:1 FORBUSH (1954) IC 500N IC 10S IC 430S 1:1:1 FORBUSH (1954) IC 500N IC 10S IC 490N IC 10S INM 420N IC 10S IC 500N IC 500N IC 500N I:1:1 FORBUSH (1954) IC 10S IC 500N IC 500N I:1:1 FORBUSH (1954) IC 10S IC 500N IC 500N I:1:1 FORBUSH et al.	amplitude A:B:0r	C FOON IC PS IC L30 IC FORBUSH (1954) Sea Sevel 11000 ft Sea Sevel 12:1 NEHER (1954) IC 500N IC PS IC L50 IC L50 IT TOOO ft Sea Sevel IC PS IT TOOO ft Sea Sevel IC PS IT TOOO ft Sea Sevel IC SOON IC SOON IC IC IC TOS IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 IC IC L50 IC L50 IC L50 IC L50 IC L50 IC L50 I	C A:B or A:B or A:B or C A:B or A:B or Sea S	C 50°N C A:B:C Sea level 11000 ft sea level WM 42°N IC 49°N IC 80°N 1:1:1 FORBUSH (1954) Sea level Sea level Sea level Sea level Sea level Sea level Sea level Sea level Sea level C (+4,5°) IC 4,9°N C (+8,5°) 3:1:7:1 SEAIDO et al. (1952) C (+4,5°) IC 4,9°N 1:5:1 SARABHAI and RAWE Sea level LC 4,5°N Sea level Sea level Sea level Sea level Sea level Sea level Sea level Sea level Sea level Sea level Sea Sea	C 50°N C 43°S 1:1:1 FORBUSH (1954) C 50°N C 1°S 1°C 43°S 1:1:1 FORBUSH (1954) C 50°N C 1°S 1°S 1°S 1°S 1°S C 50°N C 69°N 1°S 1°S 1°S C 10°O C 1°S 1°S 1°S 1°S 1°S C 1°S 1°S 1°S 1°S 1°S 1°S 1°S C 1°S 1°S 1°S 1°S 1°S 1°S 1°S C 1°S 1°S 1°S 1°S 1°S 1°S C 1°S 1°S 1°S 1°S 1°S 1°S C 1°S 1°S 1°S 1°S 1°S 1°S C 1°S 1°S 1°S 1°S 1°S 1°S 1°S 1°S C 1°S 1°S	C SOON C A:B or C SOON C A:B or C SOON C Soon C A:B or C SOON C Soon C A:B or C C A:B or C SOON C A:B or C C A:B or C SOON C A:B or C C A:B or C C A:B or C C A:B or C Soon C A:B or C C A:B or C C A:B or C C A:B or C Soon C A:B or C C C C C C C C C	C SO C A:B or	C 50°M C 10°S 10°N 10°N	C SOON C L20 Soon L2 L20 Soon L2 L20 Soon L2 L20 L20 L2 L20 L2 L20 L2 L2	C 500 C 100 C	10

 $[\]star$ The recorders are designated by IC for ionisation chamber, CT (\star x⁰) for counter telescope of semiangle x⁰ in the E-W plane and NW for neutron monitors. The geomagnetic latitude and the elevation of the observing station are indicated by numbers immediately following the abbreviation used for recorders.

angle telescope, and the effective directional sensitivity of the neutron monitor, is perhaps responsible for this discrepancy.

The amplitude of the diurnal component of the deily variation of intensity has frequency been considered an index of the degree of anisotropy of primary radiation. However, the amplitude depends very much on the directional sensitivity of the measuring instrument and on the period for which data are averaged. At the present moment we have no available data where the amplitude of the daily variation observed with a neutron monitor can be compared directly with the amplitude of the daily variation in meson intensity measured with a telescope of equivalent effective directional sensitivity. Until this is done, it would be difficult to conclude whether the anisotropy is greater in respect of the spectrum in the mean energy range of about 7 Gev which is measured in a neutron monitor at middle latitudes and in the spectrum with a mean energy of about 40 Gev which would be measured at similar station with a meson intensity recorder.

Some evidence on the energy dependence of the anisotropy is obtainable from the latitude effect of the amplitude of the daily variation observed with similar instruments. Huancayo is at a mountain elevation at the geomagnetic equator compared to Cheltenham which is at sea

level at 50°N. geomagnetic latitude. Over a period of several years, the per cent amplitude at Huancayo is about ten per cent larger than at Cheltenham. Between Huancayo and Climax there is no appreciable difference in the amplitude of the neutron daily variation over 13 months. Thus within the latitude sensitive spectrum of primaries there appears to be no marked change in anisotropy. Experimental data for high energy primaries from experiments made with large atmospheric showers or at great depths underground establish only an upper limit to the magnitude of the anisotropy at these energies and in consequence do no reveal the dependence of the anisotropy on primary energy.

4. Solar and Terrestrial Relationships of Cosmic Rays.

There is now a vast amount of evidence to show that the sun strongly influences the cosmic rays that are measured on the earth. Most of these influences have been revealed through relationships with the activity of the sun which changes markedly from time to time. Some activity persists through several solar rotations and produces characteristic 27 day recurrences. General solar activity changes with an 11 year period, while the state of magnetic polarity of bipolar sunspots has a periodicity of 22 years.

The sun appears to influence the low energy cut off of the primary spectrum over an 11 year cycle.

Independently of the change of cut off, it is known to also produce a general change of intensity, with a cycle of 11 years. It produces changes of intensity of shorter duration. Many of these are related to the central meridian passage of regions of solar activity such as sunspot groups, unipolar regions and regions of intense coronal 5303 % emission. The occurrence of the regions at low heliographic latitudes appears to favour their effectiveness in influencing cosmic rays.

The sun produces an anisotropy of the cosmic radiation. The 12 monthly average anisotropy illustrates a change which is consistent with a cycle of 22 years and perhaps constitutes the first solar influence detected so far on the earth which has a period corresponding to what may be considered the true solar cycle of activity. This requires to be verified by observations extending over several cycles. The sun also produces day to day changes of anisotropy, some of which are related to the central meridian passage of active regions as in the case of variations of intensity.

The sun emits cosmic rays in association with flares, and these are now believed at least sometimes to have particles of energy exceeding 50 GeV, if they are protons which have travelled in direct paths to the earth.

The terrestrial relationships of cosmic ray variations with geomagnetic activity arise from the latter

being themselves associated with solar activity. Similar is the case with some ionosperic disturbances. For instance DOLBEAR et al. (1951) have shown the association of cosmic ray increases with ionospheric disturbances during day time hours. Also flare type increases of cosmic rays are associated with ionospheric disturbances and radio fade outs.

5. Interpretation.

The close relationship of cosmic ray variations with solar activity has prompted various workers to investigate whether these changes are caused by the emission of cosmic rays from the sun. It the present moment there is general agreement on solar emission only in respect of the flare type increases. The view is tending towards the modulation of cosmic ray intensity to explain the other variations.

Magnetic storms on many occasions are accompanied by decreases in cosmic ray intensity, but never with increases. van HEERDAN and THAMBYAHPILLAI (1955) have shown that an increase in the general intensity is associated with the reduction of amplitude of 27 day recurrences, thus suggesting that the 27 day recurrent changes are decreases. They are therefore similar to the magnetic storm type changes and indicate that screening of cosmic ray intensity has occurred. This is in general agreement with the minimum of amplitude of 27 day recurrences occurring at minimum solar activity when there is general enhanced total

intensity.

The only evidence for an increase in cosmic ray intensity associated with visible solar disturbances is that put forward by SIMPSON et al. (1952, 1955). Fig. 8 illustrates the sharp peaks of intensity which coincide with the central meridian passage of active regions. It is not clear at the present moment that there is any reasonable argument to minimise the significance of this type of observation. Therefore there is at the present moment a real difficulty in assuming that all variations under consideration here are in the nature of decreases. More data on the association of increases with the central meridian passage of regions of solar activity are required to settle this point.

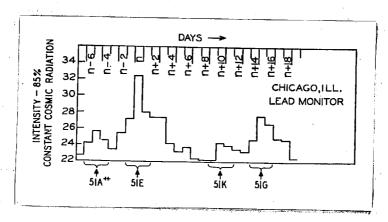


Fig. 8 Association between intensity maxima in neutron pile at Chicago and the central meridian passage of local active regions on the sun. [SIMPSON et al. (1952)].

Explanations of the daily variations of cosmic rays in terms of a solar magnetic field or the variations of a geomagnetic field became untenable quite early,

because of the failure to detect the expected large latitude dependence of the variations. BRUNBERG and DATTNER (1954) have pointed out that seen from a fixed coordinate system, the rotating sun would be strongly polarised so that there would be a voltage difference between the poles and the solar equator of the order of The combined action of the electric field produced by polarisation and the solar magnetic field will make charged particles within the solar system partake in a general rotation with the sun so that the earth will receive an excess of particles in the 18 hourly direction. They thus get a tangential anisotropy. (1954) on the other hand, has shown the possibility of an outer radial flow of energy depending on the accelerating processes within the solar system. This will impart a radial anisotropy to cosmic rays, which will change with the 11 year cycle of solar activity. These explanations require a general magnetic field of the sun having an intensity of about 10-5 gauss at the earth's orbit to account for a diurnal variation whose amplitude was believed to be about 0.2 per cent.

NAGASHIMA (1955) has recently examined the possibility of explaining a diurnal variation of the order of 0.2 to 0.5 per cent on the basis of the electric field theory suggested by him to explain the magnetic storm type change of total intensity. There would however be a large latitude dependence of the daily variation which is not observed.

Because of the neglect of the following experimentally determined features of the daily variation averaged over periods of one year or longer, it is difficult to attach much importance to any of the above mentioned theories to explain the observed facts.

- (a) The daily variation cannot at all times be satisfactorily described in terms of the diurnal component only. For several years in the past the daily variation had two significant maxima.
- (b) A shift of the principal maximum of the daily variation by as much as ten to twelve hours takes place over a period of years. The implication of this shift is that during some years, the daily variation exhibits a principal maximum during the day while in others, the maximum is shifted to the night.
- (c) The amplitude of the daily variation is markedly determined by the directional sensitivity of the recording instrument. The change of amplitude of the daily variation with change of semiangle of the telescope is very much more than can be normally expected. Large amplitudes of the order of 1.2 per cent have been observed with narrow angle telescopes at low latitudes.

The occurrence of the storm type anisotropy and the frequent day to day variations of anisotropy make it necessary to evaluate the physical meaning to be attached to the anisotropy derived from data averaged over a long period. The daily variation of the 'd' and the 'n' type,

which occur on groups of days, have times of maxima which coincide with those of the two contributions which are found to play a determining role in producing long term changes in the 12 month mean daily variation. This raises the question whether there is in fact a permanent anisotropy in addition to the variable types of anisotropy present on groups of days. If we accept the existence of a permanent anisotropy, its features and characteristics are at the present moment not known. It would appear that these have been masked by a more prominent anisotropy which is of a highly variable character. At the present moment, no satisfactory place can be found to fit in the above picture the semidiurnal type of variation observed on certain days at low latitudes.

At the present juncture it is important to find explanations for the two main types of variable anisotropies. In this connection theories which have been advanced by various workers to explain the characteristics of the storm type anisotropy assume a special significance. ELLIOT and DOLBEAR (1951) and ALFVEN (1949) have suggested that electric fields are produced within beams of ionized particles emitted from the sun in the presence of the solar magnetic field. Acceleration of cosmic ray particles traversing these beams produces an anisotropy in particular directions depending on the relative position of the beam and the earth. NAGASHIMA (1955) has examined the detailed implications of this model taking into consideration the

deflection within the beam of particles in the trapped magnetic field which is derived from the solar dipole A feature of his theory is that associated with every beam there is a minimum energy below which no anisotropy would be produced. For higher energies, the per cent anisotropy would progressively decrease with increasing energy. Nagashima has shown that the maximum anisotropy would be produced in the direction pointing towards the sun. This agrees with the experimental determination of the storm type vector by SEKIDO et al. Nagashima's theory also explains the 11 year (1955b). cycle of variation of the storm type anisotropy as being due to a change in the density of the solar streams and of the strength of the trapped magnetic field during the solar cycle of activity.

Nagashima's theory does not explain a night time maximum as observed in the daily variation on groups of days. Recently NERURKAR (1957) has extended Nagashima's work by admitting the possibility of random orientation of the magnetic field trapped within the beam. This could arise if the orientation of the field in the beam is not determined by the solar dipole field but by the field in the direct vicinity of the regions from which the beams are emitted. Since the daily variation reveals an anisotropy in the E-W plane, the component of the trapped field perpendicular to the equatorial plane has to be considered. Thus a modification of Nagashima's theory whereby the

direction of the effective magnetic field can be reversed is possible. Nerurkar has demonstrated that there can then be anisotropy in the 0800 and in the 1600 hour directions depending on the orientation of the magnetic field. Due to the effect of the magnetic field these anisotropies can produce at low latitudes maxima of intensity in the daily variation at 0300 and 1100 hours respectively. Thus it seems that the modification of Nagashima's theory by Nerurkar furnishes a plausible interpretation of several significant features of the day to day changes in the daily variation of meson intensity.

6. Purpose of the Study.

We have already seen that the work done at the Physical Research Laboratory during 1950-52 and by other workers elsewhere, had shown that, compared to the variations observed by ionisation chambers of omnidirectional sensitivity, counter telescopes having a comparatively limited directional sensitivity show much larger variations. This effect should be particularly important for study of the anisotropy of primary radiation through the measurement of the daily variation. Moreover, the dependence of the amplitude of the variation on the angle of opening of the instrument can provide valuable insight into the profile of the anisotropy. Hence, an attempt was made in the first experiment to push the narrow angle technique for the study of the daily variation

of cosmic ray intensity to what might be considered to be a practical limit.

In the first experiment, described in chapter III, the daily variation of meson intensity, incident in a very narrow vertical cone of semiangles 1.7° and 6.7° in the E-W and N-S planes respectively, was measured. Moreover, the radiation was made to traverse a magnetised iron core. A mesons in the momentum range about 0.4 to 3.0 Gev/c were in consequence deflected out of the vertical beam. Positive and negatively charged deflected A mesons of moderate momenta were separately recorded. The intensity of mesons with momenta larger than about 3.0 GeV/c was measured by recording mesons not deflected out of the vertical beam. Thus measurement was made of three separate rates, representing intensities $M_m(+)$, $M_m(-)$ and M_h , the medium energy positive, the medium energy negative, and the high energy μ mesons respectively, incident in a very narrow vertical cone.

The counting rates of deflected mesons in this experiment was very small. Because of this during the period covered by the present report the determinations of the semidiurnal components of the daily variations for each component, were not statistically significant. This has prevented us from drawing conclusions about the atmospheric effect for each component separately. The

results have however significantly demonstrated as striking and unexpected increase in amplitude of the daily variation with reduction of angular opening of a Geiger counter meson telescope.

In order to verify that the counting rates $M_m(+)$, and $M_m(-)$ were in fact due to deflected mesons of moderate momenta and are not significantly affected by other processes, α great deal of effort, after the first run, was devoted in estimating the contribution of these processes, experimentally by setting up a hodoscope recording arrangement, and by numerical evaluation from known processes with known experimental conditions. The results of this subsidiary investigation are also reported in chapter III.

Having confirmed that the counting rate, measured by the trays of counters outside the main cone, was mainly due to low energy A mesons, the electromagnet used for the first run which had provision for only one set of telescopes of the type mentioned above was modified for putting up four similar sets of telescopes. This is presently in operation.

After the preliminary results of the first experiment concerning the large amplitude of the daily variation of meson intensity measured in a vertical narrow angle telescope were known, it was felt necessary

angular opening of the telescope in a more elaborate fashion. Therefore, while the author was busy with the setting up of a hodoscope recording system, Dr. N. W. Nerurkar, a colleague of the author, made a comparative study of the daily variations of cosmic ray intensities measured by simultaneously running narrow angle telescopes of different openings in the E-W plane and by wide angle telescopes. The results are reported elsewhere [SARABHAI et al. (Sarabhai, Nerurkar and Bhavsar) (1955b), SARABHAI and NERURKAR (1955) and NERURKAR (1956)].

The investigation confirmed the author's findings, that radiation reaching sea level within a narrow angle to the vertical exhibits special characteristics. No significant difference is seen in the daily variations measured with telescopes of semiangles 5° and 2.5° in the E-W plane, and since the counting rate as well as the accuracy of the determinations is greater for 5° telescopes than 2.5° telescopes, the former provides an ideal technique for study of the anisotropy of primary radiation. Dr.Nerurkar's investigation also showed that the daily variation on individual days is of a highly variable character. It occurs generally with a day time maximum or an early morning (night time) maximum, or with two maxima. Because of low counting rates and a standard error of about

2.0 per cent for bihourly counting rate, Dr. Nerurkar's data on individual days could not be examined in great detail. Nor was it possible to classify with any great confidence the days in terms of the nature of the daily variation occurring on them. It was felt therefore, that the technique should be further refined by providing a number of similar telescopes of high counting rates, and thus reduce the statistical error.

The second experiment deals with further intensive investigation of the daily variation measured by narrow angle telescopes and the changes of anisotropy that occur from day to day. It is described in chapter IV, and deals with the results obtained with ten similar narrow angle telescopes having angles of opening 5° in the E-W and 45° in the N-S planes, and two telescopes of semiangles 26° and 45° in the E-W and N-S planes respectively.

An insight into the processes by which an anisotropy of a highly variable character is produced can be obtained if one measures simultaneous changes of anisotropy and the mean intensity. This is of great significance to theories of modulation of the cosmic radiation and of the electromagnetic state of interplanatory space. Thus, apart from characterisation of days in the manner described above, an important object

of the second experiment was to study the correlated changes of anisotropy and of intensity. This has been achieved in a fair manner, as described in chapter IV.

CHAPTER II

EXPERIMENTAL TECHNIQUES

The experimental techniques for the study of time variations of cosmic ray intensity are essentially the same as those used for other cosmic ray experiments, except that for time variation study, stability over a long period of the characteristics of the measuring apparatus is an all important consideration. In the early days, the study of time variation of cosmic ray intensity was mainly carried out by the use of ionisation chambers. The technique of preparing good and reliable Geiger-Muller counters was then not properly developed and the mechanism of the Geiger discharge was not well understood. progress has however followed the discovery of self-quenched Advancements in electronics as also in the counters. manufacturing techniques of electron tubes of different types, has also played an important role in the improvement of the reliability and stability of apparatus for cosmic ray measurements. As a result, an increasing number of cosmic ray workers is now investigating the time variation of cosmic rays with the help of counter telescopes, which

have an advantage over ion chambers because of their directional sensitivity.

The author has been actively engaged in the construction and maintenance of apparatus involving GM counterstelescopes as described in the present chapter in the following sections. 1 deals with the preparation and operation of GM counters. 2 describes the various electronic units and also deals with the automatic photographing unit. 3 describes the technique of a hodoscope arrangement which is a device, for ascertaining the particular counters of the counter telescope, which are individually involved in a particular coincidence count. The importance of this method for the interpretation of results obtained by GM counter telescopes of special types will be dealt with elsewhere. 4 deals with the methods of analysis. It describes the various statistical procedures adopted in the analysis of cosmic ray data, their errors and levels of significance.

1. Geiger Muller Counters.

A GM counter used for cosmic ray investigations, usually consists of a cylindrical metal cathode of brass or copper with an axial anode of thin tungsten wire insulated from the cathode. The whole assembly of electrodes can be enclosed in an air tight glass envelope and evacuated and filled with a suitable gas at a reduced pressure. In the early days glass counters were extensively used because

of their easy construction.

During the past few years various kinds of metal to glass joints, as well as a new class of hardening resins called "Ethoxylines" (commercially known as "Araldite") are developed. These resins are of the thermosetting type, and the setting temperatures are not very high. They have proved very helpful to experimenters for making leak-proof metal to metal or glass to metal joints. This has made possible in recnet years to prepare successfully all-metal counters without a glass envelope. In the present investigation glass counters were used in the initial stages, but were replaced in due course by metal counters. A metal counter is different from the glass counter only from the constructional point of view, and has the advantage of having a more uniform geometry and sturdier construction.

In the early days of development of GM counters monoatomic or diatomic gases like argon, nitrogen or even air were used. It was necessary to feed voltage to the counters through a very high quenching resistance, which made the counters insensitive for a long time after each Geiger discharge, resulting in large losses at high counting rates. After the discovery of the self-quenched counter by TROST (1935, 1937), where a small amount of polyatomic vapour is mixed in the filling gas, the non-self-quenched type has been extensively replaced. A self-quenched counter does

not require a large quenching resistance as in the case of a nonself-quenched counter, and therefore the losses at high counting rates are negligible.

The counters used in the present investigation are of the self-quenched type. The filling mixture has 90% argon and 10% ethyl acetate and is used at a total pressure of 10 cm. of Hg. Though this is a typical filling mixture now generally used, the author conducted in 1951 an experimental determination of optimum filling mixture for the most desirable operation of the GM counter. This is described at a later stage in this section.

1.1 Mechanism of Geiger discharge.

Many authors [KORFF and PRESSENT (1944), KORFF (1946), CORSON and WILSON (1948), CURRAN and CRAGGS (1949), WILKINSON (1950) etc.] have studied the mechanism of Geiger discharge and the role of the polyatomic vapour in quenching the discharge; and have laid down standard procedures for preparing efficient counters with good working characteristics.

A GM counter is a gas filled diode where the cathode is not the source of electrons as in normal electronic diodes. Gases are filled in it at a low pressure, of the order of a few cm. of Hg.. As described earlier the cathode for counters used in cosmic ray work is usually cylindrical in shape with a thin axial wire as an anode. When a potential is applied to the electrodes the field

decreases radially from the central wire. Let such a device be connected in the way shown in Fig. 9 to a variable voltage source through a resistance R. G is the total intra-electrode and wiring capacitance of the system.

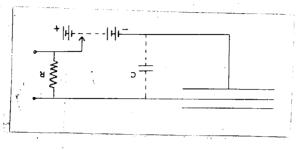


Fig. 9

Let us suppose that the applied voltage is small. Normally, no continuous current passes through such a device. If at some instant an ionising particle crosses the counter, it forms a few positive and negative ions in the counter gas. These ions are attracted by the negative and positive electrodes respectively. values of applied voltage the random thermal velocity will be in general larger than the drift velocity due to the field gradient. Therefore at this stage some ions get lost because of the process of recombination. all the ions formed are not able to reach the electrodes. When the applied voltage is increased, a stage is reached at which the field becomes sufficiently intense so that the probability of losing the ions becomes negligible. The region from no voltage condition to this point is shown as region A on the curves in Fig. 10 taken from MONTGOMERY and MONTGOMERY (1941). The curves show the charge collected by the electrodes in units of an electron charge against the

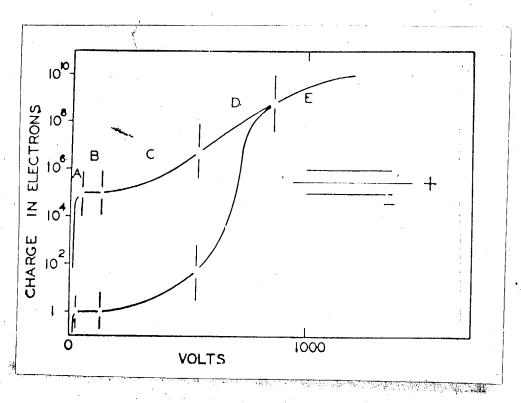


Fig. 10. Illustration of the various regions of potential showing the multiplication of an original amount of ionisation by the discharge processes in a tube with coaxial cylindrical electrodes. The ordinate shows the final charge collected, and the abscissa the initial potential difference. The upper curve represents the case where initially 105 ion pairs are created, the lower curve that for a single ion pair. The region; shown are: A - very low voltage region; B - ionisation chamber region; C - proportional counting region; D - region of limited proportionality and E - the Geiger region. [MONTGOMERY and MONTGOMERY (1941)].

applied voltage to the electrodes, for two different initial numbers of ions produced in the gas. The state of affairs remains the same till the end of region B is reached. In the region B the number of ions collected remains equal to the number of total ions formed by the initial event. This region is the ionisation chamber region of the lon counter.

As the potential is increased beyond the point where region B ends, the field at a short distance around the central wire becomes sufficiently intense to accelerate some of the electrons upto energies high enough to produce secondary ionisation by collision with the gas molecules. Because of this multiplicative process for each initial electron produced in the gas, an avalanche of (m) electrons reaches the collecting anode. As the voltage is increased further, the size of the avalanche increases. process of ionisation by collision had been the only phenomenon in operation, the avalanche would have terminated However, ionisation by collision is accompanied by emission of photons, and some of these in turn release more photo-electrons from the counter walls and the gas molecules. The number of photo-electrons will be proportional to the number (m.no) of electrons in the initial avalanche where (no) is the initial number of electrons produced. is the constant of proportionality, one can expect a second avalanche of (r.no.m²) electrons to be generated in the gas and the same process to be repeated. Thus the total

number of electrons reaching the wire for every electron initially formed in the counter gas can be given by the infinite series,

$$n_{om} + n_{om}^2 + n_{om}^3 r^2 + \dots$$
 (1)

For sufficiently small voltages $rm\ll 1$, the above series converges to the value

$$N = n_0 m/(1 - rm)$$
 or $N/n_0 = m/(1 - rm) = M$.

This means that the total number N of electrons that arrive at the central wire is proportional to the initial ionisation no. The proportionality factor, M, is called the multiplication factor and the counter operating in the region where M is a constant is called a proportional counter. This region is shown as region C on the curves in Fig. 10. For counters of similar size, filled with the same gas at the same pressure, M depends only on the applied voltage. When the voltage is further increased (rm) slowly increases and the proportional counter region extends till (rm) approaches the value unity. For (rm) values very near unity the counter goes to the region D of limited proportionality. At a voltage Vg where (rm) is just greater than unity, the series (1) diverges. Physically this can be interpreted as the occurrence of a discharge. Vg is called the threshold potential and is the beginning of the Geiger region.

For voltages not too far above Vg, (rm) is not

much larger than unity and the discharge is not self sustaining. In other words this is the region of unstable corona discharge (region E on the curves), and the counter can record separately every ionising particle passing through it. At a still higher voltage, rm >1 and the counter goes into a continuous discharge.

The Geiger region is characterised by the following features. In this region the pulse size depends only on the size and filling of the counter and the applied voltage, and is independent of the initial ionisation produced. Therefore a characteristic pulse is initiated even by a single ion pair formed in the sensitive region of the counter. As mentioned earlier, Geiger counters are of two types, the nonselfquenching type, and a counter with a polyatomic gas in it, or the selfquenching type. To understand the role of the polyatomic vapour it is necessary to look into the processes involved at the various phases of the discharge for the two different types.

1.11 The initial avalanche :

Whenever and ionising particle traverses a region of the Geiger counter, it produces ionisation in that region. The initial number (n_0) of ion pairs produced in the process depends upon the velocity and charge of the particle, as well as on the nature and the pressure of the gas in the counter and the total path length of the particle in the counter. In the initial

avalanche only electrons play an important role since the heavy positive ions have a low mobility. The electrons travel towards the central wire. Near the central wire the field is very intense and the probability for each electron to acquire during a mean free path an energy adequate to produce ions by collision is very high. Therefore near the central wire, a very rapid multiplication of the number of ions takes place and a typical avalanche developes. The duration of this process is very small, of the order of 10-7 sec. and since the positive ions formed in the process do not move much in this interval a positive ion sheath is developed around the central wire in the region which was traversed by the initial particle. sheath grows in thickness until its space charge reduces the field and prevents further ionisation by collision in this part of the counter.

1.12 The spread of the discharge:

In the absence of photons produced during the discharge, the latter would have terminated in a small portion of the Geiger counter. In a nonselfquenched counter the photons travel unrestricted in all directions and produce photoelectrons in the gas and at the cathode surface. The photoelectrons in turn produce secondary avalanches similar to the original one in different parts of the counter and the discharge thus spreads very rapidly throughout the whole length of the counter. The discharge stops only after a dense positive ion sheath is formed

around the entire length of the central wire, the whole process occurring in less than about 10-6 seconds.

In a selfquenched counter the process of the spread of the discharge is not so rapid. The heavy vapour molecules have a large absorption coefficient for the photons responsible for the spread of the discharge in a self-quenched counter. ALDER et al. (1947) have measured the absorption constant in alcohol vapour and found it to be 640 cm. This means that in a counter containing alcohol vapour at a pressure of 1 cm., the number of photons falls to 1/6 of its initial value in a distance of 1.2 mm. Because of this, the photons, which are produced very near the central wire are prevented from reaching the cathode surface, and they remain confined to a small region around the central wire. The discharge propagates only along the wire with moderate velocity. This is experimentally varified by STEVER (1942). He has shown that a small glass bead anywhere on the wire is sufficient to stop the propagation of the discharge across the bead. The spread of the discharge in a self-quenched counter of moderate length (about 30 cm.) takes about 3x10-6 seconds. After the spread the initial discharge is quenched by the positive ion sheath in the same manner as for the non-selfquenched counter.

1.13 Pulse shape, dead time, and recovery time:

The shape of the voltage pulse at the central

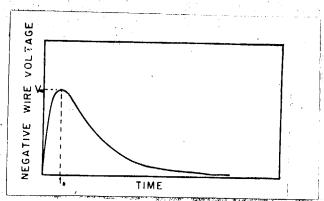


Fig. 11 A typical voltage pulse from a fast counter. As viewed on an oscilloscope with a linear sweep, the voltage across R during a pulse is shown here (counter connected as shown in Fig. 9 page 46). [STEVER (1942)].

wire of a self-quenched Geiger counter is illustrated in Fig. 17. The pulse starts with a variable delay after the traversal of the ionising particle. This delay is caused by the time required for the electron initially formed to travel upto a point from where onwards the field is sufficiently high and the gas multiplication begins. This time is of the order of 10-7 seconds. The electrons are formed very near the central wire and therefore their motion induces a small pulse on the central wire. small (of a few volts) initial rise is of the order of a few microseconds and equals the time required for the spread of the discharge along the whole length of the This rise is about 0.2 of the final pulse height, counter. and is detectable even without any amplification. past discussion about the spread of the discharge it is obvious that the pulse of the non-self-quenched counter has a smaller rise time compared to a self-quenched counter. The main contribution to the pulse comes from the motion

of the positive ion sheath towards the cathode. The total pulse width is of the order of 10⁻⁴ seconds for the non-self-quenched counter, which is the time taken by the positive ions to reach the cathode. This time is larger for self-quenched counter, because, as will be explained later, in this case the final ions reaching the cathode are all heavy vapour ions of low mobility. For such self-quenched counters the pulse width is of the order of 4 x 10⁻⁴ seconds.

As already mentioned the discharge terminates . because the positive ion sheath reduces the field around the central wire below the Geiger threshold. When this sheath travelling outwards reaches about half way to the cathode the field around the central wire gets restored to about the threshold value. Till then the counter is insensitive to any ionising event and therefore it is called the dead time "td" of the counter. Once the field has recovered to the threshold value counts are recorded but the pulses are of reduced size and remain so till the field returns to its normal value. This time is called the recovery time "tr" of the counter. STEVER (1942) has made an intensive study of the dead time and the pulse shape and size during the recovery time of a self-quenched counter with the help triggered sweep oscilloscope records. In practice the effective dead time " T_D " is larger than " $\mathbf{t_d}$ " since it depends upon the sensitivity of the recording circuit. " T_D " is given by $T_D = t_d + \alpha t_r$ where $0 < \alpha < 1$.

depends on the minimum size of pulse required, to work the recording amplifier.

1.14 After discharges and their quenching :

The positive ion sheath gets neutralised when it reaches the cathode. When an ion reaches the cathode, it has a large probability of producing an additional electron, if the energy of neutralisation \in of an ion by a free electron derived from the metal, minus the work function \emptyset necessary to detach the electron, is sufficient to detach another electron [BRADDICK (1954)] i.e. if

$$\epsilon - \emptyset > \emptyset$$
 or $\epsilon > 2\emptyset$

In the absence of a quenching mechanism, the electron thus liberated restarts the discharge. For non-self-quenched counter, the practice is to effect the quenching of such discharges by putting a high resistance in the circuit. The resistance helps in the following way. If the resistance is very high, of the order of 10⁹ Ohms, the RC time constant is very large and therefore the negative charge collected on the wire leaves it very slowly. The positive ions therefore reach the cathode while the voltage across the counter is below the threshold, and a fresh discharge does not occur.

An alternative method of quenching the discharge is to use an external electronic quenching unit. The pulse from the Geiger discharge is used to operate an

electronic device which lowers the counter voltage, below, the threshold for a definite time slightly larger than the positive ion collection time after the first discharge.

In the case of the self-quenched counters having polyatomic vapour like ethyl alcohol or ethyl acetate in the filling mixture, these molecules take care of the after discharges in the following manner. In the initial ion sheath ions of argon and the vapour are present. On their way towards the cathode, argon ions exchange charge with vapour molecules. This is possible because at normal counter gas pressures the positive ions make about 102 collisions in the counter and the electron transfer probability is very high for collision between an argon ion and the vapour molecule, as the ionisation potential of argon is larger than that of the vapour molecule. the high electron transfer probability ensures that the positive ion sheath when it reaches the cathode is composed of entirely polyatomic ions instead of argon ions. polyatomic molecules << 20 and therefore they do not produce an additional electron as in the case of argon. Again the excited neutral molecules predissociate, instead of giving photons as it happens in the case of gases like Thus the further emission of electrons from the cathode does not take place and the after discharge does not breed. This is the essential difference between the non-self-quenched and self-quenched Geiger counter.

1.2 Efficiency of the Veiger counter.

The efficiency of a Geiger counter is defined as the probability "w" for an ionising particle to produce a detectable pulse when it traverses the sensitive volume of the counter. It is easy to see that this factor depends upon two probabilities "w" and "w2" where "w1" is the probability that an ionising particle traversing the counter gas produces at least a single ion pair in the sensitive volume, and "w2" is the probability that these ions strike a Geiger discharge in the counter. "w1" depends on the size of the counter, the nature of the filling gas, and the pressure at which it is filled. It is given by

$$w_1 = 1 - \exp(- slp)$$
 ... (2)

where s = specific ionisation of the filling gas,

l = average path length in the counter
available to the ionising particle,

and p = gas pressure expressed as a fraction of an atmosphere.

" w_2 " depends upon the effective dead time, T_D , and the average number, n, of the random ionising particles entering the counter in unit time. It is given by

$$W_2 = 1 - \sum_{x=1}^{x=0} \frac{(nT_D)^x}{x!} \exp(-nT_D)$$
 ... (3)

II

1.3 The plateau of the Geiger counter.

The average probability "w" for any ionising particle to get detected is given by the relation (4). If one measures the counting rate as a function of applied voltage for a constant source of ionising radiation one should expect a constant counting rate as shown in Fig. 12. The horizontal portion of the curve is called the plateau region. In practice it is not possible to get a perfectly horizontal plateau because of the following reason. At the time of collection of positive ions at the cathode a secondary after-discharge is initiated unless proper provision is made for quenching this after-discharge. The quenching vapour takes care of the after discharges and

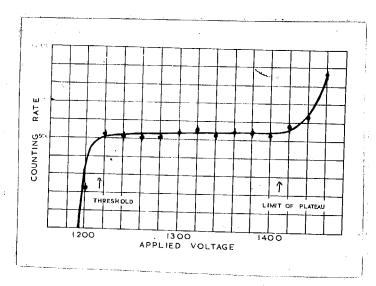


Fig. 12 Typical plateau curve of a self-quenched counter.

quenches them in self-quenched type counters. However this quenching is never perfect and in practice there is always a small probability of such after discharges taking place in the counter. This probability increases with the applied voltage, and therefore gives a rising slope to the plateau. In practice counters of normal size are considered good if they exhibit a plateau of about 150 volts or more with a slope less than about 2.5% in 100 volts.

1.4 Useful life of the Geiger counter.

The self-quenched counter has a disadvantage in that its useful life is restricted. This limitation is due to the decomposition of the heavy molecules of quenching vapour during each Geiger discharge. Because of the same size of pulse developed for each Geiger discharge the number of molecules breaking up per count is almost constant and therefore the useful life is determined in terms of number of counts during which, about half of the quenching vapour molecules are broken up. After this the plateau shows a large slope revealing a deterioration of the working characteristics. Useful life of self-quenched counter can be increased by not allowing the discharge to spread throughout the counter length by a suitable electronic device. Such a device is described later in the section dealing with electronic units.

1.5 Preparation of the GM counters.

The glass counters used during the earlier part of the work were prepared according to a standard procudure described elsewhere.

Metal counters used were of diameter 4 cm. and sensitive length 30 cm. or 85 cm. The procedure for making the metal counters is as follows:

The cathode is made of a brass tube of 4 cm. inner diameter and about 1 mm. wall thickness. The length of the tube for each type is kept 5 cm. longer than the sensitive length required. The inside surface is polished successively with three grades of emery paper, the last one being No.1 grade. It has been found that even minor grooves parallel to the axis of the counter tube affect the satisfactory operation of the counter. The ends of the tube are closed with brass pieces which fit tightly inside the brass tube. Holes are provided in the pieces for attaching glass bushings to carry the central wire and for evacuating and the filling of the counter. It is desirable to ensure a good fit of the glass bushings. Fig. 13 shows the end pieces and bushings used before assembling as well as a metal counter in its final stage. Before assembling the parts of the counters, the inside surface of the counter twoes and end pieces are carefully cleaned with ethyl acetate to remove loose dirt, grease etc. It is not advisable to use cloth for cleaning since cloth fibres

remaining inside the tube may later cause spurious discharges.

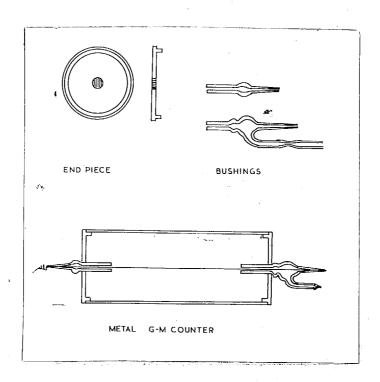


Fig. 13 showing the end pieces and glass bushing before assembling, and a complete metal counter of the type used by the author.

All parts of the counter are then assembled together and a thin tungsten wire of diameter 4 mil is threaded through the glass bushings. Metal to metal joints and metal to glass joints which fit closely are cleaned and warmed to about 300°F and "Araldite" type 1 is then applied to make the joints leak-proof. The technique of applying "Araldite" is very similar to that of soft soldering. Allojoints are kept warm until

"Araldite" sets, a process which can be observed by a change in colour. The entire assembly is then cured for few minutes. The thin tungstem wire forming the anode is spot welded at both the ends to thicker tungstem wires which protrude outside the glass bushings. The protruding pieces are provided with metal beads of nickel and silver so that copper, wire for external electrical contact can be joined to them. The inside ends of the glass bushings extend in the interior of the counter for a little more than an inch, thereby forming protecting sleeves over the ends of the central wire SAMOS and HUDES (1947).

Counters thus assembled are evacuated and joints are tested for air leakage for about sixteen hours. Satisfactory counters are then filled with 1 cm. of pure ethyl acetate and 9 cm. of argon to a total pressure 10 cm. of Hg. The gases are allowed to mix for three hours and the characteristics of each counter are then tested separately.

Fig. 14 shows the schematic arrangement for testing counters. Pulses developed across the quenching resistance of 1 meg. ohm are fed to a shaping unit which in turn feeds to the scaling and recording unit. The voltage which is fed from a variable voltage stabilized high-tension supply is slowly raised and the value at which the scaling unit starts counting is noted down. The sensitivity of the shaping circuit is adjusted to record pulses only in the Geiger region, and a regular check is

kept by observing the output pulses of the counter on an oscilloscope. After noting down the threshold, the voltage is raised in steps of 40 volts and the counting rate at each step is determined. If there is indication of a satisfactorily flat plateau rising by less than 2.5% in 100 volts, and of length of about 160 volts, the counter is sealed at the constriction provided in the glass bushing. The characteristics of the counters are rechecked after allowing the counter to operate at the middle of the plateau region for about twelve hours. Counters retaining their characteristics after this process of ageing are accepted for use.

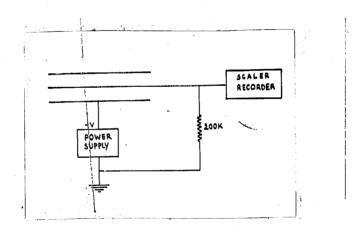


Fig. 14 Schematic arrangement for testing counters.

1.6 Experimental determination of optimum filling mixture.

In order to determine the optimum composition of the counter filling mixture and the total pressure at which it should be filled, following tests were performed in 1951

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and formed part of the author's thesis for the master's degree. The following criteria were kept in mind for judging the suitability of a counter.

- (i) Length of the plateau region,
- (ii) low operating potential,
- (ili) high efficiency,
- and (iv) stability with use and time.

All tests were performed on four glass counters

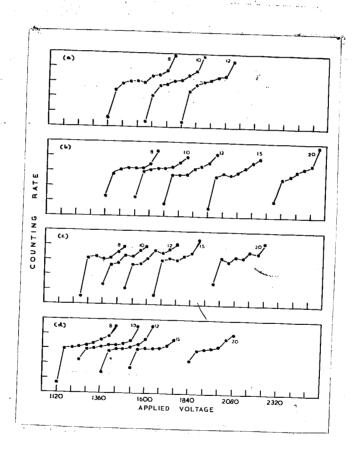


Fig. 15 Plateau characteristics curves for Geiger counters filled with different percentage mixtures of ethyl acetate and argon at different total pressures.

- (a) For ethyl acetate 25%, argon 75%.
- (b) For ethyl acetate 20%, argon 80%.
- (c) For ethyl acetate 15%, argon 85%.
- (d) For ethyl acetate 10%, argon 90%.

filled simultaneously with the same mixture. Mixtures of argon with 25%, 20%, 15% and 10% ethyl acetate at 20 cm., 15 cm., 12 cm., 10 cm., and 8 cm., total pressure were successively tried out. Plateau for all the four counters were determined in each case, and the mean counting rate at different voltages were plotted. The curves are shown in Fig. 15.

Curves for threshold potential against total pressure at constant percentage of vapour as well as for threshold potential against percentage of vapour at constant pressure were plotted. They are shown in Fig. 16 and Fig. 17 respectively.

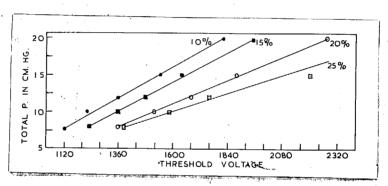


Fig. 16 Diagram showing the change of threshold potential with the change in the total pressure of the filling mixture at constant percentage of quenching vapour.

23%. 30m. 13%.

Fig. 17 Diagram showing the change of threshold potential with the change in percentage quenching vapour at constant total pressure.

From Fig. 16 and Fig. 17 one can see that increase in the proportion of organic vapour in the filling mixture raises the threshold. Increasing the total pressure of the filling mixture has also a similar effect. For smaller vapour proportions the threshold voltage is lower; but from the consideration of the life of the counters, which depends on the actual number of vapour molecules in the filling mixture, it is not advisable to reduce the organic molecules below a certain To work with larger proportion of vapour at low limit. total pressure affects the efficiency of the counters. Thus one has to seek a compromise between all these in selecting the optimum filling pressure and composition of 90% argon and 10% ethyl acetate at 10 cm. total pressure have been found to give good results. gives the length of the plateau under the different conditions that have been investigated.

Table 2. Plateau ranges for different percentages and total pressures.

otal ress	ıre,		25%.	Percentage 20%.	of vapour.	10%.
20	cm.	可以,我们的,我们就一个时间,以后的一个人的,这个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人的人,也不是一个人,也不是一个人,也不是一个人,也不是一个人,也不是一个人,也不是一个人,也不是一个人,也不是一个人,也不是一个人,也不是一个人,也不是一个人,也不是一个人,也不是一个人	OHAP	40 V.	60 V.	80 V.
15	em.		ing.	50 V.	go v.	120 V.
12	cm.		50 V.	50 V.	80 V.	120 V.
10	cm.	₩,	60 V.	80 V.	80 V.	160 V.
8	cm.		100 V.	120 V.	130 V.	160 V.

The length of the plateau is given by the voltage range in which the counting rate does not very by more than 2.5% in 100 volts. With the above filling mixture at 10 cm. total pressure, counters of 4 cm. diameter and 30 cm. length have an efficiency of 99.97% calculated according to formula (2) on page 57.

The life and the stability of the Geiger counter was tested as follows. A counter which showed good plateau characteristics was subjected to a stabilised D.C. high potential through a series resistance of 1.0 meg. ohm value. Voltage was adjusted to a value lying in the middle of the plateau region and the counter was exposed to radio activity from a thorium source to measure a counting rate of about 6400 counts per minute. On the first day its plateau was checked after every two hours and later it was allowed to operate at the higher rate and the plateau was checked twice a day. On the fourth day after 3.7 x 10' counts, the plateau showed a slight deterioration. on the fifth day after 4.6 x 107 counts, it was found that the plateau had deteriorated to a great extent. plateau curves on the first, the fourth and the fifth day for the irradiated counter are shown in Fig. 18 (a), (b) and (c) respectively.

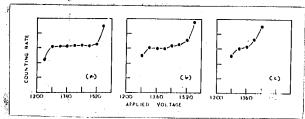


Fig. 18 Plateau curves of the irradiated counter (a) on the first day, (b) after 3.7x107 counts, and (c) after 4.6x107 counts.

1.7 Effect of external quenching unit on the characteristics and life of the self-quenched Geiger counter.

This is studied in great detail by ELLIOT (1949) for Geiger counters. PUTMAN (1948) has also studied the nature of spurious counts in self-quenched beta-ray GM counters, and their successful elimination by an external quenching circuit, which applies an artificial dead time of the order of 400 microseconds to the counter.

A quenching unit helps in improving the characteristics as well as life of the self-quenched counter in the following way. The quenching unit usually used is of the blased multivibrator (monostable) type which delivers a sharp negative square pulse of a fixed duration of about 500 to 2000 microseconds as required by the particular type of the counter. It is already shown that the plateau is not completely flat, because there is always a small probability that a secondary discharge will be generated when the positive ion sheath reaches the This probability increases with increasing voltage as well as with use, as the number of vapour molecules goes on decreasing with every Geiger discharge. The process of deterioration is thus accelerated with use. The quenching unit pulse which is fed to the central wire keeps the counter voltage below threshold till all the positive ions are collected at the cathode. This reduces the probability of the generation of multiples after each Geiger discharge. The very sharp fall of the quenching

pulse takes the voltage below the threshold in a time of the order of 1 microsecond and does not allow Geiger discharge to spread along the whole length of the wire. This reduces the number of molecules used up per Geiger discharge and increases the useful life of the counter.

In practice, precautions have to be taken to ensure that the sharp fall of the quenching pulse does not get distorted due to the capacitance of the shielded leads from the counter ends to the quenching unit. It is necessary that the leads are as short as possible, which required that the quenching unit should be mounted as near as possible to the counter. This was kept in mind, while designing the experimental set-up.

An additional advantage of using a quenching unit is that it removes the effect of the external temperature variation on the counting rate at a fixed applied voltage. This effect of lowering the counting rate of a counter at higher temperatures, arises out of the fact that a self-quenched counter used without any external quenching mechanism has always some residual slope of the plateau. Increase in outside temperature produces an increase of the internal pressure which raises the threshold and shifts the plateau bodily. Because of this the effective voltage above the threshold applied to the counter changes with temperature, even though the applied voltage is kept constant.

The cosmic ray group working at the Physical

Research Laboratory uses electronic quenching units of the monostable multivibrator type in all experiments. A suitable circuit was designed by Dr. U. D. Desai, a colleague of the author. The circuit is able to supply a square negative pulse of about 350 volts with a steep rise time. Its pulse width can be varied from about 300 microseconds to about 2000 microseconds by changing only a single capacitance. The optimum value of the pulse width to be used was decided by the author in the following way.

A self-quenched Geiger counter which had been used for a considerable length of time and no longer exhibited a satisfactory plateau with a 1.0 meg. ohm quenching resistance was connected to the quenching unit. The plateau characteristics of this counter were tested with different widths of the quenching pulse adjusted to values of about 320, 680, 860, 1020 and 1360 microseconds. The results are shown in Fig. 19.

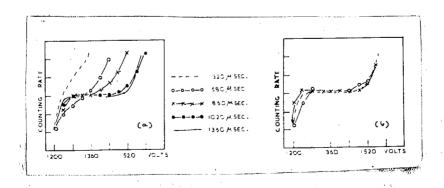


Fig. 19 Effect of the quenching pulse on the plateau characteristic of a Geiger counter on (a) an used counter and (b) a good counter.

One can see that the plateau of the used counter which had almost come to the end of its life, improves with the increasing width of quenching pulse. At about 1000 microseconds pulse width, the characteristics are almost as good as that of a newly filled good counter. From this it was decided to use a pulse width of about 1000 microseconds in all quenching units.

The increase in the useful life of the self-quenched Geiger counter because of the use of a quenching unit was tested as follows. A newly filled counter was connected through a quenching unit of about 1000 microseconds pulse width. The counter was exposed to thorium radiation. Even after 10⁸ counts, the plateau was found to be as good as the plateau in the beginning. Both the plateau curves are shown in Fig. 20 (a) and (b). This shows a definite increase in the life from 4.6 x 107 counts when used with a quenching resistance as shown earlier.

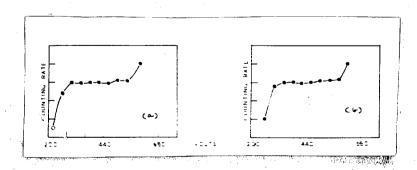


Fig. 20 Plateau curves for the stability test with external quenching circuit of pulse width 1000 microseconds (a) initial plateau and (b) plateau after 108 counts.

A quenching pulse of 1000 microseconds introduces a dead time T_D of that much duration. According to formula (3) on page 57 probability w₂ (for ions to strike Geiger discharge) for 30 cm. counters is about 0.992, and for 90 cm. counters it is about 0.976. This gives 99.2% efficiency for small size counter and 97.6% efficiency for large size counter used with above mentioned type of quenching unit. The circuit details of the quenching unit are described in the next section.

2. Electronic Units.

This section deals with electronic units utilised in the experiments described in chapter III and IV. The basic principles of circuit elements used in the units are discussed in detail by authors like ELMORE (1948), ELMORE and SANDS (1949) and SCARROTT (1950). Most of the circuits used in the present work are based on circuits already used successfully by different workers, and are modified according to the requirements and availability of the components.

2.1 Power supplies:

The mains supply voltage in the laboratory is 230 volts, 50 cycles A.C. It was necessary therefore to get different D.C. voltages from it to run the various electronic units and a D.C. high voltage for the Geiger counters. For the sake of stability it was also necessary

to have some regulating arrangement for the power supplies against load and mains variations.

The high voltage power supply for Geiger counters and other power supplies of moderate voltages (of the order of 200 to 400 volts) for different circuits were constructed by utilising degenerative type of stabilizer circuit. A complete analysis of stabilising circuits is given by HUNT and HICKMAN (1939) and GILVARRY and RUTLAND (1951).

The circuit diagram of one of the power supplies giving regulated 200 volts (maximum current 100 m.amp.) is shown in Fig. 21.

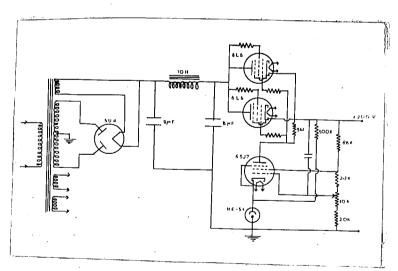


Fig. 21. Circuit diagram of a 200 volts electronically stabilised power supply.

The tube 6L6 is used as a regulator tube, while tube 6SJ7 is used as a feed-back amplifier. Two points are of importance in the above circuit. Firstly, 6SJ7 is used

as a "starvation" amplifier and therefore the gain is very large, which improves the percent regulation.

Starvation amplifier circuits are discussed by VOLKERS (1951). Very high gain upto 2500 can be obtained in such a circuit, which has a direct-coupled amplifier using a pentode with extremely low screen voltage and very high plate load resistance. Secondly, the current to the reference tube is fed from the regulated (output) side, which also ensures more stability and better regulation. For high voltage supply a similar circuit was used, but tube 807 was used in place of 6L6 and tube 606 in place of 6SJ7.

Low voltage supplies for the purpose of supplying bias voltages (-70 volts) were constructed by using glow-gap regulator tubes like VR-70.

2.2 Quenching unit:

A schematic diagram and circuit of the quenching unit used in the present work are shown in Fig. 22(a) and (b) respectively. The quenching unit is a composite unit which performs two tasks. It quenches the Geiger discharge in the associated counter, and at the same time furnishes a sharp pulse for coincidence measurements. Its first section consists of a monostable multivibrator, which rapidly supresses each Geiger discharge. This adds significantly to the useful life of the counters as shown in section 1.7 of the present chapter. The broad negative

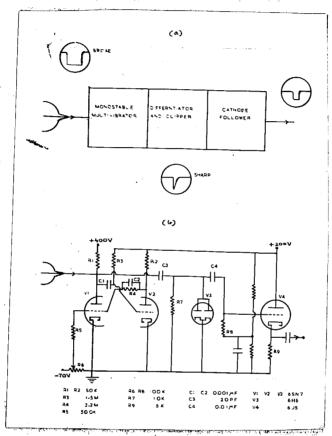


Fig. 22. Schematic diagram and circuit of a quenching unit.

voltage pulse which is used to quench the discharge, cannot by itself be used for fast coincidence work. Its edges are therefore differentiated and a sharp negative index pulse is generated from the leading edge. This is fed to the coincidence amplifier.

A 6SN7 high g_{m} twin triode is used for the monostable multivibrator. In the stable state, tube

V1 (Fig. 22) is non-conducting and V2 is conducting. Returning of the grid of the conducting tube to a positive potential helps in the stability of the circuit. When a negative pulse is applied to the plate of V1, it is fed to the grid of V2 through the condenser C1. This negative pulse is amplified by V2 giving a positive pulse on its plate. This positive pulse raises the grid voltage of V1, thereby making it conducting. The process is a regenerative one and in a very small interval of time of the order of a microsecond after the injection of the triggering event, V1 becomes fully conducting while V2 is taken into the cut off region. The grid potential of V2 starts rising exponentially and when it reaches the cut off voltage, the tube V2 starts conducting and a sudden switching to the initial stage occurs. During this time, because of the D.C. coupling between the plate of V2 and grid of V1, all voltages at the other electrodes remain unaltered. This process of double switching generates a negative square voltage pulse at the anode of V1. The duration of this pulse depends on the time taken by the grid of V2 to come to the cut off value of eg. The plate of the non-conducting tube is directly connected to the central wire of the Geiger counter, and hence the voltage to be applied to the counter cathode is less than the counter working voltage by the amount of the V1 plate supply voltage. The sensitivity of the unit which is adjustable by varying R6 is such that the pulses developed at the threshold potential on the plate load R1

are adequate to trigger the monostable multivibrator.

The quenching pulses furnished by the circuit are of about 350 volts and about 10⁻³ seconds duration. Since Geiger counters are operated at 80 volts above the threshold, such pulses are quite adequate for proper quenching. To get the quenching pulse of such a large amplitude the plate of VI is supplied with a high voltage of 400 volts, while the conducting tube is given only 200 volts.

The square negative pulse is differentiated by means of a RC network having a small time constant. This gives a negative pulse at the onset of the discharge and a positive pulse delayed by the time equivalent to the original multivibrator pulse width. The positive part is clipped by the diode V3. Since the negative pulse, is often to be fed to a number of channels and transmitted through screened cable, it is preferable to feed it through a cathode follower having a low output impedance. Thus the loss of signal is minimised.

The circuit shown in Fig. 22(b) can furnish negative pulses of about 20 volts and 3 microseconds duration at an output impedance of about 600 ohms. For the hodoscope arrangement positive pulses were required. The circuit diagram of such a quenching unit which furnishes positive pulses in the output is described in section 3.

2.3 Coincidence unit:

The circuit diagram of the triple coincidence unit used is shown in Fig. 23.

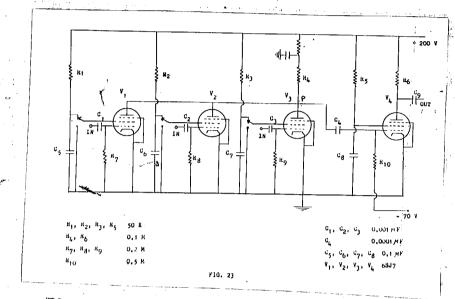


Fig. 23. The triple coincidence unit.

It is based on the original coincidence circuit due to ROSSI (1930a). In the present circuit the plates of the sharp cut off pentodes (6SJ7) are connected together and they are fed through the common load resistance Rt. The number of pentodes is kept equal to the number of counters or group of counters between which the coincidence is to be recorded. The output of each of the quenching unit is connected to the grid of its respective pentode. Normally all the coincidence pentodes are kept "bottomed". This condition is achieved by operating the pentodes with a load resistance and plate supply voltage such that the load line passes below the "knee" of the valve characteristics. This requires that the value of

the load resistance should be kept large compared with the impedance of the pentodes. When the tubes are "bottomed" most of the voltage drop takes place across plate load R4 and the plates are kept at a potential amounting to a small fraction of the applied voltage. The total current does not change much in such a circuit, if the anode current in some of the pentodes is cut off by negative pulses applied to the grids, as long as at least one pentode remains conducting. The voltage at the point P (Fig. 23) where all the anode leads meet the resistance R4 does not therefore change appreciably when some of the pentodes receive negative pulses. If however, all the pentodes receive negative pulses simultaneously, the anode current is cut off completely and a large voltage pulse results at the point P. A discriminator, which is a pentode biased appropriately below cut off, is made to respond to the large coincidence pulses but not to the smaller pulses due to discharges not involving all the counter groups. As the difference in size between the n-fold and (n-1)fold coincidences is large (about 20:1), it is easy to discriminate between them. The output of the discriminator is fed to the scaler-recorder unit.

Coincidence circuits are also known as "AND" circuits. There are many variations of these circuits which utilise triodes, diodes and recently transitors. For narrow angle telescopes described in chapter IV, triode

triple coincidence units were used. The circuit diagram is shown in Fig. 24.

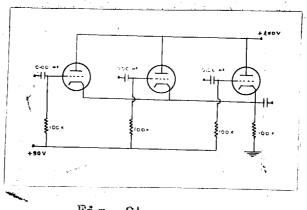


Fig. 24.

It is based on a circuit described by ELMORE and SANDS (1949). The coincidence pulses are developed on the cathode resistance, and are therefore of the same polarity (negative) as the input pulses. No separate discriminator is used, but the first scaling tube of the scaler recoder unit itself works as a discriminator against (n-1)fold coincidences.

Anticoincidence or the "INHIBITOR" circuit is a modification of the coincidence circuit in which an additional (n+1)th tube is added in parallel with the n tubes of the n-fold coincidence counting system. This (n+1)th tube when actuated simultaneously cancels the response of n-fold coincidence. This is achieved in the present case by biasing the (n+1)th tube below cut off and supplying appropriate positive pulses from the anticoincidence counter quenching and shaping unit.

2.4 Scaler and recorder unit :

The scaler recorder unit is a combination of suitable number of Eccles-Jordan type bi-stable multivibrators followed by a power amplifier. In Fig. 25 is shown a circuit of a scale of four unit which consists of two bi-stable pairs put in cascade, and a power amplifier.

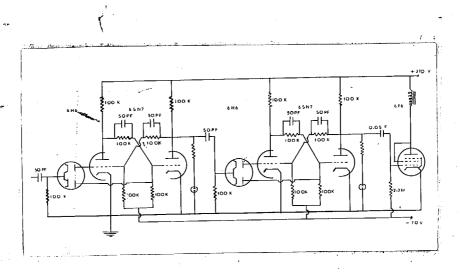


Fig. 25. Scaler and recorder unit.

Any number 'n' of such stages can be put in cascade to get a scaling factor of 2ⁿ. A bi-stable multivibrator is a two tube regenerative circuit which can exist indefinitely in either of two stable states and can be caused to make an abrupt transition from one state to the other. Many investigators [STEVENSON and GETTING (1937), LIFSCHUTZ and LAWSON (1938), REICH (1938), HIGINBOTHAM et al. (1947), FITCH (1949) etc.] have described and done a good amount of work to increase the switching rate and improve the reliability of such circuits. BUYS (1948) has given an analysis of the general response characteristics of the Eccle-Jordan type bi-stable multivibrator. An elegent

design procedure is described by RITCHIE (1953) and also by PRESSMAN (1953). For designs, where speed of operation is important, tubes having low input capacitance and high gm are selected. Twin triode tube 65N7 is very widely used for this purpose.

In practice scalers are used before recording the number of counts because of two distinct advantages. The final recording devices are always electromechanical and majority of the workers use telephone call recorders, which have a low resolution of the order of 0.2 seconds even for well shaped pulses. Introduction of the scaler unit before the final recording stage reduces the input rate to the mechanical recorder and also changes the random distribution of pulses into one where the different pulses are more regularly spaced. It has been shown by ALAOGLU and SMITH (1938) that the time interval between every rth pulse will have standard deviation given by $(1 + r)^{-\frac{1}{2}}$ so that as r increases the rth pulse will be more regularly spaced.

The cascade of scaling units is followed by a recorder driving circuit as shown in Fig. 25. It consists of a power pentode biased below cut off. Pulses from one of the plates of the twin triede of the last stage of scaler unit are fed to the grid of this tube. The tube an operates electromechanical counter whenever a positive pulse arrives at its grid. Neons are used as indicators, and are very useful for checking the function of scalers during operation.

2.5 Shaper and recorder unit :

In the experiment for the separate study of medium and high energy μ mesons described in chapter III, very low counting rates were encountered, and it was not desirable to scale down the coincidence counts with the help of a scaler and recorder unit. However, the coincidence pulse itself has not the proper shape for actuating the power amplifier which runs the mechanical recorder. Hence, a shaper and recorder unit was used, the circuit of which is shown in Fig. 26. The coincidence pulse is first fed to the shaper, which is a monostable multivibrator, and gives an output of a suitable positive pulse, every time it is actuated, which runs the power amplifier.

. 27. Automatic photographin

F on the photographic film m

Fig. 26. Circuit diagram of a shaper and recorder unit.

2.6 Automatic photographing device :

All cosmic ray records were obtained by photographing the mechanical counters every hour. The device consists of a camera unit and an automatic relay control unit. A camera unit is shown in Fig. 27.

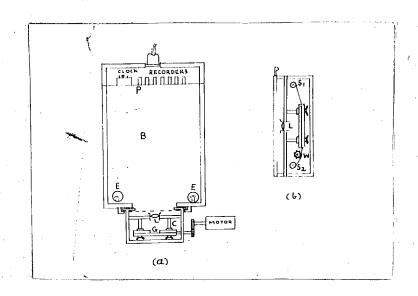


Fig. 27. Automatic photographing device.

All the counting meters are mounted on the panel P, which forms the end side of a light-tight box B. C is a detachable camera, also shown separately in Fig. 27(b), in which the lens L is adjusted so as to focus the image of the panel P on the photographic film running in the groove G. The film is wound on the spool, S1 and gets collected on the spool S2 after being pulled by the sprocket wheel W. The shaft of the sprocket protudes outside the camera box and is driven by an electric motor. With the help of a relay arrangement triggered by an electrical

contact of a few seconds duration made hourly by a clock, the following sequence of operation is achieved at regular hourly intervals:

- (i) Momentary lighting of the bulbs which exposes the film.
- (ii) Moving the film through one frame, thus leaving the camera ready for the fresh exposure.
- The electric motor has an internal gearing so that its main shaft rotates with a very slow speed, and the time required to move the film through the above length is about 15 seconds.

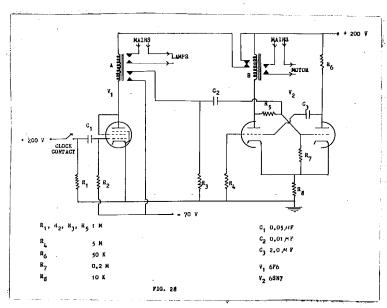


Fig. 28. Sequence control circuit.

Fig. 28 shows the relay control circuit used for the purpose. Two multi-contact telephone type relays are used. Relay A is put into the plate circuit of a 6F6 tube biased below cut off. It has two normally open contacts

which close on energizing the relay. Every hour when the clock contact closes momentarily, it feeds a positive pulse to the grid of 6F6 tube, which trips the relay. of the open contacts, when made, lights the lamps for a short time while the other contact feeds a negative pulse to the second stage. The second stage is a monostable multivibrator. Its "quasi-stable" state has a period of about 15 seconds, which is equal to the time required for the motor to move the film through one frame. Relay B is put into the plate circuit of the non-conducting section of the monostable maltivibrator. It has normally one open contact and one closed contact. The open contact is utilised for completing the electric motor circuit. plate supply voltage to the first tube (6F6) is fed through the closed contact which ensures that the first relay may not trip while the motor is on, and prevents accidental overlapping of double exposures.

The Hodoscope Recording System.

In majority of the experiments involving recording of cosmic rays with the help of counter telescope, coincidences between the appropriate counter groups are recorded. It is not normally necessary to know which particular counter or counters of the respective groups are involved in each individual coincidence. But when one wants to know what type of coincidences one is recording, i.e. due to single particles or more than one time associated particles etc., such additional information can

arrangement. In a hodoscope, all the counters are represented by mean glow lamps mounted on a display board. For each accepted event, the glow lamps of the particular counters taking part in that event are made to flash and are photographed. From the pictures thus obtained it is possible to find out exactly which counters were discharged in a particular event.

For the experiment described in chapter III such a recording system was used for the study of the nature of back-ground counts. The system was designed on the same line as that used successfully by OWEN (1950). The circuits used are described in this section.

If we want to record coincidences between three counter groups, having four Geiger counters each, and for each recorded event if we want to know which counters are discharged, the recording arrangement for this purpose can be represented schematically as shown in Fig. 29. "q and s" are the quenching and shaping units. For registering the three-fold coincidences between the three groups, pulses from each group are mixed separately and then fed to a coincidence unit. Whenever there is a three-fold coincidence it is made to generate a master pulse and also made to operate the mechanical counter. The master pulse is then fed back to the mixer unit, where it is mixed separately with individual pulses from the "q and s" units. This leads

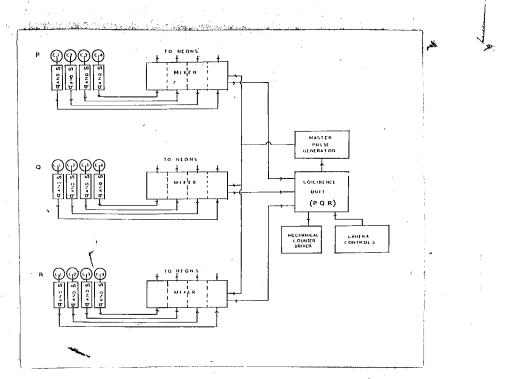


Fig. 29. Schematic diagram showing a hodoscope recording arrangement.

to striking of the appropriate means mounted on a display board, which is viewed by an unshuttered camera and recorded on film. The master pulse, with a suitable delay, also lights a lamp momentarily which helps in photographing the mechanical counter, clock, etc. also mounted on the same display board. Then the camera motor is made to run and move the film through one frame. Finally the apparatus is reset.

3.1 Quenching and shaping unit :

The quenching section of this unit is exactly similar to that of the unit described in section 2.2. In the present arrangement positive sharp pulses are required

in the output and hence the shaping section is differently designed. The circuit is shown in Fig. 30.



Fig. 30. Circuit diagram of a quenching and shaping unit which delivers sharp positive pulses in the output.

The square quenching pulse is differentiated by the R7C3 network. The negative pulse of a short time duration generated by the leading edge is inverted and shaped by the pentode amplifier, while the positive pulse is clipped because of the grid current. The pulse is then fed to the cathode follower, and a sharp positive pulse of about 20 volts and 3 microseconds pulse width is obtained in the output.

3.2 Mixer and neon control unit and the master pulse generator:

The circuit of the mixer and neon control unit

is shown in Fig. 31.

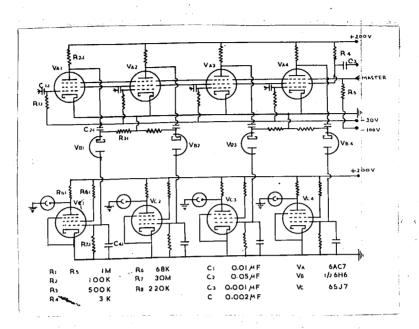


Fig. 31. Circuit diagram of a mixer and neon control unit.

All the mixer tubes Va1, Va2.... are 6AC7 pentodes. They receive pulses from the "q and s" units of counters c1, c2, c3.... of the corresponding counter group. All the input tubes are biased below cut off by giving a steady negative potential to control grids (g1). The screen grids (g2) are interconnected and fed through R4, and the supressors (g3) are joined together and biased off at -100 volts through R5. Thus for positive signals on control grids (g1) the circuit works as a tricde "OR" circuit, by turning on the screen current of the appropriate input valve for three microseconds, which generates a negative three microseconds pulse across the common screen resistance R4. Negative potential of 100 volts on g3 does not allow

any plate current to pass at this instance. The screen pulse is fed to the coincidence unit, where the pulses from the other mixer units are also brought.

The triple coincidence unit is of the type described in section 2.3 of this chapter. The coincidence pulse is fed to master pulse generator, the circuit of which is shown in Fig. 32.

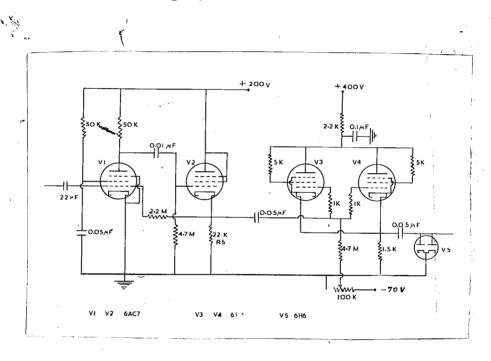


Fig. 32. Circuit diagram of the master pulse shaping unit.

Tube V1 and V2 are two 6AC7 pentodes and shape the negative pulse fed to them from the discriminator stage of the coincidence unit. A positive pulse of about 105 volts and 2.5 microseconds duration is generated on the cathode resistance R5 of tube V2 for every coincidence pulse fed to V1. V3 and V4 are two 6L6 beam power tubes, connected in parallel, and form a cathode follower through

which the master pulse is fed back to the supressors of the mixer unit valves (Vat, Va2....). V5 is a dioge clamp, which does not allow the supressors to go beyond ground potential, when master pulse output point is connected to the supressors. Each mixer tube Val etc. is an "AND" circuit, in which the plate current flows whenever there is a coincidence between the master pulse on supressor grid (g3) and the "q and s" unit pulse on control grid (gi) of a tube, signifying that the Geiger counter of that channel is involved in the original coincidence. Such coincidences give a sharp negative pulse at the plate of the appropriate mixer tube. This pulse is, in turn, integrated by the condenser C4, the resistance R7 and the appropriate diode and reduced in amplitude but increased in duration to the order of 0.5 seconds.

The tubes Vc1, Vc2,....(all 6SJ7) are normally "bottomed" with anode voltage of about 30 volts, which is insufficient to strike the neon lamp tied between the anode and earth. The broad integrated pulse described above, causes the corresponding tube to be cut off, consequently, the anode voltage rises until the neon lamp strikes, and the lamp remains in discharge until the grid of the tube returns to earth potential. The delay between the leading edge of the quenching and shaping unit pulse on control grid (g1) and the master pulse on supressor grid (g3) is of importance, for too long a delay

results in a small coincidence pulse on the plate of mixer tube (any one of Va1, Va2, etc.), which shortens the duration of the integrated pulse. Owen has claimed that in his circuits this delay was reduced to about 0.25 microseconds. In the present experiment it was about 0.5 microseconds. In his circuits Owen has used EF50 tubes throughout, but nonavailability of these tubes in India at the time of designing the units made it necessary to use 6AC7 tubes instead. 6AC7 has not got very good supressor grid (g3) cut off characteristics, and compared to EF50 cut off occurs at large value of supressor grid voltage. However, it is possible to select 6AC7 tubes having supressor grid cut off voltage about -100 volts, and these are found to function adequately in the unit.

The output pulse of the coincidence unit, is also fed to a relay control unit, which operates the recording equipment. A 16 mm. air-craft type cine camera (G.45-A.M.) was used for the purpose, after making some alterations for one shot action. The circuit diagram of the relay control unit is shown in Fig. 33.

All the tubes are of type 42 power pentodes.

Multi-contact telephone type relays are used. All the tubes are biased below cut off. The coincidence pulse is fed to the first stage through a pulse shaping monostable multivibrator of the type described in section 2.5. The first relay A, on tripping, holds itself through contact at

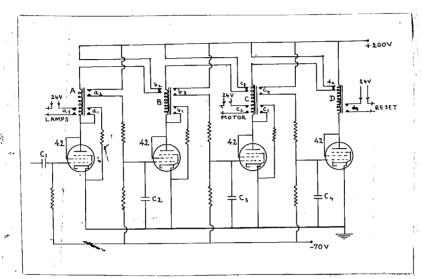


Fig. 33. Circuit diagram of the relay control unit.

and charges condenser C2 in the grid circuit of the second tube through contact a2. At the same time the lamp circuit is made ON through contacts a3. After a very short time (about 0.4 seconds) relay B closes cancelling relay A, and after 1 second more relay C closes in the same way cancelling relay B. C completes camera motor circuit through contacts c2 which moves the film through one frame. Thus relay B works as a buffer relay which makes the film to move after the lamps are extinguished. Through the contact c1 condenser C4 is charged, which trips relay D and resets the camera.

4. Methods of Analysis.

4.1 Tabulation of data :

obtained in the form of hourly photographs of the electromechanical recorders. Readings for the hours 2300, 0100, 0300.....2100 I.S.T. are noted down in the daily record sheets. Differences between the successive bihourly records give the rates of meson intensity centred at 0000, 0200,.....2200 hours for each day. From the difference between the readings at 2300 hour on successive days the daily mean meson intensity, centred at 1100 hour I.S.T. and expressed as a mean bihourly rate \bar{m} is computed. The 12 bihourly values for each telescope are then expressed as deviations, $\Delta m_0^1, \Delta m_1^1, \ldots, \Delta m_{11}^1$ from the daily mean \bar{m} for the ith telescope of a similar telescopes working on that day.

On each day the 12 bihourly deviations from the daily mean obtained in this way for different telescopes of identical geometry are tabulated side by side and examined to see whether within limits of statistical significance the deviations from mean of the rates of the different telescopes for the same bihourly interval are similar. The daily mean values m are also plotted and it is checked whether telescopes of similar geometries show similar day to day variations. Besides this, daily routine check observations of the rates of groups of counters in trays as well as voltages etc. are examined. Due to the

variety of checks so applied, it is possible to pick-out, a faulty telescope, and locate the fault too. Data for such telescopes are not taken into consideration on that particular day and if necessary for some consecutive days earlier to it depending upon the nature of the fault.

$$\Delta^* M_{\chi} = \frac{\sum_{i=1}^{2m} \Delta m_i^i}{\sum_{i=1}^{2m} \Delta m_i^i}$$

On certain days when all the telescopes may not be in operation, $\sum_{i=1}^{n}$ will be less than the usual value. In such a case the mean intensity is normalized to give a value $\sum_{i=1}^{n}$ which could represent the mean intensity had all telescopes been working. This is done by comparing the particular day's data with those of the previous five days on which all telescopes were running. Each set of this type corresponds to a telescope of a particular geometry on a particular day.

Meteorological data :- An acurate microbarograph 4.12 and a thermograph are maintained in the laboratory, and for most of the period during which the author studied day to day changes in the daily variation of meson intensity, these were maintained by the author himself. A check on the readings of the recording instruments was kept by comparing the measurements with an acurate barometer and thermometer read at one particular hour on each day, and occasionally at different hours on a particular day: The ground pressure and temperature values are then read for the hours 0000, 0200, 2200 I.S.T., and the daily means calculated. These data are then expressed as twelve deviations from mean and a daily mean value as ΔP_0 , etc. and \overline{P} for barometric pressure, and Δ To, etc. and \overline{T} for temperature respectively.

4.2 Solar daily variation :

The twelve bihourly deviations $\Delta^* M_0$, etc. of meson intensity are then corrected for the effect of the daily variation of barometric pressure by using the corresponding bihourly deviations ΔP_1 and a barometric coefficient of-2.2% per cm. Hg. The use of the particular coefficient is discussed elsewhere SARABHAI et al. (1953, 1955a). The solar daily variation of meson intensity on any one particular day corrected for barometric pressure, is then represented by the twelve bihourly per cent deviations ΔM_0 , ΔM_1 , etc. and the daily mean intensity by \overline{M} .

4.3 Daily variation on a group of days:

daily variation on a number of days taken together. The days selected may be according to a period of time such as a month or a season or a year. They may be days on which the daily variation exhibits some particular characteristics, or they may be selected according to particular geomagnetic or solar characteristics. The average daily variation for such a group of n number of days is given by twelve bihourly per cent deviations

4.4 Fourier analysis:

and its relationship with other factors, which are known to be periodic in nature, it is often convenient to resolve a daily variation into its harmonic components. The method of resolving a periodic curve into its fundamental and higher harmonics have been treated rigorously in various text books. Various authors, such as THOMPSON (1911), WHITTAKER and ROBINSON (1937), HENNEY (1941), and KANE (1954) have described labour saving computational methods for evaluating the harmonic coefficients. For most geophysical studies the first and the second harmonics of the daily variation are the

only ones of importance. The method suggested by Kane is therefore followed which compared to other methods, is quick and accurate, and gives the first and the second harmonics with minimum labour.

Any time dependent function f(t) can be written as $f(t) = a_0 + (a_1 \cos t + b_1 \sin t) + (a_2 \cos 2t + b_2 \sin 2t) + \dots$ (5)

In practice when one has to handle equally spaced values, representing a time dependent function such as the daily variation of cosmic ray intensity, or the daily variation of meteorological factors, the method of Kane is applicable if the equally spaced points are twelve or twenty-four. In the present work the twelve point scheme is utilised, because all daily variations are represented by twelve bihourly values. These twelve values when treated by this method, yield the coefficients a, b, a, and b2 for the variation of a particular day. ao is zero, as the twelve values are expressed as deviations from the mean.

Equation (5) can also be written as

$$f(t) = a_0 + A_1 \sin (t + \beta_1) + A_2 \sin (2t + \beta_2) + \dots$$

$$= a_0 + \sum A_n \sin (nt + \beta_n)$$
(6)

where
$$A_n = (a_n^2 + b_n^2)^{\frac{1}{2}}$$
 and $Tan^{-1} \phi_n = \frac{a_n}{b_n}$ (7)

4.4 "

 A_n is the amplitude of the nth harmonic and \emptyset_n is its phase. Equation (7) shows the relationship of a_n and b_n with A_n and \emptyset_n . Thus the values a_1, b_1 and a_2, b_2 give A_1, \emptyset_1 and A_2, \emptyset_2 , the amplitude and the phase of the first and the second harmonics respectively. It is customary to compute from \emptyset_n and angle Y_n where $Y_n = 90^\circ - \phi_n$. Y_n represents the time of the maximum of the nth harmonic (in degrees). (In this way the daily variation which was originally represented by twelve bihourly values can now be more conveniently represented by four values a_1, b_1 and a_2, b_2 from which the values A_1, Y_1 and A_2, Y_2 are derived.

There are two definite advantages of this way of representation :

Firstly, cosmic ray arrivals are randomly distributed. A standard deviation $6 = \pm (M)^{\frac{1}{2}}$ is therefore associated with every estimate computed from M number of counts counted by a device in a particular time interval. Each estimate of a bihourly per cent deviation is associated with a standard deviation of $\pm 100/M^{\frac{1}{2}}$ %, where M is the mean bihourly rate of that day. Normally a deviation would be considered statistically significant if its magnitude is larger than $2 \cdot 6$ or $3 \cdot 6$. If therefore, the value of M is such that $6 = \pm 0.8$ %, a bihourly deviation is not significant at $3 \cdot 6$ level unless it is larger than 2.4%. Since the harmonic coefficients are derived from twelve bihourly values, the standard deviation

of a harmonic coefficient gets reduced by a factor of $(6)^2$ or about 2.4. At the same level of significance therefore an amplitude > 1.0% is required for the significance of the harmonic coefficient.

The second advantage is that because higher harmonics beyond the diurnal and the semidiurnal are known to be unimportant, the four fourier coefficients a_1 , b_1 , a_2 , and b_2 in place of 12 bihourly deviations, are sufficient to characterise a daily variation. The quantities a_1 , b_1 , a_2 , and b_2 can moreover be added up as scalars and therefore it is simple to derive the coefficients of the harmonic components for groups of days.

4.5 Harmonic dial:

To compare variations observed by two different instruments or to study the relation between variations of two different phenomena it is desirable to plot the harmonic components in a convenient form where both the amplitude and the time of maximum of the component are represented. Such a method is called the harmonic dial. To represent the first harmonic of the daily variation, a circular scale where 360° equal 24 hours measured in a clockwise direction is used. For representing the second harmonic a time scale where 360° is equal to 12 hours is used. The amplitudes and the time of maxima are represented by plotting vectors having lengths proportional to the amplitudes, and pointing in the directions which make angles

equivalent to the times of maxima with a fixed O or zero hour line.

4.6 The form of the daily variation:

variation is to examine the twelve bihourly deviations on an individual day, as way done by SARABHAI and NERURKAR (1955). For less subjective method to study the changes in the nature of daily variation, it is necessary to have parameters describing the data on each day. On most days it has either a single maximum or two maxima. The most significant features of the daily variation may therefore be considered to be the relative magnitudes of the diurnal and the semidiurnal components, as well as the amplitude and the time of maximum of the dominent component. To get an insight into this problem a family of curves was plotted after taking A₁ and A₂ in different proportions and with different possible phase relationship taken in steps. They are shown in Fig. 34.

On examining these one can easily see that,

- (i) for any relationship between the phases p_1 and p_2 if $A_1/A_2 > 1.5$, the variation is mainly diurnal;
- (ii) for any type of relationship between the phases p_1 and p_2 , if $A_1/A_2 \le 0.75$ the curve is mainly semidiurnal;
- (iii) for intermediate values, when $0.75 < A_1/A_2 < 1.5$ there is a degree of ambiguity in referring to the variation

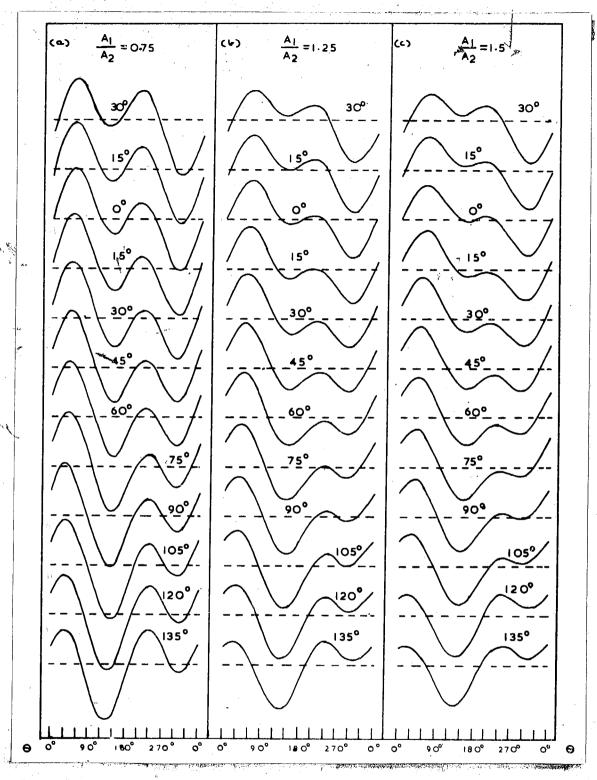


Fig. 34. Plots of the function $f(\theta) = A_1 \sin(\theta + \phi) + A_2 \sin 2\theta$ for three different values of $A_1/A_2 \text{ viz.}$ (a) 0.75, (b) 1.25, and (c) 1.5 respectively and different values of ϕ , indicated near each plot.

as diurnal or semidiurnal. In this case the phase relationship and value of the ratio A₁/A₂ have both to be considered.

4.7 Chree analysis :

of analysis, named after him, for the investigation of quasi-periodic phenomena. By his technique of superposed epochs, it has been possible to discover a 27 day recurrence tendency in a number of geophysical and solar phenomena which by themselves have no definite periodicity of occurrence. The 27 day recurrence arises from the synodic rotation of the sun round its own axis so that regions of long lasting activity on the sun's disc have central meridian passage after an interval of about 27 days.

In Chree analysis, the values of a parameter on successive days on either side of a chosen epoch are arranged in rows. The columns for the days of epoch as well as for the days preceding and following epoch upto any desired stage are then added up. The sums of the columns are then compared with each other to determine if there is any periodicity related to the days of epoch.

4.8 Correlation analysis :

The degree of relationship between different variables can be studied by calculating the correlation coefficients. Thus if ΔM and ΔP represent the deviations

from mean for cosmic ray intensity and ground pressure respectively over a common interval of time, the correlation coefficient between the two is given by

$$\Gamma_{MP} = \frac{\sum (\Delta M \cdot \Delta P)}{\sum (\Delta M)^2, \sum (\Delta P)^2}$$
(8)

the summation being carried out for all the pairs of Δ M and Δ P values for that period.

The regression equation between the variates is

$$\Delta M = b_{MP} \cdot \Delta P$$
 where $b_{MP} = r_{MP} \left[\frac{\sum (\Delta M)^2}{\sum (\Delta P)^2} \right]^2$. (9)

For studying the relationship between more than two variables the partial correlation analysis is employed. This method gives a measure of the relationship between any two variables, the rest of them remaining constant. Thus if ΔM , ΔP , and ΔT represent the deviations from mean for cosmic ray intensity, pressure and temperature respectively over a common interval of time, then correlation coefficient between M and P with T remaining constant is given by the relation

$$r_{MP}.T = \frac{r_{MP} - r_{MT}.r_{PT}}{\{(1 - r_{MT}^2)(1 - r_{PT}^2)\}^{\frac{1}{2}}}$$
 (10)

and a similar relation for r_{MT.P}.

The regression equation expressing the relation between the three variates is given by

where
$$\alpha_{P} = \alpha_{P} \Delta P + \alpha_{T} \Delta T$$

$$\alpha_{P} = \frac{r_{MP} - r_{MT} + r_{PT}}{1 - r_{PT}^{2}}, \quad \sum (\Delta M)^{2}$$

$$\sum (\Delta P)^{2}$$
(11)

and a similar relation for α_{+} .

The pressure and temperature coefficients of cosmic ray intensity can be evaluated from $\alpha_{\rm p}$ and $\alpha_{\rm T}$ as follows :

Pressure coefficient $\overline{\alpha}_p = 100 \alpha_p / \overline{M} \%$ per cm. Hg., and Temperature " $\overline{\alpha}_T = 100 \alpha_p / \overline{M} \%$ per degree C.

where $\overline{\mathbb{N}}$ represents the mean value around which the deviations $\Delta\mathbb{N}$ of cosmic ray intensity are expressed.

Partial correlation can also be extended to cases where there are more than three variates. The standard error associated with the correlation coefficients is given by the relation

$$p_T = \pm \frac{1 - r^2}{(n-1)^{\frac{1}{2}}}$$

where r is the correlation coefficient and n is the number of pairs from which r is calculated. The larger the value of n the lesser would be the value of the standard error and hence greater the significance of r.

4.9 Correlation coefficient for grouped data :-

It is not possible to apply the method of partial correlations when data are not available for some of the variate which are known to influence a In such circumstances the method measured variable. of grouped data can be used with advantage to study the relationship of the measured variable A with one of the varietes B for which information is available. values of A are computed for values of B drawn from the entire data but divided into various ranges. data relates to an extended period of time, the values of the unknown variates may reasonably be assumed to approximate to a constant average in each group. correlation between the mean values of A and B in each group may then be deemed to approximate to the partial coefficients of A with B the other variates remaining constant.

The correlation coefficient between any two periodic variates of the same periodicity is given by the cosine of the difference between the phase angles of the two.

Thus if

 $y = a_k$ Sin kx and

 $z = a_k \sin (kx + d)$

the correlation coefficient between y and z will be

 $r_{yz} = \cos d$

irrespective of the value of k.

CHAPTER III

THE STUDY OF THE DAILY VARIATION OF LOW AND HIGH ENERGY P. MESONS INCIDENT IN A VERTICAL NARROW COME

1. Cosmic Ray Experiments Utilising Magnetised Iron Core for Deflecting Charged Particles.

Several cosmic ray investigators have conducted experiments utilising magnetised iron core for deflecting particles, for either measuring their momenta or separating them according to their charge.

TUVE (1930) pointed out that for investigating high energy cosmic ray particles (mesons were not known then) a three-fold or higher coincidence method has advantages over an arrangement utilising double coincidence between two counters. The advantages are:

(i) a pair of counters can be used to define a beam of ionising particles which is subsequently picked up by a third counter after being scattered, deflected by magnetic field or otherwise experimented upon, and

(ii) the number of multiple coincidences occuring by chance can be reduced to a much smaller fraction of the true coincidences, making it possible to work a beam of much smaller angle than can be used with only two counters.

Following this idea an experiment was planned by MOTT-SMITH (1930), where a pair of Geiger counters were to be used to "collimate" a beam of particles, which were then to pass through a region of strong magnetic field, and were to be finally detected by a third counter placed at a suitable distance.

His calculations had shown that for this purpose, a very strong uniform magnetic field over a considerable volume was necessary. To generate such fields in an air gap of such large dimensions is very difficult. He overcome this difficulty by following a suggestion of SKOBELZIM (1929) that magnetic deflection of particles of such enormous penetrating power could be produced by passing them directly through a magnetised iron bar. He estimated the widening of the beam due to straggling in the iron bar to be negligible for particles of such high energies as observed in cosmic rays.

The experimental arrangement used by MOTT-SMITH (1931, 1932) is shown in Fig. 35. M is the magnetised iron bar. Triple coincidences ABC were recorded with different positive and negative values of 'd', the displacement of counter C from the central axis, with iron core and without, and with field ON and OFF when iron core was in use. Within

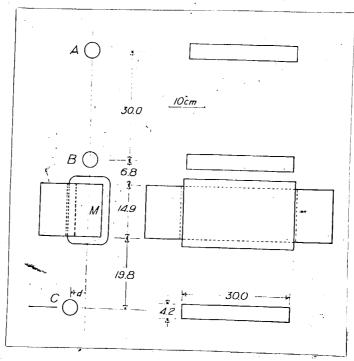


Fig. 35. Arrangement of apparatus [MOTT_SMITH (1932]].

the limits of the errors of the experiment no deflection was observed and he concluded that particles were of very high energy, greater than 10 ey. This was the first experiment of its kind.

ROSSI (1930b) performed a similar experiment, quite independently of Mott-Smith, about the same time, but also without any success. Having not been able to observe any deflected particles ROSSI (1930c, 1931), improved the experimental technique by having two parallel oppositely magnetised plates, which lie close together, and putting two counters above and below them. In Fig. 36 is shown a Rossi's original magnetic lens arrangement.

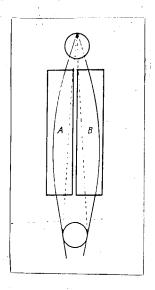


Fig. 36. Magnetic lens arrangement [ROSSI (1931)].

The charged particles passing through the upper counter were either concentrated upon or deflected away from the lower counter, depending on the direction of magnetisation. He came to the conclusion that the corpuscular rays which were then supposed to be electrons, are not deflected by passing through the magnetised iron to such a great extent as one expected for 10 ev. energy. Rossi raised a doubt about the interpretation of such experiments, that the magnetic induction B which represents the average value of the microscopic magnetic field strengths might not be the true value which is responsible for such deflections. But afterwards he came to the conclusion that in all media, including ferromagnetic media, the deflecting force on a moving charge is determined by the magnetic induction B.

Due to the smallness of the effect observed by Rossi and Mott-Smith, the technique of Wilson cloud

chamber superseded this method. From the experiments it became clear that particles are not electrons, as was assumed previously and that positive and negative particles present are in equal numbers with a slight positive excess.

To investigate this BERNARDINI et al. (1941) improved Rossi's technique by using two pairs of magnetised iron plates and by properly choosing the direction of magnetisation in the plates they were able to concentrate only positive or negative particles. The arrangement is shown in Fig. 37.

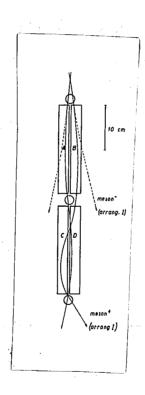


Fig. 37. Arrangement of counters and magnetised iron plates [BERNARDINI et al. (1941)].

After this, several other workers such as

BERNARDINI et al. (1945), CONVERSI et al. (1947), GROETZINGER and McCLURE (1948), GROETZINGER et al. (1951), BERETTA et al. (1952), QUERICIA and RISPOLI (1954) and FILOSOFO et al. (1954) have successfully tried this method of deflecting A mesons in a magnetised iron core for selecting them according to their charge or momenta or for both.

In the present investigation the author has used an experimental set-up, utilising a magnetised iron core, in which low and high energy a mesons could be counted separately. The purpose was to study the time variation of high and low energy cosmic ray mesons. The apparatus and the results are discussed in what follows.

2. The Apparatus.

The apparatus used in this experiment consists of two main parts, saturated core electromagnet, and Geiger counter telescopes for the measurement of the intensity of low energy positive and negative μ mesons deflected in the magnetic field, and the intensity of high energy μ mesons.

The electromagnet is constructed out of high grade silicon steel transformer laminations of suitable dimensions. An uniform magnetic field of about 19000 guass (very nearly the saturation value) is easily generated in it.

2.1 The electromagnet :

The first run of the experiment which covers the period June 1952 to August 1953, was carried out with the

magnet of a closed E shape as shown in Fig. 38(a). The central limb, which was used for deflecting the low energy particles, had length 60 cm. breadth 10 cm. and height 60 cm. Two outer limbs of 60 cm and breadth 5 cm. were used for winding the coils over them. The coils had 3364 turns. A constant D.C. current of about 3 Amps. was continuously passed through the coils. The current was fed from a D.C. motor generator set. The magnetisation was almost upto saturation and under this condition field fluctuations are very small for current variations due to mains voltage fluctuations. In this arrangement only the central limb of the magnet was available for experimentation.

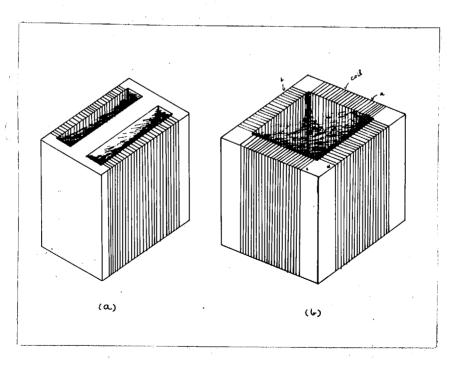


Fig. 38. The electromagnet, (a) used during the first run and (b) the newly designed magnet used during the second run of the experiment.

Towards the end of 1953, when the laboratory was shifted to its new building, the magnet got damaged in transit, and it was necessary to rebuild it. From results obtained during the first run it was felt necessary to run more than one similar telescopes for this experiment, as the counting rates involved were very small. This could be done by changing the shape of the magnet such that more limbs would be available for experimentation. Accordingly, a new magnet of closed square geometry was constructed by the end of 1954. The second run is with the new magnet which is shown in Fig. 36(b).

All the four limbs a, b, c, and d of the magnet are available for the erection of telescopes and are of the same dimensions as the central limb of the old magnet. A single layer coil is wound on all the four limbs. It has 700 turns and can carry a current upto 14 Amps., without requiring any external cooling arrangement.

2.2 The Geiger counter telescope :

Fig. 39 shows cross section of the apparatus in an E-W plane. The associated electronic units are also shown schemetically. The axes of the Geiger counters lie along the N-S direction and hence the counters are represented as circles in the diagram. Each Geiger counter has a diameter of about 4.0 cm. and sensitive length of about 30 cm. For convenience of representation, only the cross section of the core used for deflecting the particles

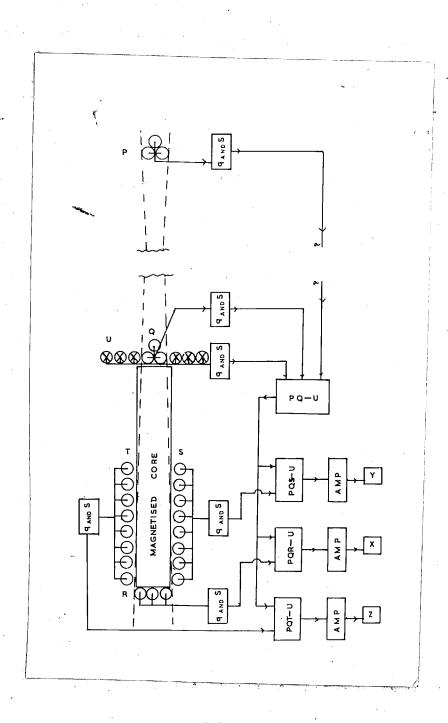


Fig. 39. Schematic diagram showing the arrangement of the counters with their associated electronic units.

is shown. The field is perpendicular to the plane of the paper, and is reversed regularly by changing the direction of the current through the coils.

Geiger counter arrays P, Q and R have three counters each. Array P and Q have each a sensitive area of about 280 sq.cm., and R has a sensitive area of about 360 sq. cm. The two arrays Q and R are put above and below the iron core respectively. The third array P is kept vertically above these two arrays in such a way that the cone of the counter telescope is covered by the iron core in the E-W plane. Thus every particle in the cone of acceptance determined by the arrays P and R must traverse the iron core. When the core is saturated the telescope PR cannot register low energy M mesons which are deflected out of the main cone. The cone had semiangular opening of 1.70 in the E-W plane and 6.70 in the N-S plane. In the second arrangement the Lare 2.20 in the E-W plane and 5.5° in the N-S plane. The two vertical arrays S and T of eight Geiger counters in each one are kept on two sides of the iron core. The side arrays are placed so that no single undeflected particle in the vertical cone, determined by the arrays P and Q, can traverse the counters in S and T.

Six Geiger counter tubes shown in the diagram as circles with crosses and designated as U are arranged in groups of three on either side of the array Q. They are used as anticoincidence counters.

All Geiger counters in a particular array are connected in parallel to a single quenching unit. These quenching units shown as "q and s" in Fig. 39 are of the type described in chapter II (page 74). Each quenching unit gives a sharp negative output pulse of about three microseconds duration for each Geiger discharge in any one of the counters of the array.

All events measured in the experiment involve a double coincidence PQ-U where the anticoincidence counters U are not simultaneously triggered. The pulse PQ-U and the outputs from R, S and T are then fed to three double coincidence units. Thus the three triple coincidence rates PQR-U, PQS-U and PQT-U are separately measured by the mechanical recorders X, Y and Z, and designated as N(X), N(Y) and N(Z) respectively. The mechanical recorders are mounted on a panel and photographed every hour as described in the previous chapter.

2.3 Back-ground counts:

From the geometry of the arrangement it is evident that no single particle incident in the vertical cone determined by the arrays P and Q, can give a coincidence of type PQS-U or PQT-U unless it generates secondaries in the core, gets scattered or gets deflected when the magnetic field is ON. More than one time-associated particles (showers) can also give such coincidences provided their paths do not encounter any of the anticoincidence counters.

From the geometry of the arrangement, the probability of such events should be small. Chance coincidences add a fraction to the back-ground, but this is quite small.

Since an attempt is made in the experiment, with field ON, to associate coincidences of type PQS-U and PQT-U with low energy M mesons, it is necessary to estimate the contribution of other processes to the counting rates N(Y) and N(Z). With field OFF these rates are appreciable and constitute a large back-ground due to processes other than deflection in the magnetic field. Scattering of low energy M mesons undoubtedly make a contribution to this back-ground. When the field is ON, these same A mesons would be deflected and be legitimately counted with the rest of the deflected A mesons. Thus the magnitude of the back-ground rate with field OFF, by itself gives no indication as to the validity or otherwise of associating with low energy M mesons, the rates N(Y) and N(Z), when field is ON.

The crucial point to establish, therefore, is the contribution of scattered mesons to the back-ground rate. The balance contribution as a percent of the total back-ground establishes an upper limit to the extent to which rates N(Y) and N(Z) with field ON are made up of processes other than those associated with low energy mesons.

One can estimate the contribution of different processes, to the rates of the side arrays PQS-U and PQT-U with field ON and OFF by a hodoscope arrangement, which

indicates the exact counters involved in a particular coincidence count. Alternatively, it is possible to estimate this numerically, from knowledge of the theory of multiple coulomb scattering. In the present study both these methods are adopted, and the results are compared.

2.4 The hodoscope arrangement :

Fig. 40 shows, schematically, the modifications made in the recording arrangement, for introducing the hodoscope circuits. The circuits employed are of the type used by OWEN (1950), and described in chapter II (page 66) of the present thesis.

Sixteen Geiger counters of the two side arrays S and T are divided into eight groups of two adjoining counters, each connected to a quenching unit. Per each accepted event of type PQR-U, PQS-U and PQT-U, one hodoscope picture is obtained, where the nine neons, representing the eight groups of arrays S and T and the array R, show by their corresponding flashing which pairs of Geiger counters, were triggered in the particular event.

Experimental Results.

The data presented in this section fall into two groups depending upon the period during which the data were collected. The first run covers the period from June 1952 to August 1953, taken with the magnet in the first

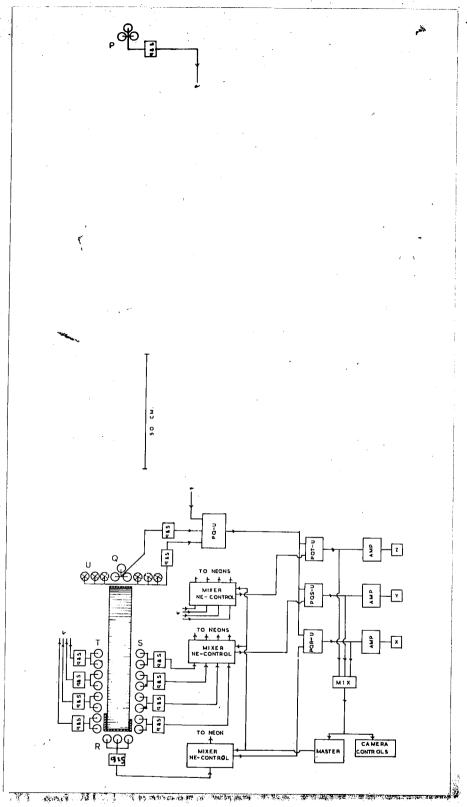


Fig. 40. Schematic diagram showing the modified counter arrangement and associated electronic units during the hodoscope recording for the investigation of the back-ground counts.

arrangement. The later run with the magnet in the second arrangement covers the period from March 1955 to October 1955. The hodoscope unit was run only during some of the days in the second period. The main purpose of this second run which incorporated the hodoscope arrangement, was not so much to measure the daily variation of meson librarity, as to understand the nature of processes responsible for coincidences PQS-U, PQT-U with field ON and OFF.

Table 3 shows the period of the two runs, the number of days for which daily variation data are available for the low energy and high energy A mesons, and the mean bihourly counting rate N(X), N(Y) and N(Z). In the second run there are many breaks, because of several reasons, and the useful data collected is for a few days only.

When the field is OFF there are no magnetically deflected particles, and therefore all the N(Y) and N(Z) counts are back-ground counts. N(X) corresponds to the energetic μ mesons, of momentum about 600 MeV/c or more, which are able to penetrate about 64 cm. of iron and are incident in a very narrow vertical cone. In all cases one can see that the counting rate N(X) decreases while the rates N(Y) and N(Z) increase when the field is switched ON. This shows that some of the μ mesons in the vertical beam are deflected out of the main vertical cone.

Pable 3.

Total number of days on which data are available for telescopes P(R-V), P(S-V), and P(V-V) (indicated as X, X, and Z respectively) for different periods with their mean bihourly counting rates.

100 100 100 100 100 100 100 100 100 100	Angular opening semi-ancies	Eggnetic Felc	S S S S S S S S S S S S S S S S S S S	days o	of days on which		Mean binourly rates for the period.	rates.
	Plane plane			5 7 M	7635TD	•	(A)	2
June 1952	Or A			30	30	45.50	5.0	125
Aug. 1953		õ	202	244	27.00	10°0°	& ¢. %.0.	200°
Mar. 1955 to	2,20	OF				1.25	2.2	2.5
0ct. 1955				3	2	44 44	27	= 0
Hodoscope	2,20 5,50	i i		क्षेत्र प्रकार सम्बद्धाः स्था व	and an	1 25 C	12.21	7:07
4. Select 6-19.		ð	100	'00	ಯ	25 20 20	200	50 C

the change in the geometry of the set up in the first and the second arrangement was such that rates for the second period should be higher than those in the first period, as is found to be the case. However, the increase in the N(Y) and N(Z) type of counts is proportionately more than that for the N(X) type of counts. For the percent back-ground with the field OFF, expressed as $\frac{N(Y)+N(Z)}{M(X)}$.100, one gets the values 42.1%, 59.0% and 58.0% for the first period, second period and the hodoscope run respectively. The hodoscope results are comparable with those of the second period since the arrangement of counters is the same in both the runs. The proportionately low back-ground rates M(Y) and N(Z) with field OFF in the first arrangement is probably due to the shielding of the side counters from shower particles by the outer limbs of the magnet. second arrangement does not provide this shielding to the side arrays S and T. To test this, an additional counter array V was put between the arrays P and Q and fourfold coincidences PVQR-U, PVQS-U and PVQT-U were recorded. Let us call these coincidence rates as $N(X^*)$, $N(Y^*)$ and $N(Z^*)$. If the increase in the back-ground in the second arrangement is due to inclined showers which are able to trigger counters of arrays P, Q and S or T without triggering the anticoincidence counters U, one should expect that N(Y') and N(Z') will be less than or comparable to N(Y) and N(Z) of the first arrangement. Since the efficiency of the anticoincidence counters was high, it is assumed here that such

showers can only be low density inclined showers, and the probability of their missing anticoincidence counters as well as counters of array V is high. Results from such a run are as follows, which fits with the assumption made above.

per cent back-ground (field OFF) =
$$\frac{N(Y^*)+N(Z^*)}{N(X^*)}$$
.100

= 32.3% for PQRV-U

as against 59% for PQR-U, both in the second arrangement.

This reduction of back-ground counts when four-fold coincidences are recorded is not due mainly to a reduction in the number of chance coincidences, since even for three-fold coincidences the chance coincidence rates are negligible, because the pulses employed are very sharp (3 microseconds) and the coincidence circuits are fast. This was confirmed experimentally by irradiating the array P by radiation from a thorium salt. This increased the individual counting rate of the array P by a factor of 10. No significant increase in the coincidence rates N(X), N(Y) and N(Z) was observed.

3.1 Hodoscope results :

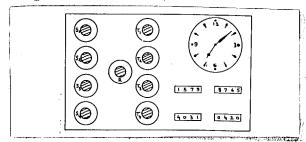


Fig. 41. Arrangement of neons, clock and recorders on the display board.

Fig. 41 shows the arrangement of neons on the display board for the hodoscope camera unit. As mentioned earlier, 16 counters of the two side counter arrays S and T are grouped into eight pairs of adjacent counters, four pairs for each side. These eight pairs and three counters of array R are represented by nine neon glow lamps S1, S2, S3, S4, T1, T2, T3, T4 and R respectively and are mounted in the manner as shown in Fig. 41. For each recorded coincidence a film record of the board is obtained on a 16 mm. film with a movie camera. The neons of those groups which are involved in a coincidence appear as black dots on the film.

For an understanding of the hodoscope results, it is convenient to classify the observed events into three types, A, B, and C and associate them with the different known processes.

"A" type events are those where R is flashed singly or is associated with the flashing of only one of the eight groups on the sides.

"B" type events are those in which only one side group, singly, or two adjacent groups on the sides are flashed.

"C" type events are those in which two side groups which are not adjacent or more than two neons are flashed.

When the field is OFF the processes are as follows:

(i) "A" type events :- A fast M meson travelling in the cone of acceptance, with sufficient momentum to traverse the whole length of iron core, gives a coincidence of type PQR-U. This contributes to the rate N(X) and also gives rise to an event recorded by the hodoscope camera unit, in which only the neon which represents the array R is-flashed.

When such a fast M meson produces a knock-on electron which comes out on one of the sides it gives two counts simultaneously, one of the type PQR-U and one of the type PQS-U or PQT-U, depending on the side on which the knock-on electron comes out. Such an event is recorded by the hodoscope by flashing of a neon on the sides and the neon representing the array R. This type of event which contributes to N(X) and N(Y) or N(Z) constitutes only about 6.6% of all A type of events.

We can conclude that all $\mathbb A$ type events are associated with high energy M mesons.

(ii) "B" type events: If the incident μ meson is not very energetic, multiple coulmb scattering is appreciable. There is then a probability that it may come out on one of the sides and give a coincidence of type PQS-U or PQT-U. Such an event will give a contribution to either N(Y) or N(Z) and at the same time will give rise to a hodoscope event, where a single neon representing one of the eight side groups has flashed. If the μ meson

stops in the core, and produces a sufficiently energetic electron which can come out on one of the sides, a similar event occurs.

It is possible that a scattered meson travelling in an inclined direction may trigger two adjacent counters belonging to two different adjacent groups. Though such an event contributes to either N(Y) or N(Z), the hodoscope event is recorded as flashing of two adjacent neons on any one side. A knock-on electron coming out on one of the sides with the parent A meson coming out on the same side in a narrow cone can also give a similar hodoscope record.

All B type events are thus associated with low energy u mesons.

generated in the roof and walls of the surrounding building, and missing the anticoincidence counters, and showers produced in the core and counter walls by fast knock-on electrons produced by mesons, can trigger many counters on the side and bottom array. These contribute to N(X), N(Y) and N(Z) either singly or to any combination of them. The hodoscope events in such cases are recorded either by the flashing of two side group neons which are not adjacent or by the flashing of more than two neons. About 29.3% of C type events involve arrays on both sides. This fraction therefore contributes to counts N(Y) and N(Z) simultaneously.

It should be noted that there is some embiguity

in interpreting B type events where two adjacent groups of a side array are triggered. This is because the event may be due to a single particle in an inclined direction or to two particles. In the latter case, the event can represent a shower and is similar to the processes responsible for C type events.

Table 4 shows the average bihourly rates of the A, B, and C type events recorded by the hodoscope arrangement when the field was OFF and when it was ON. With field ON there is an additional contribution to B type of events due to magnetically deflected low energy M meson.

Table 4.

Average bihourly rates of the hodoscope events, classified into groups A, B and C according to their nature.

iold	Average	bihourly rates of events		
rs ara sig vio ens .	A CYDO	N(B) B type	C type N(C)	Total N(A+B+C)
)r.r.	27.3±0.8	9.640.4	4.1.10.4	41.0±1.0
ON	21.440.5	16.3±0.5	5.3±0.3	43.040.7
112,	5.911.3	+6.7±0.9	11.2+0.7.	+2,011.7

On examining the results presented in the above table it is seen that A type of events decrease on switching

the field ON, which indicates that the low energy M mesons are deflected by the magnetic field. There is an appreciable increase in B type events which is of the same order as the decrease in A within statistical limits. This indicates that the side arrays are receiving most of the deflected particles.

Both B and C type events involve at least one counter in a side array and therefore contribute to the rates N(Y) and N(Z). The proportionate increase of this rate with field ON due to B and C type events separately is given by

% increase of B type =
$$\frac{N(B)_{ON} - N(B)_{OFF}}{N(B)_{OFF} + N(C)_{OFF}}.100$$
$$= 43.1\%$$

% increase of C type =
$$\frac{N(C)_{ON} - N(C)_{OFF}}{N(B)_{OFF}} \cdot N(C)_{OFF}$$
= 0.9%

It is observed that the contribution of C type events remains alsmost unchanged by the application of the field. We can also conclude that our interpretation of associating B type events with low energy A mesons is substentially correct.

The estimate of per cent count in N(Y) and N(Z) which is not connected with low energy mesons when field

is ON is given by

$$\frac{(1 + x).N(C)_{ON} + y.N(A)_{ON}}{N(B)_{ON} + (1 + x).N(C)_{ON} + y.N(A)_{ON}}.100$$

where x represents the proportion of C events when both sides are involved. y represents the proportion of A events when either of the sides is involved.

The above relation gives a value 33.3% as the upper limit of the contribution of counts not due to low energy mesons to the counting rates N(Y) and N(Z) when field is ON.

The hodoscope results do not tell us whether in B type events when the field is ON, scattering or magnetic deflection is more important. The answer to this question is not of much importance, if one is only interested in the distinction between low and high energy μ mesons. But for the separate study of positively and negatively charged low energy u mesons, this has much importance. This problem can be tackled from theoretical considerations as is done in the following treatment. We can then also reconcile the high proportion of B type events in the back-ground when field is OFF with the process of scattering of low energy μ mesons.

Numerical estimation of the back-ground counts N(Y) and N(Z) with field OFF:

To start with, one can safely assume that in all

coincidences of the type PQR-U there is always a M meson involved, which is able to go right through the iron core within the cone of acceptance of the central vertical telescope. Let this rate be N(X), when the magnetic field is OFF. This represents the rate of those μ mesons which emerge from the bottom of the core out of a rate $N(X_0)$ of mesons which enter the core at the top. The relation between $N(X_0)$ and N(X) can be given as

$$N(X_0) = N(X) + k_1 + k_2$$

where k_1 stands for the total rate of μ mesons scattered out of the cone of acceptance and k_2 the rate of μ mesons stopped in the core. The single particle back-ground measured as B type events is then represented by $\beta_1 k_1 + \beta_2 k_2$ where β_1 and β_2 are two positive factors less than unity.

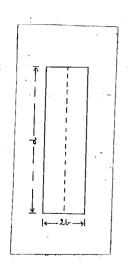
N(X) is experimentally determined. The mass of iron, the dimensions of the core, and the geometry of the apparatus are known, From a knowledge of "X" the momentum loss in iron; $\langle \theta \rangle_{av}$ most probable angle of multiple scattering; and the momentum spectrum of μ mesons at sea level, it is possible to estimate the quantities k_1 and k_2 .

In the present experiment where side counters do not extend beyond 37.5 cm. above the bottom of the core which is of about 64.0 cm. depth, the low energy mesons $(p \lesssim 320 \text{ MeV/c})$ are stopped in the top portion of core which

has no side counters. Therefore they are not involved in the factors k_1 and k_2 . However, for mesons in the momentum range 400 to 800 MeV/c, a consideration of the relative importance of stopping and scattering is necessary for evaluating ($\beta_1 k_1 + \beta_2 k_2$).

1 is dependent on the configeration of the core and the side counters surrounding it. As the coverage of the side counters increases, this factor tends to unity. β_2 is a product of two factors. The first is 0.5, since in an element like iron (Z > 10) only positive μ mesons produce a decay electron on stopping. The second depends on the configeration of the counters and the energy of decay electrons.

The specifications of the iron core are as follows:



Density of the core material (4% silicon steel) = 7.6 gm/cm³

The total depth 'd' in iron core, a vertical M meson encounters.

d = 64 cm. alternatively

= 486.4 gm/cm² or

= 33.8 radiation lengths.

Half breadth 'b' of the iron core.

b = 5 cm. alternatively

= 38.0 gm/cm² or

= 2.64 radiation lengths.

Momentum loss dp/dx = α per unit length for a meson with a momentum p \geq 100 Mev/c, in iron.

= 1.59 Mev/c per gm/cm?

= 22.9 Mev/c per radiation length.

For the sake of simplicity we shall assume that all the u mesons in the cone of incidence travel along the central axis of the core. Initially, we can consider the case when the field is OFF.

A μ meson travelling along the axis has a total ionisation loss of $p = \alpha.d \approx 775$ MeV/c in traversing the full depth of the core. For all mesons having a larger momentum than 775 MeV/c, stopping in the core does not occur and scattering is the only process to be considered. For mesons of momentum below 400 MeV/c consideration is not necessary since they would be stopped or decay in the top of the core and would not give any contribution to N(Y) and N(Z), where the topmost counters are at a depth of about 202 gm/cm² from the top of the core.

For mesons in the range 400-800 Mev/c it is necessary to consider the relative contribution of scattering and stopping processes to the back-ground rate.

To calculate the scattering contribution, the core may initially be considered to have infinite extension side-ways, i.e. $b\to\infty$. ROSSI (1952) has given a relation for calculating $<9^2>_{\rm av.}$, the mean square angle in the

projected plane for the process of multiple scattering, when energy losses are no longer negligible.

$$\langle e^2 \rangle_{av} = \frac{E_s^2}{c^2} \cdot \frac{1}{2N_0} \int_{p_1}^{p_2} \frac{1}{c^2} \left(\frac{dp}{dx} \right) p^2$$

where $E_{\rm g}$ is a constant equal to 21.0 MeV, $X_{\rm o}$ is the radiation length expressed in gm/cm², x is the path length in gm/cm², and $p_{\rm g}$ and $p_{\rm l}$ are the initial and final momenta respectively.

For sufficiently high values of p_2 , and down to a value of $p_1 \ge 100$ MeV/c the momentum loss per unit length due to ionisation is $dp/dx = \infty = const.$ and $v/c \sim 1$. The above relation then leads to the relation

$$\langle \theta^2 \rangle_{av.} = \frac{1}{2} \cdot \frac{E_{st}^2}{e^2 p_1 p_2}$$

where t is the path length in the scatterer in units of the radiation length. For reasons given earlier it is necessary to consider the relative contribution of scattering and stopping only for μ mesons of momenta p_2 where

$$400 \text{ MeV/c} \leq p_2 \leq 800 \text{ MeV/c}$$
.

Taking p_2 in steps of 100 MeV/c, and for each value of p_2 in this range, keeping p_1 constant and equal to 100 MeV/c we can compute the root mean square angle of scattering. This is the most probable value of the angle of scattering

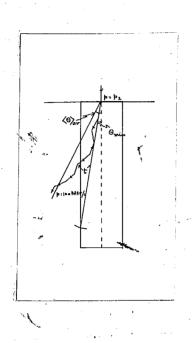
for a μ meson of momentum p_2 scattered by the time it reaches the momentum value p_1 (100 MeV/c). As p_1 is fixed, the path length t at the end of which the momentum is degraded from p_2 to p_1 is given by $t = (p_2 - p_1)/\alpha$ (in proper units). With the value of t obtained in this way, for each value of p_2 upto momentum 800 MeV/c, $\langle \theta \rangle_{aV}$ is computed. The values are given in Table 5.

Table 5.

Path length t and most probable value of the angle of scattering $\langle \Theta \rangle_{aV}$. (projected) for a μ meson of initial momentum p_2 and final momentum 100 MeV/c. Θ_{\min} is the minimum angle of scattering necessary, in the path length t, for the particle to emerge from the sides of the core of width 10.0 cm.

in Mev/c	t	Zo>av.	enina en
TIT MEAN C	in radiation lengths	in degrees	in degrees
400	13,10	15.40	
500	17.47	15.90	8.7°
600	21.84	16.20	6.90
700	26.21	16.5°	5.8°
800	30.57	16.6°	5.0°

When the core has infinite extension sideways, the values of $\langle\theta\rangle_{av}$, will give the most probable value of the angle through which a μ meson with initial momentum p_2 will get scattered in a path length t. But, in our case the extension is not infinite, and has a fixed total width



2b = 10 cm. If, with the upper end of the central axis as centre, an arc of a circle of radius equal to t is drawn (in each case), it will cut the side at some point only when t > b. Let us call the angle subtended by the line, joining this point and the centre of the circle, with the axis as θ_{min.} θ_{min.} represents the minimum angle of scattering in a path length t for the particle to emerge from the core. It is

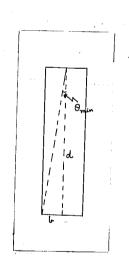
dependent on b, the width of the core. The values of θ_{\min} computed this way, for each momentum value are tabulated in the last column of Table 5. Then, for a particular momentum if $\langle \theta \rangle_{\rm av} > \theta_{\min}$, the μ meson will have larger probability for getting scattered out of the core before it comes to a step in the iron core.

This is not rigorously correct as the scattering angle is distributed normally about the calculated root mean square value $\langle\theta\rangle_{\rm av}$. Thus there are chances for a μ meson not to get scattered out even though the value of $\langle\theta\rangle_{\rm av}$. is greater than the computed value of $\theta_{\rm min}$. However this chance decreases as the difference between $\langle\theta\rangle_{\rm av}$ and $\theta_{\rm min}$ increases. We have not attempted to take account of the spatial distribution of scattering about $\langle\theta\rangle_{\rm av}$ as derived

by MOLIERE (1948).

On studying the values of $\langle\theta\rangle_{\rm av.}$ and $\theta_{\rm min.}$ in table 5 (page 137), one can see that for all values of p_2 (greater than 400 MeV/c) $\langle\theta\rangle_{\rm av.}\rangle\theta_{\rm min.}$, and therefore scattering is the more important process, and stopping of mesons within the core can be neglected.

When $p_2 > 800$ MeV/c, the particles can always traverse the entire depth of the core, and t=d. For this value of t, we shall compute the $\langle \Theta \rangle_{\rm aV}$ for different values of p_2 . Now p_1 would be, $p_1=p_2-\alpha.d$.



The minimum scattering angle O_{\min} , would in this case be given by the half width and the total depth of the apparatus as shown in the diagram.

$$\theta_{\text{min.}} = \tan^{-1}(b/d),$$

 $\approx 4.5^{\circ}$

It should be noted here that θ_{\min} , does not vary with momenta as earlier. Table 6 gives the values $\langle \Theta \rangle_{\text{av}}$, for $p_2 > 800$ MeV/c.

From table 6, one can see that $\langle 9 \rangle_{\rm av.} > e_{\rm min.}$ for all values of $\rm p_2 \le 1500~Mev/c$. Thus all the $\rm passes$ mesons whose momenta are greater than 1500 Mev/c will pass through the core without emerging from its sides. They correspond

Table 6.

The most probable values of the angle of scattering $\langle \theta \rangle$ av. (projected) for μ mesons of momentum p_2 (> 800 Mev/c) if they traverse a path length equal to the depth of the core viz. 64 cm. The residual momentum p_1 is also given.

Initial momentum p ₂ in Mev/c.	Momentum p ₁ , in Me v/c. , at the end of a path length of 64 cm.	<pre>in degrees</pre>
900	n dan dan dan dan dan dan dan dan dan da	14.70
1000	225	10.40
1100	325	8.30
1200	425	6.90
1300	525	6.00
1400	625	5.30
1 500	725	4.70
1600	825	4.20
1800	1025	3.6°
2100	1325	3.00

to N(X) with field OFF, which is almost the same as the number of A type hodoscope events with field OFF. Taking the differential μ meson spectrum at sea level, given by the empirical relation $n(p_s) \sim (p_s + 38)^{-3.0}$ as used by TREFALL (1955a), where p_s is in units of the rest energy of u meson, we can calculate the rate k_4 corresponding to the particles of momenta between 400 and 1500 MeV/c which

should get scattered out of the central cone of incidence, and compare it with the number of B type of events with field OFF.

The calculated value of k_1 turns out to be 16.2 as against the value of 9.6 \pm 0.6 corresponding to the B type events of the hodoscope analysis (page 130). It is not surprising that the experimental value is less than the calculated one because the latter has to be reduced by a factor β_1 (page 133,134) to allow for a geometrical factor. The value of the B type back-ground with field OFF is consistent with the interpretation, that most of it is made up of scattered mesons of energies between 400 and 1500 Mev/c. The value of the factor β_1 turns out to be about $\frac{9.6}{16.2}\approx 0.59$.

We can now consider the case when magnetic field is switched ON,

The radius of curvature R (in cm.) of the track of a particle of momentum p Mev/c in a magnetic field of H gauss is given by

Suppose a charged particle of momentum po, travelling in the plane of paper, vertically downwards along OA, enters an iron core at the point O (Fig.42). The core is initially assumed to have infinite dimensions, and magnetised uniformly in a direction perpendicular to

the plane of paper.

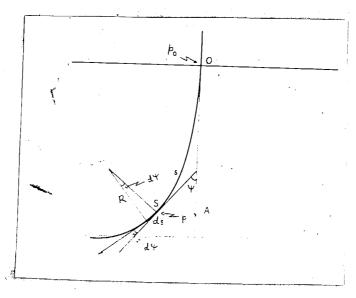


Fig. 42.

If α is the momentum loss per unit length of path, the momentum p at the end of a path of length s will have the value p = p_0 - α s. If the angle between the initial direction OA of the trajectory, and tangent at the point S is ψ , we can express the angle d ψ by which the particle will be further deflected in a distance ds as

$$d \Psi = ds/R$$

$$= 3.H.10^{-4} \frac{ds}{p_0 - \alpha s}$$

Integrating the above equation from 0 to Y,

$$Y = \frac{3. \text{H.} 10^{-4}}{\alpha} \log \frac{\text{Po}}{\text{Po} - \alpha \text{s}}$$

or
$$\Psi = \frac{3.11.10^{-4}}{\infty} \log \frac{1}{1 - s/(p_0/\infty)}$$

 p_0/∞ has the dimensions of length and is the range of the meson before coming to rest. 0_{ne} can conveniently use it as the unit of length in the above equation.

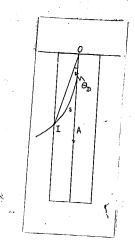
Then
$$Y = \frac{3.11.10^{-4}}{\infty} \log \frac{1}{1-s}$$

where s is is units of (p_0/α) .

This unit is particularly useful since it allows one to determine with ease for a magnetised core of any fixed dimensions the point of emergence of the trajectory of a particle of any initial momentum p_0 . The trajectory is first plotted on a graph paper starting from an arbitrary point 0 and an arbitrary direction of entry 0A and taking small convenient steps Δ s in (p_0/α) units. The dimensions of any given core are then converted into units of (p_0/α) and traced on the graph so that the actual point of entry and direction of entry coincide with 0 and 0A respectively. The point at which the trajectory cuts the trace of the core gives the point of emergence of the particle.

For different values of p_0 the outlines of the core were drawn. In each case, the intersection of the trajectory with the boundary of the core was noted down. The path length s and the angle θ_0 between the initial

direction OA and the line joining the intersection with



point 0, were then measured. For each pair of parameters po and s the value of $\langle 8 \rangle$ av. (projected) for multiple coulomb scattering was also derived. The values are given in Table 7 for comparison.

Table 7.

Total deflection θ_D from the original direction of entry for mesons of various initial momenta after emergence from the core. For comparison, the $\langle\theta\rangle_{av}$ values for the same paths are also given.

P ₀	COM MAN COST COST COST COST COST COST COST COST	CONTRACTOR OF THE CONTRACTOR O
in Mev/c	in degrees	in degrees
400	14.10	11.5°
500	12.30	9.10
800	9.40	5.8°
1000	8.30	4.70
1200	7.50	4.00
1500	6.70	3.20
, 2000	5.70	2.60
3000	4.60	1.90
And with state state with many right with state and other state.		

It is seen that for all momenta greater than

400 MeV/c, the magnetic deflection is more important than coulomb scattering. Therefore the B type events can all be considered as due to magnetically deflected μ mesons when the field is ON.

The magnetic deflection $\Theta_{\rm D}$ for 3000 MeV/c μ meson is almost equal to 4.60 which corresponds to $0_{\rm min}$. (page 139) the minimum deflection necessary for a particle to come out of the core of dimensions used in the present experiment.

Therefore, when the field is ON, the side counter arrays receive magnetically deflected μ mesons within the momentum range 400 to 3000 MeV/c. Trefall's relation (page 140) gives the number of particles in this momentum range, and travelling in the cene of acceptance, as 26.9. This should be comparable to the rate of B type events after reducing it by the factor β_1 , which, as referred to earlier, arises because the side counter arrays do not cover completely the sides of the core. When thus reduced the number of computed B type events comes to 15.9, which is comparable to 16.3±0.5 (page 130) the rate of B type events with field ON. Thus we are fully justified in assuming that all B type events with field ON are due to magnetically deflected medium energy μ mesons in the momentum range of about 400 to 3000 MeV/c.

The total number of counts of type N(Y) and N(Z) with field ON is about 23.4 (page 124) out of which the

number of counts 16.3, due to B type exents, are genuinely deflected μ mesons. In conclusion, we can interpret that with field ON about 30% of the rates N(Y) and N(Z) are not connected with low energy mesons. In other words about 70% of the side rate is due to magnetically deflected μ mesons in the momentum range 400 to 3000 Mev/c.

4. (The Daily Variation.

As mentioned earlier, an attempt is made in the present experiment, to separate the medium and high energy M mesons, by deflecting them in the magnetic field of a saturated iron core. The rates N(Y) and N(Z) represent fairly well the deflected medium energy M mesons having momenta in the range about 400 to 3000 Nev/c.

For a field of 19000 gauss as is used in the present experiment, we have proved that the magnetic deflection is more important than the coulomb scattering in iron, and therefore, the deflected particles are separated according to their charge, the positive and the negative being each separately recorded by the appropriate side counter arrays.

 M_{Θ} shall denote the medium energy and high energy M mesons as M_{m} and M_{h} respectively, and the former can be further divided according to charge so that we have

$$M_m = M_m(+) + M_m(-)$$
.

4.7 Daily variation of positively and negatively charged μ mesons of medium energies:

The results obtained for the medium energy positive and negative μ mesons during both the periods are presented here. During the run the field was reversed regularly on each day. Thus, telescopes PQS-U and PQT-U recorded positive and negative μ mesons alternately. The two telescopes have therefore spent about the same number of days, recording $M_{\rm m}(+)$ and $M_{\rm m}(-)$. This reduces the chances of systematic errors, because of geometrical and other assymetries.

Bihourly values of the percentage deviations from mean of the medium energy positive and negative A meson intensities.

Hours L.S.T.	June 1952 Mm (+)	to Aug. 1953	Mar. 1955 to	Out.1955 Mm(-)
00	\sim 0 \sim 2	an ina na na ma	and an air air is a sec or an an air an ar ar ω	en no con con con des con
02	-6.3	-3.1	4	+3.7
Ol_{i}	-2.0	-3.9	47.7	+6.2
06	+2.8	+3.3	+3.2	+6.7
03	+1.6	-3.5	+1.5	-3.0
\$ O	+4.7	+5.1	-1.7	-1.9
12	+2.0	0.0	-1.1	+1.5
14	+4.0	13.1	-3.6	-7.6
16	+0.4	+4.1	 7.3	-0.6
18	+0.6	+2.3	-0.3	+4.1
20	-2.0	-3.9	+4.6	-1.0
22	-5.5	-1.2	≈3.8	-6.5
ed.error	The same and the s	A CONTRACT OF THE PART AND A CONTRACT OF THE PAR	me made these states were first access taken made desire states of	and the the test are and the test time the test two
Number of lays.	252	2477	Life 55	non, man class and Anny and Nove and Class spec

In Table 8 are given the per cent bihourly deviations from mean for $M_m(+)$ and $M_m(-)$ after combining the results obtained for the particles of same sign by two sides. Fig. 43 shows the nature of the average daily variation of $M_m(+)$ and $M_m(-)$. The harmonic coefficients are given in Table 9.

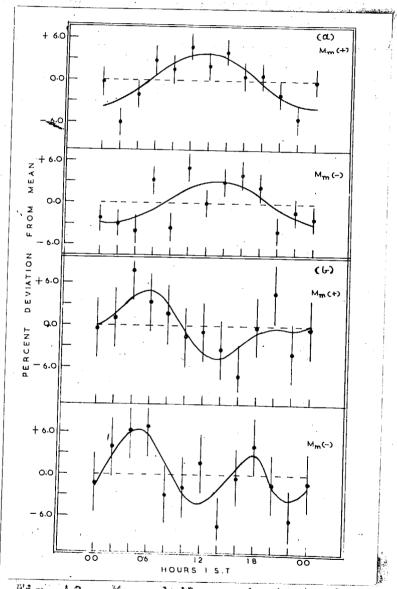


Fig. 43. Mean daily variations of positively and negatively charged medium energy μ mesons $(M_m(+))$ and $M_m(-)$, (a) for the period June 1952 to August 1953, and (b) for the period March 1955 to October 1955.

Table 9.

Percentage amplitudes and the times of maxima, \mathbb{M}^D and \mathbb{M}^D for the first harmonic and \mathbb{M}^S and \mathbb{M}^S for the second harmonic, of the daily variation of medium energy positive and medium energy negative \mathbb{M} mesons $\mathbb{M}_m(+)$ and $\mathbb{M}_m(-)$ respectively, measured by a narrow angle vertical telescope.

Persod		Man and while the case one one of the case one of	MOD	Mr. Hard Comp. Comp. Comp. Comp. State Comp. State Comp.	Mos
June 1952 to	$M_{\mathbf{m}}(+)$	3.8 <u>+</u> 0.8	1720+120	0.6±0.8	Acto.
Aug. 1953	M ₂₁₁ (-)	3.040.8	π+17°±15°	0.7±0.8	Mare
Mar. 1955	MM(+)	3 . 5 4 1 . 7	56°±26°	2.011.7	π+110+400
Oct. 1955	$M_{m}(-)$	2.8±1.7	65°±31°	3.6+1.7	1430±250

Following points can be observed from the results:

- (i) the first harmonic for both $M_m(+)$ and $M_m(-)$ for the period June 1952 to August 1953 are significant and large, but there is no significant difference in the values of amplitude and the time of maximum between $M_m(+)$ and $M_m(-)$,
- (ii) results obtained during the second period are statistically insignificant to draw any conclusion,
- (iii) for the results obtained during the first period, semidiurnal components are not statistically significant.
- 4.2 Daily variation of the medium and high energy μ mesons:

 On combining the results of $M_m(+)$ and $M_m(-)$ the

daily variation for M_m the medium energy M_m mesons is obtained. The bihourly rates of coincidence PQR-U, with field ON, give the daily variation for high energy M_m mesons M_h . The measurement of PQR-U was started only in November 1952.

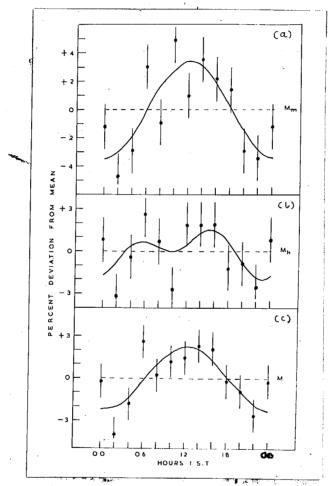


Fig. 44. Daily variation curves for (a) $\rm M_m$ as observed during the period June 1952 to August 1953, (b) $\rm M_h$ as observed during the period November 1952 to August 1953 and (c) the total meson intensity $\rm M(=M_m+M_h)$ incident in a very narrow vertical cone as observed during the period November 1952 to August 1953.

Fig. 44(a) and (b) show the average daily variation for the period June 1952 to August 1953 for

Mm and for the period November 1952 to August 1953 for Mh respectively. The percent bihourly deviations are given in Table 10. The harmonic coefficients for the first two harmonics are given in Table 11.

Table 10.

Bihourly values of the percentage deviations from mean of the medium energy and high energy a meson intensities, and the total a meson intensity incident in a very narrow vertical cone (E-W semiangle 1.7° and N-S semi-angle 6.7°).

Hours I.S.T.	June 1952 to August 1953.	November 1	952	to August 1953
गडुक स्थाप केएल समय केरकेर रहता बडाड	s carp esto esta man ante chen nega man man tente tente esta esta esta esta esta esta esta es	M1	Carl Gat use man	$M(=M_m+M_h)$
· 00 ,	*1.2	+0. 8		-0.2
02	-4.7	-3.2		-4.O
04	-2.9	~(). 4		-1.8
06	+3.0	+2.6		+2.6
08	-0.9	+0.7		+0.2
10	+4.9	-2.7		+1.2
12	+1.0	+1.9		+1.5
14	*3.5	+1.9		+2.3
16	+2.2	+1.9		+2.1
18	rd ob	-1.2		-0.2
20	-2,9	0.0		-0.9
22	-3.4	-2.5		-2.6
Std.erro	en e	e can an our gan air an	in the star same same	e sure same man same case case case case case case case cas
No. of day	y (3) 247	* 000 any min can up can an a	D SQUE SAME SAME COM	202

Table 11.

Percentage amplitudes and the times of maxima, \mathbb{M}^D and \mathbb{M}^D for the first harmonic and \mathbb{M}^S and \mathbb{M}^D for the second harmonic, of the daily variation of medium energy mesons \mathbb{M}_m , high energy mesons \mathbb{M}_h and total μ meson intensity \mathbb{M}_m , measured by a narrow angle vertical telescope.

Period	(MTJ	MOD TO	Mg come come come come come come come come	and fore near sets cold sees from your work your
June 1952 to Aug 1953	M _m	3.4.10.7	77+3°+13°	0.4+0.7	ude wire mitter fahrt diem gesch enzu esse eusse e Geste
Nov: 1952		1.110.7	π±33°	1.0.10.7	1300+400
Aug. 1953	in the same and and care and	2.210.5	π+4°±14°	0.4+0.5	· .

The following features are noticed:

- (i) The medium energy μ mesons M_m show a large diurnal variation of amplitude 3.4+0.7 % and a time of maximum near noon.
- (ii) The amplitude 1.1 \pm 0.7% of the diurnal component of high energy μ mesons M_h is smaller than for M_m and cannot be considered as statistically significant.
- (iii) Second harmonic components are not large enough to be measured at an adequate level of significance for either the medium or high energy M mesons.

The M meson component in a vertical narrow angle, expressed as $M = M_m + M_h$ has a substantial daily variation. The diurnal component has an amplitude of 2.2±0.5 % and the maximum occurs near the noon for the

period November 1952 to August 1953. The corresponding daily variation curve is shown in Fig. 44(c).

The above study leads to the following conclusions.

- (1) Narrow angle meson telescopes exhibit a large daily variation hitherto unobserved by normal wide angle telescopes.
- (2) There is no difference, which can be significantly established, in the daily variations of the medium energy positively and negatively charged u mesons observed at sea level.
- of medium energy μ mesons (momenta in the range 400 to 3000 Mev/c) is significantly larger than the diurnal amplitude of the high energy μ mesons of momenta in excess of 3000 Mev/c.

CHAPTER IV

OF THE INTENSITY OF COSMIC RADIATION WITH NARROW ANGLE TELESCOPES

As mentioned in chapter I (page 40), an attempt is made in this experiment to study accurately the changes of anisotropy that occur from day to day, and changes of mean intensity correlated with them. To undertake this task we have firstly to have an experimental technique which permits us to select days on which significant daily variation of different types occur. Since the magnitude of the solar anisotropy and the consequent amplitude of the daily variations changes from day to day, it is important to have an instrument with as high a counting rate as possible so that even days on which the amplitude is small can be significantly classified. Therefore the experimental technique should involve the use of narrow angle telescopes of as large aperture as is possible.

It is also necessary to examine the world wide character of the changes in anisotropy. While it has been

shown that some aspects of changes in the 12 month mean anisotropy are correlated for a station at the equator (Huancayo) and at stations in the middle latitudes (Cheltenham or Christchurch) it has also been noticed [[SARABHAI et al. (1956)] that day to day changes which are correlated for Ahmedabad, Freiburg and Amsterdam are not correlated with the day to day changes at the equatorial station of Kodaikanal. Classification of days according to the nature and magnitude of the anisotropy occuring on each day is an important task which is meaningful only if changes of the daily variation exhibit certain global characteristics. As a first step in this direction one can conveniently compare the changes in the daily variation observed by more than one simultaneously working telescopes at a particular observing station.

Finally, having classified days in terms of the character of the anisotropy, it is worthwhile to examine the values of physical quantities such as \mathbb{I} , the mean cosmic ray intensity and \mathbb{C}_p the daily planetary magnetic character figure on days of different classifications.

The present chapter deals with the first results of an investigation started in July 1955 at Ahmedabad (Lat. 23° 01' N, Long. 72° 36' E, Geomag.lat. 13° N, Alt. 180 ft.).

1. Apparatus.

By the end of May 1955 the laboratory had one meson telescope of cubical geometry, constructed according

Committee for the International Geophysical Year. Instead of constructing an entirely new apparatus for narrow angle telescopes, the author modified the cubical meson telescope so that it could furnish data from narrow angle telescopes as well as from the standard telescope. In Fig. 45 the arrangement of the counters with their associated electronic units is shown schematically.

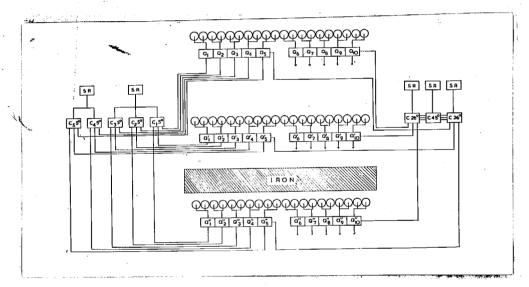


Fig. 45. Schematic diagram of the counter arrangement and the associated electronic units. For 5° telescopes only the left hand side for electronic units is shown.

Q = Quenching unit. C = Coincidence unit SR = Scaler and recorder unit.

The experimental arrangement, as shown, consists of three trays of counters kept equally spaced one above the other. Each tray has a square sensitive area of dimensions 85 cm. x 85 cm. The distance between the top and the bottom trays is also 85 cm. so that the complete

apparatus has cubical geometry. 96.5 gm./cm². of iron is kept between the second and the third trays to absorb the soft component of cosmic rays. There are twenty Geiger counters in each tray, of diameter about 4 cm. and sensitive length about 35 cm. The counters are placed with their axes parallel to the N-S direction. The whole set up is enclosed in a box with sides of thermally insulated compressed fibre sheet. This reduces the fluctuations of the temperature inside the box.

ten sets of two counters each. Anodes of each pair of counters are connected in parallel to a common one shot multivibrator type quenching unit. The ten quenching units of each tray are divided into two groups of five units, with a common cathode follower for each group. The thirty quenching units are shown in Fig. 45 as Q1, Q2.....Q10, Q'1, Q'2.....Q'10, and Q"1, Q"2.....Q"10 for the top, central and the bottom trays respectively. The ten differentiated outputs from the quenching units in each tray are fed to ten triode triple coincidence units, of the type described earlier (page 30), C1, C2.....C10 respectively. Thus we get ten narrow angle triple coincidence telescopes, each having a semiangle of 5° in the E-W plane.

In addition to these the cathode follower outputs of the three left hand side composite quenching units (Fig. 45) are fed to a triple coincidence unit of the pentode

type. A similar arrangement is made for the right hand side composite quenching units. Thus two telescopes of semiangle 26° in the E-W plane are obtained.

Finally the cathode follower outputs of the two composite quenching units of each tray are combined and fed to a triple coincidence unit. This gives a telescope with semiangle 45° in the E-W plane. It should be noted that the semiangle in the N-3 plane is 45° for all telescopes viz. ten of 5° semiangle, two of 26° semiangle and one of 45° semiangle in the E-W plane.

The outputs of the different coincidence units are recorded after suitably scaling them down. The outputs of the ten independent narrow angle telescopes are not all separately recorded. This is because the rate of each telescope is not large enough to provide a valid basis for drawing conclusions. However, the rates of the telescopes are recorded jointly for two sets of three telescopes each, and for two sets of two telescopes each. The electromechanical recorders are kept in a automatic camera unit of the type described earlier, and photographed every hour. Table 12 shows the number of telescopes of each type with their approximate bihourly individual counting rates, as well as the total rate of all similar telescopes. The per cent standard deviation for each total bihoarly rate is also indicated.

Table 12

Specifications of the various telescopes in the apparatus.

Seni-	engle	Number of	Biliourly	Total	% standard
E-W	N-S	telescopes available	counting rate per	bihourly counting	deviation for bihourly rate
	. कार्य केल इसे प्रके स्थान साह	dada tuun kada adah chaa ah nada tada kada kata kaba ah na aka akk	telescope	rato N	100/(N) ²
5 [©]	45 ⁰	10	1300	13000	± 0.9 %
26 ⁸	45 ⁰	2	29000	5 8 00 0	± 0.4 %
45 ⁰	45 [©]	1	100000	100000	± 0.3 %

2. Experimental Results.

The data presented in this chapter are obtained during the period July 1955 to December 1956. The apparatus described came into operation in May 1955, when records were obtained with a cubical meson telescope 45T, having semiangles 45° in both the E-W and the N-S planes. In July 1955 the author modified it to get simultaneous records of meson intensity in ten independent narrow angle telescopes 5T all identical with semiangles 5° in the E-W plane and 45° in the N-S plane. In December 1955 the apparatus was stopped as it required overhauling. It was started again in the month of February 1956 after it was further modified to give a simultaneous record of meson intensity measured with two identical telescopes 26T of semiangles 26° in the E-W plane and 45° in the N-S plane.

The ²⁶T telescope came into proper operation only from March 1956 onwards. Therefore, for the comparison of the average characteristics of the daily variation as observed by a narrow angle and a wide angle telescope operating simultaneously, data obtained during the period March 1956 to December 1956 are considered.

Since the main object of the experiment is to study the day to day changes in the nature of the daily variation and their relationship with the day to day changes in mean cosmic ray intensity continuous and reliable data over a long period are essential. Table 13 shows the number of days in each month on which the mean intensity values for 5T telescopes and the daily variation values for 5T and 26T telescopes are available. It will be seen from the table that the data obtained during the period July 1955 to November 1955 have more interruptions compared to data obtained during the period February 1956 to December 1956. In fact the breaks in 5T telescope data for the latter period are only due to camera unit failures and not due to failures of counters or other electronic units.

For the period 7th February to 31st December 1956 the ⁵T telescopes were in continuous operation. There are 329 days in this period, out of which on 318 days the daily mean intensity is available, and there are 304 days on which the daily variation can be derived from bihourly records. This period is therefore selected for the study of the relationship between the day to day changes in the

Table 13

Number of days in each month on which mean cosmic ray intensity data for 5T and daily variation data for 5T and 26T telescopes are available.

Nonth and Year	Total number of days in the period	Number of days on which daily mean intensity data for "T are available	oidw Isairev	of days on th daily on data are lable
1955 July.	chie das mir tipe das ass hom tom trei ass das ass das trei Tombus	प्राप्त क्षात्र त्यांत्र त्यांत्र क्षात्र क्षात्र व्याप्त क्षात्र व्याप्त क्षात्र त्यांत्र व्याप्त व्याप्त व्या स्थापन	48	a ayada sariny dagiya dhilinda ayadi, kiligin dakina verene dagiga bagadi, darah
Aug.	.31	19		• • • • • • • • • • • • • • • • • • •
Sept.	30	21	19	494 1
Oct.	31	27	21 27	dicta-
Nov.	30	24	24	**
1956			* * * * * * * * * * * * * * * * * * *	
Fab.	23	22	22	-
Mer.	31	31	31	26
Apr.	30	30	28	19
May	31	. 29	27	24
Jun.	30	30	28	26
Jul.	31	28	28	28
Aug.	31	. 31	27	26
Sept.	30	30	30	28
Oct.	31	28	26	26
$N_{\mathbf{O}}\mathbf{v}_{\bullet}$	30	30	30	30
Dec.	31	29	27	27
Total da in 1956.	ys ()29	318	304	260

anisotropy and in the mean intensity as observed by a 52 telescope.

It is shown earlier in chapter II (page 97) that the daily variation on each individual daysis represented by twelve bihourly per cent deviations from the mean on that day corrected for barometric effect. There, it is also shown (page 100) that for characterisation of the form of the daily variation on each day, and for its comparison with other days, it is advantageous to deal with the first two harmonic components, rather than the actual twelve bihourly deviations. The solar daily variation of meson intensity corrected for barometric pressure is therefore harmonically analysed and the percentage amplitude and pime of maximum of the first harmonic and second harmonic viz. M^D and Mp^D for the diurnal component, and $extbf{M}^{ extsf{S}}$ and $extbf{M}^{ extsf{S}}$ for the semidiurnal component are obtained for each day. These are listed in a tabular form in Appendix I for all the 304 days for 5T telescope data obtained during the period 7th February to 31st December 1956. The ratio MD/MS on each day is also indicated in the table. In the last column of the table the normalised and pressure corrected (reduced to a standard pressure of 750.0 mm of Hg.) mean cosmic ray intensity is also indicated.

The pressure coefficient α_8 =-1.6% per cm.Hg. is used to correct the mean cosmic ray intensity, and is derived from the present experiment in the following way.

Correlation if it exists between the 318 pairs of mean cosmic ray intensity and mean pressure values obtained during the run of the experiment from February 1956 to December 1956. The correlation was low. As upper air meteorological data were not available it was not possible to apply the method of partial correlations. Instead, the procedure described in chapter II on page 107 was used. In Table 14 are shown the average values of pressure and cosmic ray intensity after the grouping of the whole data into eight groups according to pressure values on each day.

Table 14.

Average values of daily mean pressure and cosmic ray intensity for days grouped according to fixed pressure intervals.

Pressure interval (mm. Ng.)	Number of days	Mean pressure for the interval	Mean cosmic ray intensity
740.1 to 744.0	2 1 2 1	742.8	3216 x 4
744.1 to 746.0	30	745.1	3175 x 4
746.1 to 748.0	68	747.0	3181 x 4
748.1 to 750.0	41	749.0	3151 × 4
750.1 to 752.0	41	751.1	3162 x 4
752.1 to 754.0	48	753.2	3149 x 4
754.1 to 756.0	38	755.0	3132 x 4
756.1 to 760.0	42	757.0	3124 x 4

These eight pairs give a correlation coefficient $r_{\rm MP}$ = -0.94 and barometric coefficient $\propto_{\rm B}$ = -1.8 % per cm.Hg.

This value is employed for correcting the mean intensity variation for the barometric effect.

Types of Daily Variations.

In the present study, a 25 level of significance has been adopted when examining the types of daily variations that occur on different days. The amplitude and time of maximum of the diurnal component are physically meaningful only on days on which the daily variation curve is essentially diurnal in character and exhibits one principal maximum during 24 hours. Similarly the amplitude and the time of maximum of the second harmonic are physically meaningful when the daily variation is semidiurnal in character with two maxima in 24 hours. examining the daily variation formed by super-position of diurnal and semidiurnal components having a ratio of amplitudes MD/MS ranging from 0.2 to 2.0 (page 102) it is clear that when this ratio is less than 0.75 the final curve always exhibits two pronounced maxima in 24 hours. On the other hand when the ratio is larger than 1.5 the daily variation exhibits only one maximum.

For 5 T, in Fig. 46(a) is given the histogram showing the frequency of occurrence of the diurnal maximum for each of 12 bihourly intervals of a day for 103 days on which the diurnal amplitude $M^D > 2 \circ$. If we now impose the condition that $M^D/M^S > 1.5$, the resulting histogram is shown in Fig. 46(b). This relates to 71 days on which we

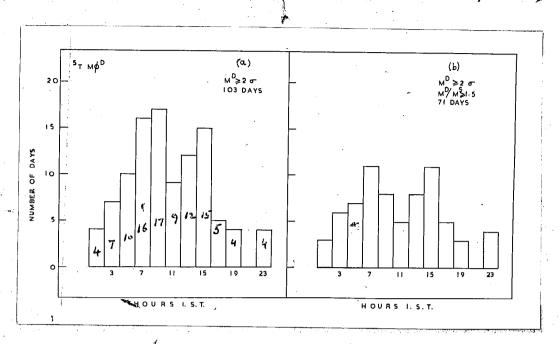


Fig. 46. The distribution of occurrence of the diurnal maximum for ^{5}T for each of 12 bihours of a day, (a) when $^{M^D}>2^{\circ}$, and (b) when $^{M^D}>2^{\circ}$ and $^{M^D}/^{M^D}>1.5$. $^{M^D}$ and $^{M^D}$ are the per cent amplitudes of the diurnal and the semidiurnal components of the daily variation.

can conclude from the ratio of the amplitudes of the diurnal and the semidiurnal components that the daily variation has one maximum only. It is observed that by restricting attention to significant days which have only one maximum during 24 hours, the histogram clearly reveals the tendency for the diurnal maximum to occur in one of two preferred periods of the day, at 0700 and at 1500 hours I.S.T. We can therefore distinguish days on which the maximum of the diurnal variation occurs between midnight and noon from those on which the maximum occurs between moon and midnight. A similar classification into 'n' and 'd'

type days was undertaken by SARABHAI and NERURKAR (1955) who observed during an investigation in 1954-55, the tendency for narrow angle telescopes to exhibit daily variations with one of two preferred times of maxima for the diurnal component, when the semidiurnal component was small compared to it. However, at that time, the maxima occurred at 0300 hours and at 1100 hours instead at 0700 hours and at 1500 hours respectively, during 1956. The shift to later hours of both maxima during the period of about two years from 1954 to 1956 is probably connected with the shift to later hours observed in the time of maximum of the diurnal component of the 12 month mean daily variation since the last minimum of solar activity in 1954.

On days when the ratio $M^D/M^S \leq 0.75$ and $M^S \geqslant 26$ we have a daily variation which has a significant semidiurnal component, predominating over the diurnal component. On such days, the daily variation exhibits two maxima instead of one and we can classify the day as an 's' type day.

In order to study the nature of the daily variation on days when the diurnal and the semidiurnal components are of comparable amplitude, i.e. $1.5 > M^D/M^S > 0.75$, and the diurnal component is significant at the 2 < 0 level, we can consider separately the harmonic component of the mean daily variation of such days when the diurnal component has a maximum occurring between midnight and noon, and between noon and midnight.

Table 15.

Comparison of the average daily variations for days on which $\rm M^D/M^S$ lies in three distinct groups; $\rm M^D/M^S < 0.75$, $0.75 < \rm M^D/M^S$ and $\rm M^D/M^S > 1.5$.

	; (·)		•	a ·			
	nexina for	2.2	୍ଦ୍ର ବ୍ୟୁ ଏହି	6.57 6.00 6.00 6.00 6.00 6.00 6.00 6.00 6.0		es Cs	7.00	
4	times of	27.0	92	0		%	270	007
	amplitudes and the triding all components.	0.3 \$ 0.1	0.1240.05	70.0490.0		0.04.40.07	0.1110.06	0.2340.06
		1200	000	1070	51 +270	ob5+ 5	025+ 15	1100
	Average percentage the diumal and ser	0.8 + 0.1	50.0456.0	70.04.20.0	10+01	0.9040.07	0.92±0.06	0.16±0.06
	Character of the variation on each day.	1. 1.5 > MD/W ⁵ > 0.75 00< Mg Brd 800	2. ND/M2>1.5 and 00 <np<sup>D<180°</np<sup>	3. 1 and 2 combined	4. 1.5 > 11 / 11 > 0.75 and 180° < 1100 360°	5. 14/14 > 1.5 and 150° < 149 2 < 360°	6. 4 and 5 combined	7. #\$>26 and MD/m\$<0.75

In Table 15 are indicated the amplitude and time of maximum of the diurnal and the semidiurnal components for the mean daily variation during the two groups of days. Also indicated in the table for comparison are the characteristics of the diurnal and the semidiurnal components of the 'n' and 'd' type days when $M^D/M^S > 1.5$ and M^D is significant at the 26 level. It is observed that even for days on which individually H^D/M^S is between 1.5 and 0.75, the average daily variation has a ratio much larger than 1.5. This indicates that while on individual days we have a semidiurnal component which is comparable to the diurnal component, there is no strongly preferred time of maximum of the semidiurnal component. In consequence, the resultant average daily variation for the 2 group of days is diurnal in character. Moreover, the time of maximum and amplitude of the diurnal component of the average for the two groups do not differ significantly from those of the 'd' and 'n' type days respectively where even on individual days the ratio $M^D/M^S > 1.5$. The days relating to the two groups can therefore be grouped with 'n' and 'd' type days respectively. In effect therefore classification of days can be undertaken on the following criteria:

- (a) 'n' type days are those days on which the daily variation has $M^D > 2\sigma$, $M^D/M^S > 0.75$ and the diurnal maximum occurs between midnight and noon.
- (b) 'd' type days are those days on which the

daily variation has $M^D > 26$, $M^D/M^S > 0.75$, and the diurnal maximum occurs between noon and midnight.

(c) 's' type days are those days on which $M^S > 2\sigma$, $M^D/M^S \leq 0.75$.

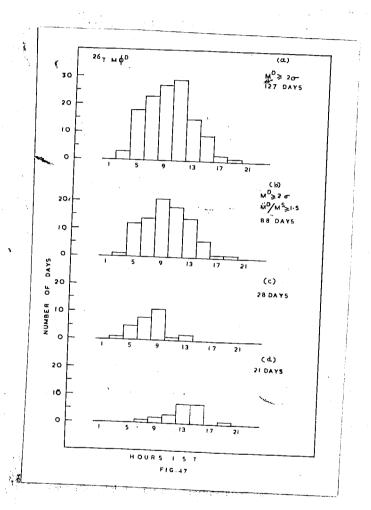


Fig. 47. The distribution of occurrence of the diurnal maximum for 22 T for each of 12 bihours of a day (a) when $^{M^D} > 26$, (b) when $^{M^D} > 26$ and $^{M^D}/^{M^S} > 1.5$, (c) for days on which 5 T has a daily variation of 'n' type and (d) for days on which 5 T has a daily variation of 'd' type.

Fig. 47(a) and (b) show histograms for ²⁶T corresponding to the histograms shown in Fig. 46(a) and (b)

for the 5T telescopes. It will be observed that the separation of groups of days on which the daily variation has maximum in the morning or in the afternoon is not distinct in 26T as for the narrow angle telescope 5T. However, the reality of the occurrence of the daily variation with a diurnal maximum at one of two preferred times of maxima even in 26T is seen by separating the days included - in Fig. 47(a) according to the type recorded by 5T. Thus the histograms of occurrence of time of maximum of the diurnal component of 26T on days on which 5T has a maximum before noon of in the afternoon are shown in Fig. 47(c) and (d) respectively. It is clear that days on which there is a morning maximum in 5 T are associated with earlier time of maximum in 267 than days on which 5T has a maximum in the afternoon. The separation of the two groups in 26T is however only by about four hours in place of about 8 hours for 5T.

In Fig. 48 we show separately the daily variations for $^5\mathrm{T}$ and $^{26}\mathrm{T}$ averaged for all days on which

- (a) there is a significant 'n' type of variation,
- (b) there is a significant 'd' type of variation,
- (c) there is a significant 's' type of variation,
- and (d) there is any one of the above three types, i.e. at least one of the harmonic components is significant but there is no other criterian to separate the days.

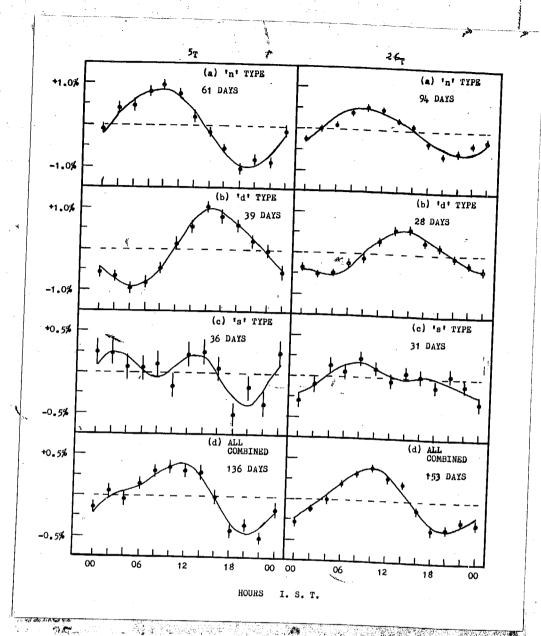


Fig. 48. Average daily variation for 'n', 'd', and 's' type days for T and 26T telescopes and the average daily variation for all these types of days taken together.

Percentage amplitudes and the times of maxima of the diurnal and semidiurnal components of average daily variations ahown in Fig. 48 are given in Table 16.

Table 16.

Percentage amplitudes and times of maxima for the first two harmonic components of average deily variations shown in Fig. 48.

Vari	ation Pe	M.).)	$M_{\mathcal{D}}$	data atau angir mga man ajau tuka tuka tuka tuka tuka tuka tuka tu	MD 2
***	And Greek Greek States States States	0.92+0.04	107°	0.06±0.04	1 30
* 11 *	2 6 g	0,52 <u>+</u> 0,02	1210	0.07 <u>±</u> 0.02	-32 ⁰
Mari Paris Line Cold	5T ~	0.90+0.06	л +52 ⁰	0 . 1140 . 06	270
, G 8	26 _T	0.53±0.04	T+27°	0.09 <u>+</u> 0.04	10
151	5 <u>T</u>	0.16 <u>+</u> 0.06	1100	0.23+0.06	480
. S	2 6 7	0.13±0.04	1450	0.08 <u>+</u> 0.04	7+110
A11	5eg	0.37±0.03	142	0.1240.03	35 ⁰
comb1	ned 2 6 T	0.36+0.02	137 ⁰	0.05+0.02	-34°

It is observed from the Fig.48(d) that if all days with significant variation are considered, but no classification is undertaken, the average daily variations of $^{5}\mathrm{T}$ and $^{26}\mathrm{T}$ are not significantly different from each other. The amplitude of variation recorded by narrow angle telescopes $^{5}\mathrm{T}$ is no greater than the amplitude from

the wider angle telescope's 26T. However, if we classify the variations into the 'd', 'n' and 's' types there is marked difference in the results from 5T and 26T telescopes. The amplitude of the daily variation in narrow angle telescopes is much greater than in telescopes with wider angles. It has been pointed out by EHMERT (1951) and by SARABHAI and NERURKAR (1955) that the ratio of amplitudes of variations_measured by narrow and wide angle telescopes is not constant. However, the average ratio of amplitudes of the diurnal components of 5T and 26T is 1.8 for 'd' type and is 1.7 for 'n' type. The ratio of amplitudes for the semidiurnal components of narrow and wide angle telescopes is 2.9 for 's' type days. These ratios may be compared to the average ratios of 3.0, 2.0 and 1.0 reported by NERURKAR (1956) for 5T and 15T telescopes for the period 1954-55.

By the side of the curves in Fig. 48 the number of days are indicated on which daily variations of significant amplitude of each type are observed by ⁵T and ²⁶T telescopes during the period February 1956 to December 1956. Of the total number of days on which data are available, significant daily variation is observed on 44.7 % of days for ⁵T and on 58.6 % of days for ²⁶T. The 'n' type of daily variation occurs most frequently. It accounts for 44.8 % of the days of significant variation for ⁵T and 61.4 % for ²⁶T. The corresponding

percentages for 'd' type days are 28.7 % and 18.3 % respectively; while for 's' type days they are 26.5 % and 20.3 % respectively. The percentages given here do not indicate directly the relative frequency of occurrence of the daily variations of different types. This is because the amplitudes of 'n', 'd' and 's' type variations for the same telescopes are not equal, as can be seen from Fig. 48. The level of significance which establishes a lower limit of amplitude below which we disregard data for the purpose of classification, thus acts differentially in respect of the distribution of amplitude of each type of variation.

4. Classification of Days According to the Character of the Daily Variation.

It has been demonstrated in the preceding section that there is a tendency for 'n' and 'd' type days selected according to ⁵T telescope to be respectively associated with earlier and later times of maxima of the diurnal component of ²⁶T telescopes. The validity of classification of days into 'n' and 'd' types is more clearly indicated in Fig. 49 where the time of maximum of the diurnal component of ⁵T is plotted against the time of maximum of the diurnal component of ²⁶T on each day on which both the diurnal components are significant at their respective 20 levels.

There are 49 such days, and it is clear that there

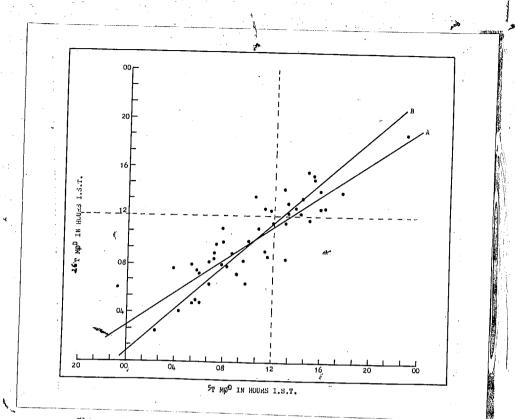


Fig. 49. Diagram showing the relation between the times of maxima of the diurnal components of the daily variations measured on individual days by ⁵T and ²⁶T telescopes. The line of regression A is of ²⁶T MØ^D on ⁵T MØ^D, and B is of ⁵T MØ^D on ²⁶T MØ^D.

is a remarkable association of the time of diurnal maxima recorded by the ⁵T and ²⁶T telescopes. The correlation between the pairs of values in Fig. 49 relating to each day is +0.86+0.04. The regression lines indicate that narrow angle telescopes reveal larger changes than the wider angle telescopes, in confirmity with the observation made by SARABHAI et al. (1955a) from a comparison for Huancayo Ion Chamber and Ahmedabad counter telescope data. The grouping of times of maxima around two epochs, one before noon and the other after noon, is clearly seen, as in the histograms

of Fig. 46. The horizontal and vertical lines corresponding to noon indicate the boundary for the classification into 'n' and 'd' type days. There are only two points out of 49 where there is substantial disagreement between T and 26P telescopes in classifying according to 'n' and 'd' types. There are 11 days on which ⁵T and ²⁶T telescopes simultaneously register significant 's' type daily variations. As against this, there are 20 days on which either ⁵T or ²⁶T has a 'd' or an 'n type variation, and the other has an 's' type variation. If we, therefore, consider all classifications, we have a total of 58 days on which both types of telescopes are in agreement. As against this, there are 22 cases of disagreement, most of them involving an 's' type variation. When one realises that a large semidiurnal component, significant at the 25 level, can arise either as an adjunct to a main diurnal component, or by itself because the variation is truly semidiurnal in character, it is clear that the present system of classification into 's' type days requires further refinement.

In Fig. 50 we show on a Bartel's diagram, days classified as 'n', 'd' and 's' according to the daily variation recorded by ⁵T telescopes. Also indicated on the diagram are those days on which no data is available for evaluating daily variation. It will be observed that there is a tendency for at least the 'n' and 'd' type days to occur in groups of 2 to 3 days. There is also evidence

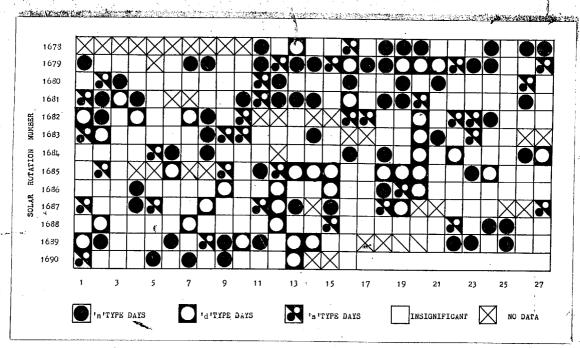


Fig. 50. Bartel's diagram showing the dates of occurrence of 'n', 'd' and 's' type of daily variation. Days on which '5T is inoperative are indicated as "no data" days.

of a 27 day recourrence tendency, particularly for 'd' type days.

5. Correlated Changes of Anisotropy, Mean Intensity and Cp the Daily Magnetic Planetary Character Figure.

For studying correlated changes it is convenient to use the method of superposed epochs. We consider as an epoch each day when a particular type of daily variation occurs, and compute the average of daily mean intensity I and Cp on days of epoch as well as on 5 days on either side of epoch. Such analysis is conducted separately for 'n'

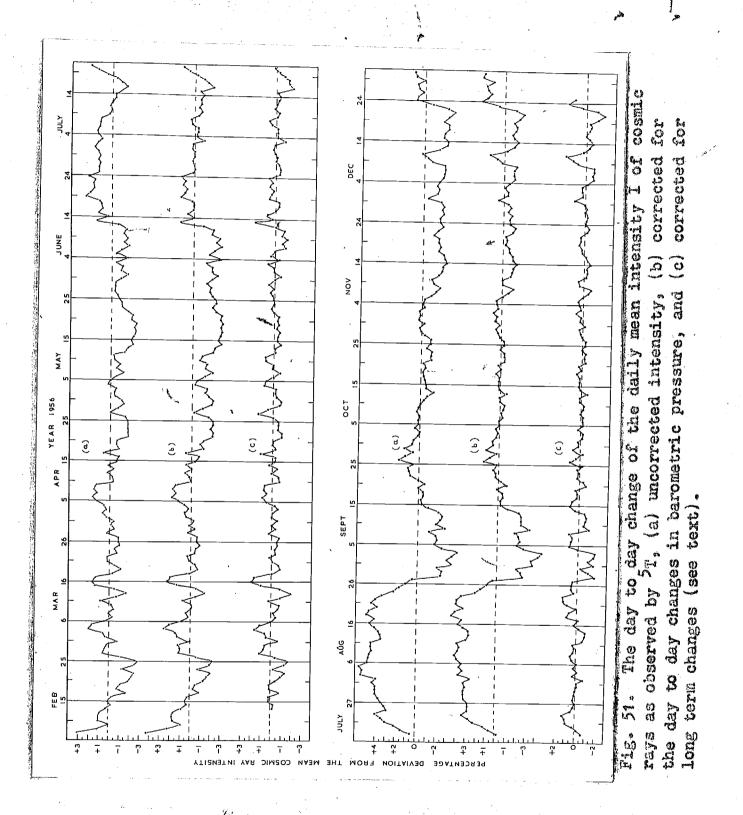
type, 'd' type and 's' type days indicated in the Bartell's diagram in Fig. 50.

In studying the correlated changes of the daily variation and of the daily mean intensity I, the latter is first corrected for the influence of change of daily mean barometric pressure using a coefficient $\alpha_{\rm B}=-1.8$ % per cm.Hg., derived experimentally from the present data as mentioned earlier (page 163). The corrected daily mean intensity still exhibits changes of a long term character due to seasonal and other factors. The long term changes are next removed, without eliminating short term fluctuations of I over periods of 5 to 10 days, by taking moving averages of I over a period of 13 days and applying correction for the variation of the moving averages.

In Fig. 51(a), (b) and (c) are indicated the values of I before applying pressure correction, after applying pressure correction and after removing long period variations respectively. The latter values of I are used in the analysis of correlated changes.

The result of this analysis for the daily mean intensity measured by 5T is shown separately in Fig. 52(a), (b) and (c) for 'n', 'd' and 's' type days respectively. The change of $^{\rm C}_{\rm p}$ in each case is also shown.

A remarkable result of this analysis is that 'n' type days are accompanied by an increase of intensity of





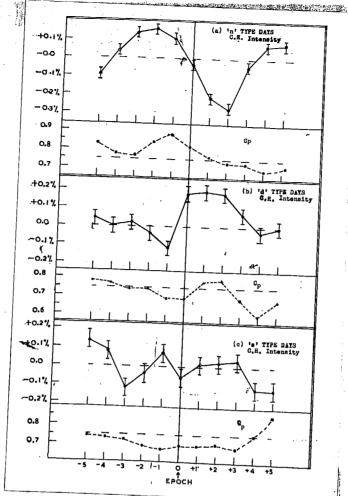


Fig. 52. Average daily mean cosmic ray intensity changes on -5 to +5 days, (a) for 'n' type days as epochs, (b) for 'd' type days as epochs and (c) for 's' type days as epochs. The corresponding average change of magnetic character figure Cp in each case, is also shown.

about 0.16±0.03 % from 3 days prior to epoch. The intensity is normal on epoch, but decreases significantly after epoch to reach, 2 days later, a minimum value about 0.27±0.03 % less than the average daily mean intensity for the entire period of observation. 'd' type days on the other hand are associated with increase of mean intensity which remains about 0.17±0.04 % above the average, from epoch to +2 days. A slight decrease in intensity before epoch is not significant. For 's' type

days, the mean intensity is hearly normal during the epoch period and on 3 days before and after it. For Cp, the values are high compared to the mean of the entire period, from -3 to +1 days of the 'n' type epochs. For 'd' type epochs this is also true for +1 and +2 days after the epoch day, but there is a Cp minimum in the interval O to -1 days before the epoch. For 's' type epochs, Cp values show a minimum near the epoch day and an increase 4 days after the epoch.

6. _ Discussion.

The results presented here are of a preliminary character and indicate certain tentative conclusions which can be drawn from the analysis of data from narrow angle telescopes operated over a period of 11 months in 1956.

It is seen that on a majority of days, which have a daily variation of significant amplitude, the variation can be designated as belonging to the 'n', the 'd' or the 's' type. The experimental technique at present does not permit a variation to be established at the 25 level of significance unless it has a harmonic component of amplitude greater than 0.74 % for 5T and 0.34 % for 26T telescopes. With an improvement of technique involving a larger effective aperture of narrow angle telescopes than at present, it would be possible to extend the study to variations of smaller amplitude than is now possible. It is not known what characteristics would be shown by the daily

variations of small amplitude.

The difference between 'd' and 'n' types of variations is more marked for narrow angle telescopes than for wide angle instruments. Thus in deriving an average of the daily variation over an extended period of days, the reduction of amplitude for ⁵T is much greater than for ²⁶T. If we wish to compare the amplitudes of daily variations recorded by narrow and wide angle telescopes, the comparison should be made separately for each type of variation and not for an average variation having a combination of all types of variations. This point requires to be borne in mind when considering the results of other workers who have compared the amplitudes of the daily variations of narrow and wide angle telescopes without attempting to classify the different types of variations.

The shift towards later hours, by about four hours, from 1954 to 1956, of the time of maximum of 'n' as well as of 'd' type of variations seems to indicate that the striking changes observed in the 12 month mean daily variation can be due not only to the change of frequency of occurrence of days of each type, but to an intrinsic shift of time of maximum and of the anisotropy. Close study over an extended period with narrow angle telescopes is required to understand better the nature of the changes that occur.

The classification of days according to the

character of the observed daily variation requires to be further refined so that when the classification is made, it relates to a characteristic of the anisotropy, and is therefore detectable on a global basis. In the present study the validity of the characterisation is tested only by comparison made of two types of telescopes operating at one station. It is important to extend this comparison to other instruments at the same station and at different stations.

One of the most important conclusions that can tentatively be drawn from the present study is the one concerning correlated day to day changes of anisotropy and the daily mean intensity. The main weakness in the evidence that is presented lies in the absence of upper air meteorological data with which the daily mean intensity could properly be reduced to standard atmospheric conditions. We have been unable to evaluate the extent of error which can be introduced on this account in our analysis. At low latitudes however, day to day changes are not as important as at high latitudes, and it is believed therefore that a more accurate correction for meteorological changes than we have been able to apply to our values of daily mean intensity, would not alter our conclusions substantially.

The observation that 'n' type days are associated with decreases of intensity and 'd' type of days with increases of daily mean intensity after the respective epochs is one of great significance in the interpretation of processes responsible for the anisotropy and changes of

result either by the presence of a source of cosmic rays within the solar system, or what is more likely, by a modulation process involving the increase of energy of cosmic rays incident from certain directions. In the latter case one would require the creation of an ordered electric field in appropriate regions of interplanetary space as viewed from the earth. Since the space is believed to be often filled with clouds of ionised solar matter, it would be difficult to sustain the field in the absence of trapped coherent magnetic field within the ionised streams.

The present evidence, along with that of SIMPSON et al. (1952, 1955), are the only ones in support of the existence of variations of intensity which represent not just decreases, as shown by van HEERDAN and THAMBYAHPILLAI (1955), but increases of intensity as well. Since, as discussed above, they are indicative of the existence of coherent magnetic fields and not just turbulent fields in interplanetary space, it is of great importance to confirm experimentally these findings with a large number of independent investigations extending over a long period of time. The present study relates to only 11 months of observations and it is therefore necessary to take the present conclusions as tentative for the time being.

CHAPTER V

SUMMARY AND CONGLUSIONS

The thesis describes two separate experiments, dealing with different aspects of cosmic ray time variations investigated with narrow angle telescopes at Ahmedabad (Lat. 23°01' N, Long. 72°36' E, Geomagn. Lat. 13° N, Alt. 180 ft.).

The first experiment was started with two principal aims. Firstly, for studying the effect of the reduction of semiangle of opening of a Geiger counter telescope on the nature of the daily variation observed by it. And secondly to study separately the daily variations of high energy A mesons and positive and negative A mesons of moderate energies. The former have momenta in excess of 3000 MeV/c while the latter have momenta mostly in the range 400 to 3000 MeV/c. Because of the very low counting rates conclusions can be drawn at this stage only about some of the aspects that are studied. They are:

(1) The average daily variation of moderate

energy M mesons $M_{\rm m}$ (momenta range about 400 to 3000 MeV/c) observed at sea level, with a vertical narrow angle telescope of semiangles about 1.7° and 6.7° in the E-W and N-S planes respectively, has a large amplitude. The average daily variation during the period June 1952 to August 1953 has an amplitude and time of maximum for the first harmonic of 3.4 \pm 0.7% and 1205 hours I.S.T. respectively.

- (2) The average daily variation of high energy μ mesons μ_h (p > 3000 MeV/c) has a smaller amplitude than for μ_m , and is not statistically significant.
- (3) The average daily variation of the total meson intensity (p > 400 Mev/c) represented by $M(=M_{\rm m}+M_{\rm h})$, and incident in the narrow angle telescope mentioned above has a first harmonic component of amplitude 2.2 \pm 0.5 % and time of maximum 1200 hours I.S.T. for the period June 1952 to August 1953.
- (4) There is no significant difference observed in the average daily variations of moderate energy positively and negatively charged μ mesons, $M_{\rm m}(+)$ and $M_{\rm m}(-)$ (momenta range about 400 to 3000 MeV/c).
- (5) The semidiurnal components of the daily variations are not statistically significant.
- $\mathbb{Q}(6)$ It is confirmed by a hodoscope arrangement as well as by numerical estimates, that the rates $\mathbb{M}_m(+)$ and $\mathbb{M}_m(-)$

in the present experiment, mainly represent the intensity of moderate energy A mesons of momenta between 400 to 3000 Mev/c deflected out of the vertical cone of incidence by the magnetically saturated core.

The second experiment was conducted with vertical counter telescopes of two types. ⁵T telescopes had a semiangle of 5° in the E-W plane and a semiangle of 45° in the N-S plane. ²⁶T telescopes had in the E-W plane a wider semiangle of 26°, but in the N-S plane the semiangle of 45° was the same as of ⁵T telescopes. Both ⁵T and ²⁶T had 96.5 gm/cm² of iron absrober and in consequence the intensity measured by them relates to the u meson component at sea level. The purpose of the experiment was to study the changes in character of the daily variation measured by ⁵T and ²⁶T telescopes and to classify days in terms of the character of the daily variation occurring on them. The study of the correlated changes of character of daily variation and daily mean intensity was also undertaken.

The principal conclusions of the study are :

(1) The daily variation of meson intensity is of a highly variable character. On individual days the daily variation having amplitude significant at the 2 of level, i.e., about 0.74 % for ⁵T telescopes when all the ten telescopes are operating and about 0.34 % for ²⁶T

phenomenologically classified as belonging to the 'n', the 'd' or the 's' type of variations. On 'n' and 'd' type days the daily variation has only one principal maximum. This occurs in the early morning on 'n' type days and shortly after noon on 'd' type days. On 's' type days the daily variation has two maxima instead of one.

- variations of each type are better revealed with $^{5}\mathrm{T}$ telescopes than with $^{26}\mathrm{T}$ telescopes. Not only is the amplitude of the daily variation larger in $^{5}\mathrm{T}$ telescopes than in $^{26}\mathrm{T}$ telescopes, but the separation of the maxima of the 'n' and 'd' types of variations which is about 8 hours for $^{5}\mathrm{T}$ telescopes is only about 4 hours for $^{26}\mathrm{T}$ telescopes. These observations are in confirmity with the results of SARABHAI and NERURKAR (1955). However, in 1954-55 they found that the maxima occurred at 0300 hour and 1100 hour instead of at 0700 hour and at 1500 hour respectively during the period of the present study (1956).
- (3) The average daily variation of cosmic ray intensity derived by adding all significant 'n', 'd' and 's' type days observed during the period February to December 1956 for $^5\mathrm{T}$ and $^{26}\mathrm{T}$ telescopes have their diurnal amplitudes 0.37 \pm 0.03 % and 0.36 \pm 0.02 % respectively, which are not significantly different from

each other. The time for the occurrence of the diurnal maximum in both cases is at about 0900 hour. Thus, the larger amplitude of the daily variation in narrow angle telescopes, when compared to the amplitude of the daily variation measured with wide angle telescopes, is observed during this period only if we compare separately the variations of each type.

- type days according to the daily variations of significant amplitude observed by ⁵T and by ²⁶T telescopes, agreement in classification of individual days, is found on 58 days. As against this, there are 22 cases of disagreement, most of them involving an 's' type classification. This suggests that 's' type classification requires further refinement, but on the whole the basis of classification is reasonably valid.
- (5) 'n' and 'd' type days exhibit a tendency to occur in groups of 2 to 3 days, and there is also a tendency for recurrence after 27 days.
- (6) 'n' type days are accompanied by an increase of intensity of about 0.16 ± 0.03 % from 3 days prior to epoch. The intensity is normal on epoch, but decreases significantly after epoch to reach, 2 days later, a minimum value about 0.27 ± 0.03 % less than the average daily mean intensity for the entire period of observation.

 'd' type days on the other hand are associated with

increase of mean intensity which remains about 0.17 ± 0.04% above the average, from epoch to + 2 days. The mean intensity is normal, for 's' type days, during the epoch period and on 3 days before and after it.

- (7) The daily mean magnetic planetary character figure C_p shows high values, compared to the mean of the entire period, from 3 to + 1 days of the 'n' type epochs. For 'd' type epochs this is also true for + 1 and + 2 days after the epoch day, but there is a C_p minimum in the interval 0 to 1 days before the epoch. For 's' type epochs, C_p values show a minimum around the epoch day.
- The evidence presented here is strongly suggestive of the creation of a variable anisotropy of primary cosmic radiation which is accompanied by an increase, a decrease or normal daily mean intensity, depending on the type of anisotropy that is produced. If this is confirmed by further more extensive experimentation involving global studies over a long period of time, the technique would provide a valuable new tool for the measurement of the coherent amgnetic fields in ionised matter in interplanetary space.

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BY COUNTER TELESCOPES OF SEMIANGLES 5° IN THE E-W PLANE AND 45° IN THE N-S PLANE.

and M^S are the times of maxima of the diurnal and the semidiurnal components respectively of the solar daily variation for each day, corrected for the barometric effect. Amplitudes are expressed in unit of 0.01 of a per cent. Column (7) gives the standard deviation for the percentage amplitudes on each day. The daily mean intensity I tabulated in the last column represents the number of mean bihourly counts on each day centred at 1100 hour I.S.T., corrected for the barometric effect, normalised to a value when all the ten telescopes are operating, and scaled down by a factor of 4.

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21 22 23 24 25	2 9 7 8	51 82 155 111 66	-52° 163° 110° 157° 144°	119 60 80 49 46	570 -230 1460 1370 π+320	83 39 39 44 41	0.4 1.4 1.9 2.3 1.4	n n n	3109 3099 3139 3101 3096
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8 8 8	84 78 91 136 30	123° π+620 -680 145° 165°	55 62 44 174 71	π+49° -53° 131° 3° π+73°	41 48 41 41	1.5 1.3 2.1 0.8 0.4	n	3223 3210 3220 3212 - 3165
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10 10 8	51 30 21 - 96	52° -65° π+55°	29 13 34 90	76° 76° -40° -58°	37 37 41 52	1.8 2.3 0.6	cose chie	3103 3121 3132 3132
57 10 87	89 66 82 21 136	π+440 π+640 570 π+740 1160	67 36 39 26 155	π+520 1410 -390 -410 -230	52 44 37 41 44	1.3 1.8 2.1 0.8	n n	3200 3232 3247 3269 3249 -
10 10 10 10 10	51 88 41 77 55 50	π+520 π+560 π+560 π+630 π+630 1550	8 77 37 27 57 56	-60° 88° π+39° -12° 84° -56°	37 37 37 37 37 37	6.4 1.1 1.1 2.9 1.0 0.9	d	3250 3250 - 3261 3262 3262 3258
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Day	No. of tele- scopes	M	and the the test and the test the size of	maps quals speed stree when attails	Mg S	5 (**)	MD/MS	Ty]	90 I
1 2 3 4 5	10 10 10 10 7	67 103 96 21 64	-76° 34° -73° 83° 135°	11 22 36 51 117	180° 120° -11° -91° 45°	37 37 37 37 44	6.0 4.7 2.7 0.4 0.5	n d	3262 3242 3280 3269 3279 \
6 7 8 9 10	7 7 7 10 5	37	137° π+83°	12 - 42	π+46° π+31°	37	3.0	d	3269 3284 3290 3283 3280
11 12 13 145	58 10 10 10	·39 46 111 57	72° -84° 134° 2°	106 35 100 92	109° 30° -25° 157°	41 37 37 37	0.4 1.3 1.1 0.6	s	3283 3255 H 3251 3248 - 3269 L
16 17 18 19 20	86558	102 115 124 81 70	π+37° π+13° π+25° 63° -68°	60 101 33 57 87	70 800 370 1400 350	41 48 52 52 52	1.7 1.1 3.8 1.4 0.8	d d d	3283 3273 - 3304 3294 3267 -
21 22 23 24 25	5	155 130 151 28 53	777 ⁰ 尔+85 ⁰ 尔+15 ⁰ 45 ⁰	111 10 57 48 14	-290 π+600 1080 1710 -300	41 52 44 37 37	1.4 13.0 2.6 0.6 0.4	d d d	3291 - 3287 3274 3229 3215
26 27 28 29 30 31	10 10 5 7 7	82 176 47 67 81 57	149° π +6° 107° +17° 120° π+32°	63 53 60 54 32 88	π+310 π+430 530 π+530 840 -10	37 37 52 44 44 56	1.3 3.8 1.2 2.5 0.6	n d	3193 3176 3081 3087 3100 3050

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State and the	*						*		
Day	No. cole-		THE SAME CHAIR CHA	MS	MOS	(*)	MD/M	3 Ty	pe I
12345	7725	82 33 190 59 24	-29 ⁰ 56 ⁰ 53 ⁰ 161 ⁰ 166 ⁰	41 31 120 56 33	66° π+43° 15° 68°	e come with many state likely to	2.0 1.0 1.6 1.0	i tion cam cam cam cap	3059 3033 3021 # 3074 3101
6 7 8 9 10	10 10 10 10	17 50 79 78 71	1150 π+190 1520 -400	32 57 63 34 75	136° 164° 53° -7° -24°	37	5.9 5.9 5.3 5.9 5.9 6.9	d	3095 3097 3112 3059 3089 -
11 12 13 14 15	10 10 27 8	104 46 92 103 22	π+53 π+70 1680 π+360 -260	65 55 13 23 53	176 1150 -790 -330 -20	37 37 83 44	1.6 0.8 7.1 4.5 0.4	d - d	3088 3088 3099 3134 3154
16 17 18 19 20	8 8 8	61 85 29 110 68	-530 1460 100 π+640 1610	13 70 82 64 82	180° 66° 77+18° -22° 107°	41 41 41 41	4.7 1.2 0.4 1.7 0.8	n s d	3157 3147 3153 3168 3137
21 22 23 24 25	8 8 10 10 10	65 37 37 45	π+17° -34° 129° 126°	49 41 33 57 64	π+50 π+700 600 π+60 1260	41 37 37 37	1.3 0.9 1.2 0.6 0.7		3154 3175 3473 3179 3168
26 27 28 1 29 30	7 10 10 7 7	56 35 57 27 93	114 ⁰ 56 ⁰ 24 ⁰ -78 ⁰ 69 ⁰	72 96 33 52 89	340 1480 590 11+110 -280	44 37 37 44 44	0.8 0.4 1.7 0.5 1.0	s - n	3210 3191 3172 3201 3181 -

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Day	No. c tele- scope	M	Må D	M ^S	MØ ^S	(#)	MD/MS	Тур	e I	
1 2 3 4 5	10 7 7 10 10	32 31 44 85 67	920 210 1130 7+180 1040	84 52 58 37 40	π+60° 158° 0° 78° 66°	37 44 44 37 37	0.4 0.6 0.8 2.3	S d	3183 N 3173 3163 3175 3161	Л
6 7 8 9	10 10 10	44 42 189 97	π+690 1280 π+430 1710	54 81 106 23	62° 7+16° 84° 34°	37 37 37 37	0.8 0.5 1.8 4.2	s d n	3163 3156 × 3159 – 3153	\ ;~
11 12 13 14 15	77444	114 42 28 84 116	89 ° 117° -24° л +67° л +50°	73 50 81 155 87	590 第4850 -360 440	44 44 56 56 56	1.6 0.8 0.3 0.5 1.3	n s d	3163 3163 3139 3166 3166	<u> </u>
16 17 18 19 20	10 10 10	55 9 57	168° -61° -11°	- 41 65 54	л+39° -140	37 37 37 37	1.3 0.1 1.0	5000 1000 1000 1000 1000 1000	3177 3161 3172	
21 22 23 24 25	10 10 10 7	- 24 72 106	1559 1219 元+259	- 87 19 91	150° 17+28° -19°	- 37 44 44	0.3 3.8 1.2	8 6	3149 3151 3152 M 3165 3153 -	
26 27 28 29 30 31	7 10 10 10 10 10	45 55 46 17 103 9	五+57 ⁰ 86 ⁰ -25 ⁰ 137 ⁰ 五+58 ⁰ 五+35 ⁰	40 15 61 51 64 53	π+77° π+60° -55° π+84° 101°	44 37 37 37 37	1.1 3.6 0.8 0.3 1.6 0.2	ess de de	3156 3168 3175 3181 3167 3180	•

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De	No. Ly tel sco		MØ ^D	MS	May 2	(**)	MD/MS	Ту	e I
12345	10 10 10 10	64 48 57 90 29	π +20° 135° π+45° π+77°	34 48 65 54 73	30° 122° 73° 35° 71+31°	37 37 37 37 44	1.9 1.0 0.9 1.7 0.4	ere ere ere ere er	3176 3175 3176 3176 3179
6 7 8 9	7 5 10 10 5	73 36 51 10 43	129° -10° 34° 130° 132°	58 172 40 28 102	1470 430 440 1350 30	44 52 37 37 52	1.3 0.2 1.3 0.4	3	3160 3141 L 3127 3161 3160
11 12 13 14 15	10 10 10 10	62 27 36 55 13	50° 141° -56° 117° -42°	28 69 37 79 58	81° 170° 0° 71+66° 35°	37 37 37 37	2.2 0.4 1.0 0.7 0.2		3135 3131 3128 3116 H
16 17 18 19 20	10 10 10 10	130 76 31 38 80	143° 149° 148° -76° -13°	40 64 55 49	75° -87° -19° -89° 2°	37 37 37 37	3.2 1.6 0.9	n n -	3133 3142 3142 3154 3150
21 22 23 24 25	10 10 10 10	115 29 43 45 76	135° 119° -87° 164° 135°	43 50 27 4	138° 71+60° 19° 138° 71+23°	37 37 37 37 37	2.7 0.6 0.2 11.2 1.9	II Mar Mar Mar Mar	31 54 31 33 31 27 31 43 31 41
26 27 28 29 30	10 10 10 5	26 54 126 116 165	150° 163° 125° ग+50° 17°	53 75 88 84 77	172 ⁰ 155 ⁰ 刃+67 ⁰ 刃+48 ⁰ 123 ⁰	37 37 37 52 52	0.5 0.7 1.4 1.4 2.1	s n d	3136 3147 M/ 3139 3147 3180

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Day	No. of tele- scopes	MD	MO D	MS	MøS	o (+)	MD/MS	Тур	J
12345	10 10 10 10	33 ' 76 108 31 78	л+38 л+16 л+56 -290 121	51 73 68 73 33	157° 70° 163° 20° я+79°	37 37 37 37 41	0.6 1.0 1.6 0.4 2.4	d d	31 53 31 52 31 58 31 44 31 29
6 7 8 9	5 7 7	91 142 37	980 -690 7+50	204 190 84	π+76° 107° -15°	52 44 44	0.5 0.7 0.4	5 5	3124 3172 3187
11 12 13 14 15	77777	89 137 49 105 28	50° 95° 107° π+59°	59 67 83 83	60° 130° π+40° π+16° 171°	44 44 44 44	1.5 2.0 0.6 1.3 0.3	n n	3207 3155 3132 3121 3134
16 17 18 19 20	7777777	40 79 55 68	π+67° 92° π+28° 110° 128°	37 134 56 67 77	-16° 9° 100° -54° -39°	44 44 44 44	1.1 0.6 1.0 1.0	6100 6001 8000 6004	3139 3129 3126 3137 3117
21 22 23 24 25	75577	230 12 104 157 113	80° -43° 135° 110° 170°	79 103 71 75 87	10 ⁰ 可+4.7 ⁰ 51 ⁰ 可+4.5 ⁰ -4 ⁰	44 52 52 44 44	2.9 0.1 1.5 0.8 1.3	n n n	3102 3130 3184 3233 3222
26 27 28 29 30	77777777	29 31 79 90	-64° 115° 112° π+58°	83 74 52 53	-70° - 6° -70° π+60°	44 44 44 44	0.4		3206 3216 3220 3200 3233 3232

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