Summary:

The problem of anomalous showers has been discussed with a view to compare their fluctuations with those for two other samples of electromagnetic cascades. It is concluded that the observed discrepancies result on account of the individuality of the events and that the fluctuations are similar to those for normal cascades. In general the fluctuations are found to be not very much larger than those for a Poisson distribution.
INTRODUCTION

An electromagnetic shower having a much too rapid development in the number of electrons and/or having lateral spread much larger than the angles allowed in the process of bremsstrahlung may be called anomalous. A genuine event of this nature should not find explanation on the conventional processes of bremsstrahlung and pair production after allowance were made for the fluctuations expected in the processes.

The first observation on an anomalous electromagnetic shower was reported by Schein et al (SHG.54). They had attributed their unusual shower of photons to have been produced most likely by a hitherto unknown process occurring outside the atmosphere. But for the large lateral spread and a rapid development with respect to the point of entry into the stack considered as the origin of the cascade, it appeared that the event might not necessarily require the hypothesis of a "new process" because the shower could possibly be explained as a soft cascade in which the fluctuations had been rather large and the probability of multi-photon origin was not negligible. The observation of SHG.54 was soon after followed by several other reports DGTW. 54, DGT. 55, DGTW. 56, DGT. 56, KK. 56, BBDILPR. 56, MSW. 57, YY.57, on isolated events observed in different stacks and having somewhat similar characteristics. It appeared useful to collect a large sample of cascades and examine them with a view to find the extent of fluctuations.
An investigation on this subject was undertaken. The showers were obtained from two stacks of stripped emulsions exposed in the stratosphere over India. The details on the procedure and the data collected are given in Appendix (A). Recognising the large fluctuations intrinsic in the nature of the involved processes, in the present sample no shower depicting abnormal behaviour was observed. However, if an individual event were selected from this sample by neglecting the other events (the situation is somewhat similar to if only one particular event was observed) it could possibly be classified as an anomalous shower. In order to clarify this point, in this chapter, the problem of anomalous showers has been discussed, keeping in view the various events known from literature and find out whether the observed anomalies may be called apparent or genuine.

**FACTORS RESPONSIBLE FOR AN APPARENTLY ANOMALOUS GROWTH.**

Before labelling an observed shower as anomalous it is essential to take into account a number of factors on account of which the shower is likely to be called anomalous. These are:

a) Indefiniteness of the nature and number of primary particles.

b) Uncertainty in energy estimation of the various components of the shower.

c) Contribution to shower development by processes other than conventional.

d) Fluctuations.
2.6. INDEFINITENESS OF THE NATURE AND NUMBER OF PRIMARY PARTICLES.

(i) Photon-initiated showers: If the origin of a cascade is a pair of two tracks originating in the emulsion, it is natural to assume that the primary has been a photon at the point of its materialisation and that point is considered as the origin of the cascade. It is however not possible to say without doubt whether the photon had been created outside the stack and so has been single since the entry into the stack, or it has been emitted by an electron in the stack, for which case it is possible that the photon is accompanied by one or more photons. The primary electron in this case could have experienced a large angle scattering after a sudden loss of a major part of its energy and appear at such a steep angle as to be missed during experimental detection. This probability depends strongly upon the experimental factors such as the steepness of the event, the clarity of the emulsions and the level of minimum ionisation. Failure to detect the single electron near the origin of the primary pair can lead to an event anomalous in regard to either or both of the longitudinal development and lateral spread. In case the experimental conditions ensure the detection of the electron, if present, and the event gives evidence on multi-photon origin, one is left to assume the production of a large number of photons by either of the following processes:

(α) Upto two photons can be associated with the decay of a \(\gamma^0\)-meson. Inspite of the time dilatation at
very high energies, the \( \pi^0 \)-meson because of its very short life-time (\( \approx 10^{-16} \) sec) is not expected to have entered the stack from outside. A local source such as a high energy disintegration is not difficult to detect, unless it is a rare collision between a high energy proton or neutron and a nucleon in the emulsion, involving production of only the neutral particles.

(\( \phi \)) There could be some other neutral particle of long lifetime decaying into photons. At the present state of knowledge, the existence of such a particle is not known.

(\( \psi \)) Two or more photons can be produced in an annihilation process between a proton-antiproton or an electron-positron. Corinaldesi (Co.54) has estimated the probability for \( p^+ - \bar{p}^- \) annihilation. In order to explain as many as 20 photons, suggestive of the anomalous shower observed by SHG. 54, his results require an energy of \( \sim 10^{52} \) eV to explain the event. In view of the antiprotons being rare, and in view of the impossibility of having energies of that order, the probability of such a process being responsible for the large number of observed anomalous events is negligible. Gupta (Gu.56 b) and Joseph (Jo.56) have estimated that in \( e^+ - e^- \) annihilation at very high energies the probability of multiphoton production of upto 4 or 5 photons is comparable to that for the normal 2 photon production. Since in the electromagnetic processes high energy positrons are created in equal number as electrons, the probability of a very high energy positron entering the stack from
outside and getting annihilated in the stack must be considered. This probability, according to Heitler (He.64, Page 271) is negligibly small because at very high energies the positrons are likely to lose their energy by radiation instead of by annihilation. It may be mentioned that in emulsions such a process cannot be directly identified, since it is not possible to detect a stopping minimum ionization track and associate it with a cascade that originates after one of the photons materializes. When occurring in an already developed cascade it is possible to recognize an electron track stopping in flight, but its annihilation photons when materializing cannot be distinguished from the background of the normal bremsstrahlung photons.

From the factors mentioned above it may be concluded that electron-positron annihilation is a possible explanation for an event in which a much too rapid development is observed. Whereas for an event showing large lateral spread, the experimental limitation of missing the singular electron track offers a possible explanation.

2.A.(ii) Electron-initiated showers: If a cascade when followed back to its origin leads to a single track at minimum ionization, it is most likely initiated by a single electron. In the first place, it is absolutely essential to follow such a track to its point of entry into the stack, because unless that is done the origin of the cascade cannot be precisely defined. It may be possible to judge the potential range of such a track, if it is not convenient to follow it back, but by such a procedure
an unknown bias is introduced against some low energy pairs that might have materialised in the unfollowed length and do not show up now at the point one finds apparently a single track. The tracing back of a single track at minimum ionisation involves great care and is associated with uncertainty in track following. If followed to the point of entry into the stack, it is conventional to assume the entrance point as the origin of the cascade and consider the electron as alone. This is a reasonable assumption for most of the cases, but will not be valid in a case when the electron loses energy by radiation while traversing the packing material beyond the sensitive volume of the stack. In view of the fluctuations, possible in the process of bremsstrahlung, this possibility is not small. Because such photons are likely to materialise at any stage on or near the primary track, these pairs can give rise to an anomalous event with an apparently fast growth and wide aperture. The situation is particularly bad in the case of emulsions, because only a limited portion of the cascade near its origin can be observed. It appears therefore unsafe to derive conclusions on the anomalousness of an event that has been observed only for a restricted length and is initiated by one or more electrons entering the stack from the outside.

2.B. UNCERTAINTY IN ENERGY ESTIMATION

The rate of cascade development can be predicted by the cascade theory provided the energy of the primary can be estimated by independent means. To utilise the cascade theory it is also essential to estimate the secondary
energies. For most of the anomalous events the anomalies are found to disappear if the estimated energies are allowed large uncertainty. This departure in some cases is required to be more than an order of magnitude. With the methods currently in use, the energies are always underestimated as higher energies are approached. The underestimation of primary energy leads one to classify a cascade as depicting an anomalously rapid growth. At present a number of methods of varying merit are available for energy estimation. These are:

1. multiple coulomb scattering;
2. opening angle of the pair;
3. suppression of ionisation near pair origin;
4. lateral spread of the shower and
5. the longitudinal cascade development.

In brief it may be mentioned here that primary energies \( \gtrsim 10^2 \) GeV can be determined equally well by either of the methods (iii), (iv) and (v) wherever applicable. The first of these methods i.e., the suppression of ionisation near pair origin is particularly useful for those events which cannot be followed for sufficient length in the stack. Neither of these methods can be used for estimating energies of the secondary order. The first two methods i.e., multiple coulomb scattering and the opening angle may in some cases be used for pairs of energy \( \sim 10^{10} \) eV, but are suited more to the low energy secondary pairs.

On account of emulsion distortion, microscope stage noise, personal reading error and above all spurious
scattering, energy measurements at $> 10^{10}$ eV cannot always be relied upon. The neglect of relative multiple scattering while estimating energies from the opening angle also leads to underestimation of energy. From the present work it was concluded that if a proper account of both these contributions to the observed opening angle is taken the energy of the pair can be estimated to a fair degree of reliability. The details on this method and the applicability and limitations of the various methods are given in Appendix (C).

2.C. PROCESSES OTHER THAN CONVENTIONAL;

In the development of showers, the cascade theory takes into account only the conventional emission from the electron of bremsstrahlung photons and their subsequent materialisation. If the growth of the shower is too rapid, it is useful to assume that apart from the conventional processes, there might be some contribution due to other phenomena such as:

(a) trident production;
(b) production of two or more photons at the electron-positron annihilation;
(c) multiple bremsstrahlung by an electron;
(d) multiple pair production at the materialisation of a single photon and
(e) the direct pair production of more than one pair by an electron.

Since the cross section for trident process has been theoretically predicted to be negligibly small at energies commonly dealt with, no account of the trident process
has so far been taken in most of the cascade theory calculations. A detailed discussion on the trident problem is given in Chapter 3. As a result it may be stated that the contribution of the trident process in the general development of the cascades is not significant because the trident cross section is highly energy dependent.

Some aspects of process (b) have been already considered in the previous section. For multiple processes, one might expect according to Heitler (He.54, page 228), that the cross section for these processes being proportional to \((\alpha/\pi)^n\), falls rapidly with \(n\), where \(n\) is the multiplicity and \(\alpha = 1/137\) in the fine structure constant. For process (c), Gu.65a has estimated the cross section to be negligibly small even at extremely high energies. It may be mentioned that such a process cannot be observed under the conditions of the experiments with nuclear emulsions. Isolated examples of multiple pair production by a single photon (HK.60) and of the direct production of two pairs by an electron (CM.68) have been experimentally observed. No conclusions on the frequency of these events can be drawn since only these few events do not exhaust the whole material (VGT.57). Such processes though directly observable, are difficult for unambiguous identification if occurring in already developed cascades, because alternative assumptions such as accidental coincidence between individual events are more likely. Under the present circumstances it is not possible to separate the
contribution due to multiple processes from the normal cases.

3.D. FLUCTUATIONS

The theoretical formulation of the fluctuation problem in the case of soft cascades is hopelessly complex. Since the production of successive generations of electrons is dependent upon the number and energy of the previous generation, the fluctuations from the average are expected to be much more than those expected for a Poisson distribution of the events. The consequences are most serious if the fluctuation occurs in the most initial stages, and that is one reason that the problem is of great importance for studies made in emulsions. On the various theoretical attempts, good qualitative and quantitative discussion is given in the books by Rossi (Ro.56, page 288) and by Heitler (He.54, page 394). Arley (Ar.43) has worked out in detail the nature of the stochastic problem, and proposed a model involving the Polya distribution of events. Accordingly the fluctuations are expected to be in some cases as much as the average itself. In the present work it had been considered advisable to restrict the comparison of experimental data collected in different samples. For the sake of reference the Poisson distribution fluctuations have been included. The results as presented can be compared with other theoretical estimates.

3. EXPERIMENTAL DATA

Experimentally observed fluctuations have been derived for all the anomalous events known to the author.
The only criterion adhered to while collecting the events had been to include those showers that originated with a pair materialising within the emulsion or which started with a closely collimated pair of tracks entering the stack. The development of the "mean anomalous cascade" derived from these showers has been plotted in Fig.1, curve (a). The horizontal lines have been drawn to indicate the root mean square deviation of the distance fluctuation derived for the respective pairs. For comparison, plotted in the same figure are the data of Fay (Fa.67a) and the present work, as curves (b) and (c) respectively. Inspite of the probability of there being in some cases more than one photon at the stage "considered as the origin of the cascade" the individual fluctuations in curve (a) do not seem to be appreciably different from those in curves (b) and (c). It may be mentioned that for curve (a), since the energy of the secondary pairs has not been precisely defined in relation to the energy of the primary, a particular value of the parameter \( y = \ln(E_o/E_m) \) cannot be defined, whereas in the case of curves (b) and (c) it is known. This uncertainty is likely to allow for larger deviations in the case of anomalous events and would consequently affect the slope of the "mean anomalous cascade".

In order to be able to find the fluctuations in the number of electrons observed at a certain distance from the origin, data is available from Fa.67a and the present work. In order to find the number of electrons present...
Fig. 1. Distribution of the distances at which each of the first 14 pairs materialised, plotted against the number of the pairs. The horizontal lines denote the r.m.s deviation of distances.
at a certain depth for the anomalous events, it was considered necessary to take into account the difference in the number of electrons from twice the number of pairs materialising in the same distance. This arises due to the scattering out of the low energy electrons. The corresponding values for the anomalous events were derived by making use of the present data and utilising it to estimate the number of electrons in the case of the mean cascade. The root mean square of the "number fluctuation" was obtained from the average number observed at various depths and the percentage fluctuation \((P,F)\) computed. For the observed data as well as for the Monte Carlo calculations of Fa.57 b, the percentage fluctuation was defined as:

\[
P_{F} = \frac{100}{n_{\text{mean}}} \sqrt{\frac{\sum n (N_{\text{observed}} - N_{\text{mean}})^2}{n}}
\]

In the case of the Poisson distribution, \(P_{F} = \frac{100}{N_{e}} (N_{e} - 1)^{1/2}\)

where \(N_{e}\) is the total number of electrons at a certain depth, (or \(N_{e} - 1\) is the number of secondary electrons). \(n\) here is the number of cascades used in a particular sample, being 6 for Fa.57a, 16 for Fa.57 b, and 20 for the present work. The results are presented in the form of Figure 2. It would appear convenient to plot \(P_{F}\) against distance from origin rather than the number of electrons, but since at a certain depth the average number of electrons is subject to the fluctuations and to the cascade theory calculations used for comparison, the \(P_{F}\) were plotted against the number of electrons. The
Percentage Fluctuation (for definition see page 16) plotted against the number of electrons observed at a certain depth. The Poisson fluctuation based upon the number of secondary electrons has been included for comparison.

Fig. 2. Percentage Fluctuation (for definition see page 15) plotted against the number of electrons observed at a certain depth. The Poisson fluctuation based upon the number of secondary electrons has been included for comparison.
"Number fluctuations" for the anomalous events were found to be no different from those for the other samples. It is important to realise that the anomalous events considered for this study have been the extreme cases observed in samples where other normal cascades were also observed. It may also be noted that the fluctuations do not seem to be very much larger than those expected for a Poisson distribution, as is generally believed. For example according to the results of Ar.43, \( r_2 \), could be \( \sim 80\% \) for the region of Fig.2, which is in contradiction with the experimental data.

From these considerations it may be concluded that the decision on a single event being anomalous is hard to make unless comparison can be made of a number of events of that nature with those considered normal.

4. CONCLUSIONS:

From the foregoing considerations the following conclusions may be drawn:

1) In order to classify an event as anomalous, it is essential to make sure of the nature and number of the primary particles. Events originating with a single pair are superior to those initiated by one or more electrons. In order to avoid the observational bias it is useful to select events having smaller angle to the plane of the emulsion and make extensive scrutiny in the vicinity of the original pair.

2) The fluctuations of the so called anomalous showers are not larger than those for normal cascades. In most of the cases the fluctuations are of the same order as expected for a Poisson distribution of individual events.