The Thermodynamics of Duststorms.

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DUSTSTORMS are among the striking instability phenomena in which considerable amounts of energy are manifested They are of the same class as thunder storms, indeed, a typical duststorm (called *Andhi* in North West India), which should be distinguished from a mere dust raising wind, is not essentially different from a thunderstorm except that the former is associated with less precipitation than the latter and possesses the additional peculiarity of raising large quantities of dust The autographic records of wind, pressure and temperature relating to a duststorm show the same characteristics as those relating to a thunderstorm

So far as India is concerned, duststorms chiefly occur in North West India and the neighbourhood during summer, although they are known to occur occasionally in other parts of the country and in other seasons They are associated with vigorous squalls during which the wind often attains enormous force (instances are on record when velocities of over 70 miles per hour have been reached) and usually undergoes a change in direction A sharp rise of pressure and a marked sudden drop in air temperature are the other usual characteristics Visibility is extremely poor during the phenomenon on account of the dark rolls of dust which rise to a considerable altitude The vigorous squalls and the poor visibility renders duststorms a danger to aerial navigation

The authors have chosen the duststorms of Agra for study because, in addition to being a station typical of the region commonly affected by duststorms, the location of the Central Upper Air Observatory for India at that place has made it possible to obtain records of upper air soundings pertaining to duststorms, in addition to the usual meteorological records

A statistical analysis of the characteristics of 152 duststorms which occurred at Agra between 1924 and 1930 has been made The following table gives the monthly frequencies of duststorms brought out by this analysis

J	F	M	A	M	J	J	A	S	O	N	D
0	0	3	15	63	58	9	0	0	3	0	1

It is seen from the above table that the frequency of duststorms increases with the progress of the hot season and reaches a maximum in May In June the number becomes slightly smaller although it still remains quite high It should be mentioned that, in this month we get a larger proportion of thunderstorms as the amount of moisture in the atmosphere becomes greater Ramanathan[1] has explained these variations with reference to the mean monthly tephigrams relating to the soundings of the atmosphere over Agra After the monsoon establishes itself (which happens in Agra by about the middle of July) duststorms cease to occur There is a secondary maximum of frequency for duststorms in October, but this is very small, only 3 duststorms having occurred in this month in 7 years The hourly frequencies of occurrence of duststorms show that no duststorms ordinarily occur between 6 and 8 A M The frequency increases thereafter with advance of the day and reaches a maximum between 16 and 18 hours, suggesting that insolation plays an important part in duststorm phenomena The frequency falls somewhat rapidly after 18–19 hours but a fair number of duststorms do occur at night being probably associated with the passage of cold fronts Other results of the statistical analysis will be given in a detailed paper to be published eslewhere A word or two may be said about the precipitation in duststorms In the earlier duststorms of the season, the precipitation is usually slight, often consisting of a few drops only With the progress of the season when more moisture is brought into the atmosphere the associated precipitation increases in amount and ultimately, when the phenomenon merges into the pure thunderstorm type, the precipitation becomes copious

In order to study the mechanism of duststorms a few special sounding balloons were let off from Agra at the instance of one of the authors (B N Sreenivasaiah) in the summer of 1932 whenever conditions appeared favourable for duststorms to occur Meteorographs of the Dines type with magnified scales[2] of temperature and pressure were used, and the ascents were restricted to 6 km Of the records retrieved, four have been found useful for study, two of these relate to one duststorm day, one of the instruments having been sent up before and the other after the duststorm, the third record was obtained during the progress of a duststorm while the fourth was obtained from a meteorograph sent up 6 minutes before a duststorm set in In addition to these special records a few of those obtained from such of the routine sounding balloon ascents as happened to have been made before a duststorm have also been used for detailed study

Two records relating to 28–6–1932 have been reproduced in Figs 1 and 2 The thick continuous line represents the tephigram and the thick broken line the estegram (same for all practical purposes as the curve of wet bulb temperatures) relating to the ascents

The first record shows a layer with super adiabatic lapse rate of temperature between surface and 0 9 km (about) As explained later, the magnitude of the lapse rate is sufficient to cause instability in the layer Consider a particle A (unit mass) in this layer to ascend on account of its instability It will gain an amount of energy represented by the area A B F in its journey to F and there have sufficient kinetic energy to carry it to the condensation level G and then to H, making it lose an amount of energy equal to F G H in this part of the journey F G H being smaller than A B F, the particle can reach H Beyond H the particle is again unstable and rises to K gaining energy equal to H J K The total energy gained is thus H J K + A B F – F G H This is a case of real latent instability [3,4] It is to be noted too that, in this instance, the initial ascent can take place, on account of instability present in the layer, without expenditure of energy (*Cf* instance of insolation acting as trigger discussed by Normand [4])

The subject of latent instability has been fully discussed by Normand and also by Sohoni and Paranjpe[3,4] In accordance with their criteria, layers of "latent instability" are given by points on the 'Estegram' which

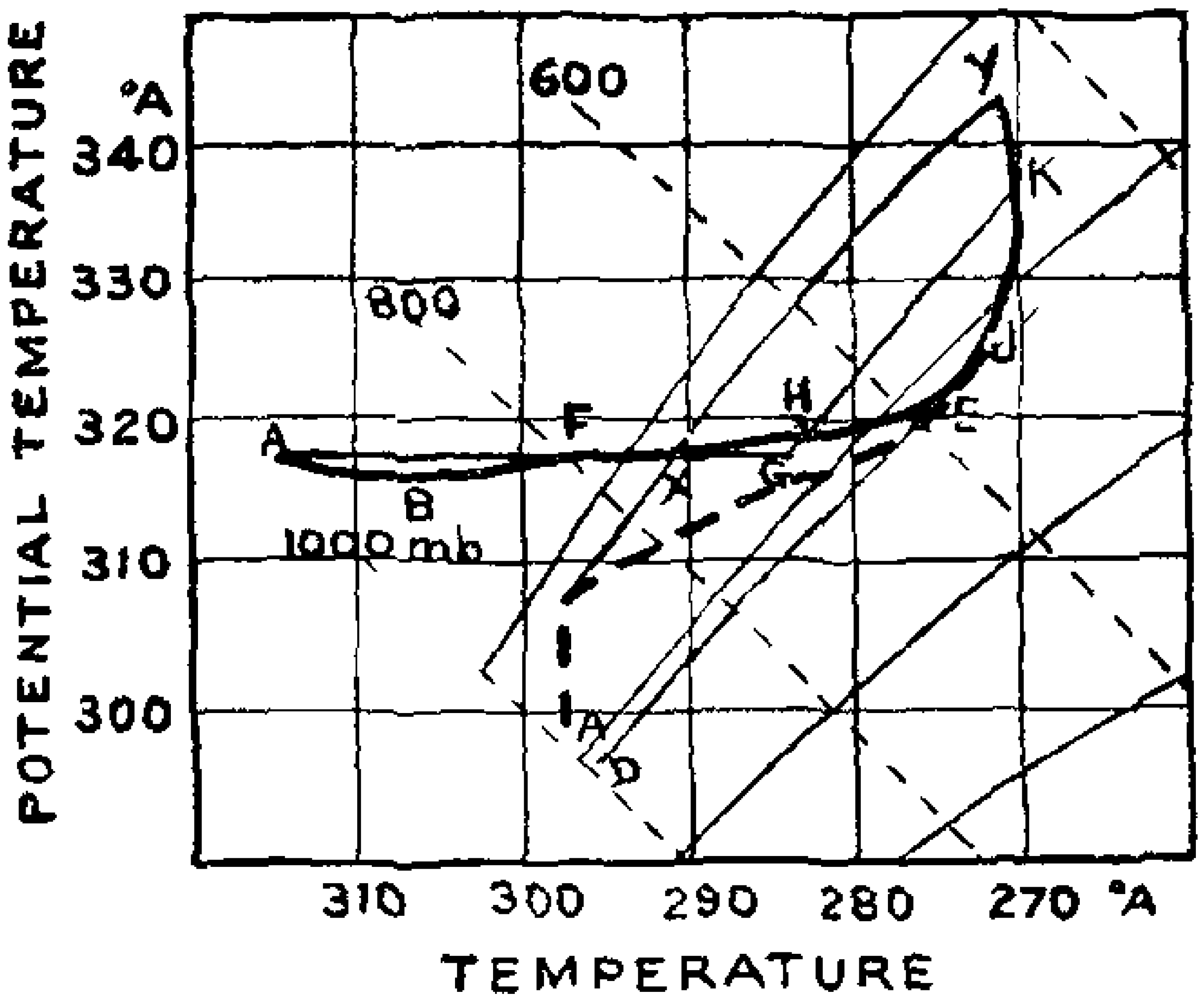

Fig 1
Tephigram of the Sounding at $14^h\ 57^m$ on 28 6-32
—— Tephigram ---- Estegram

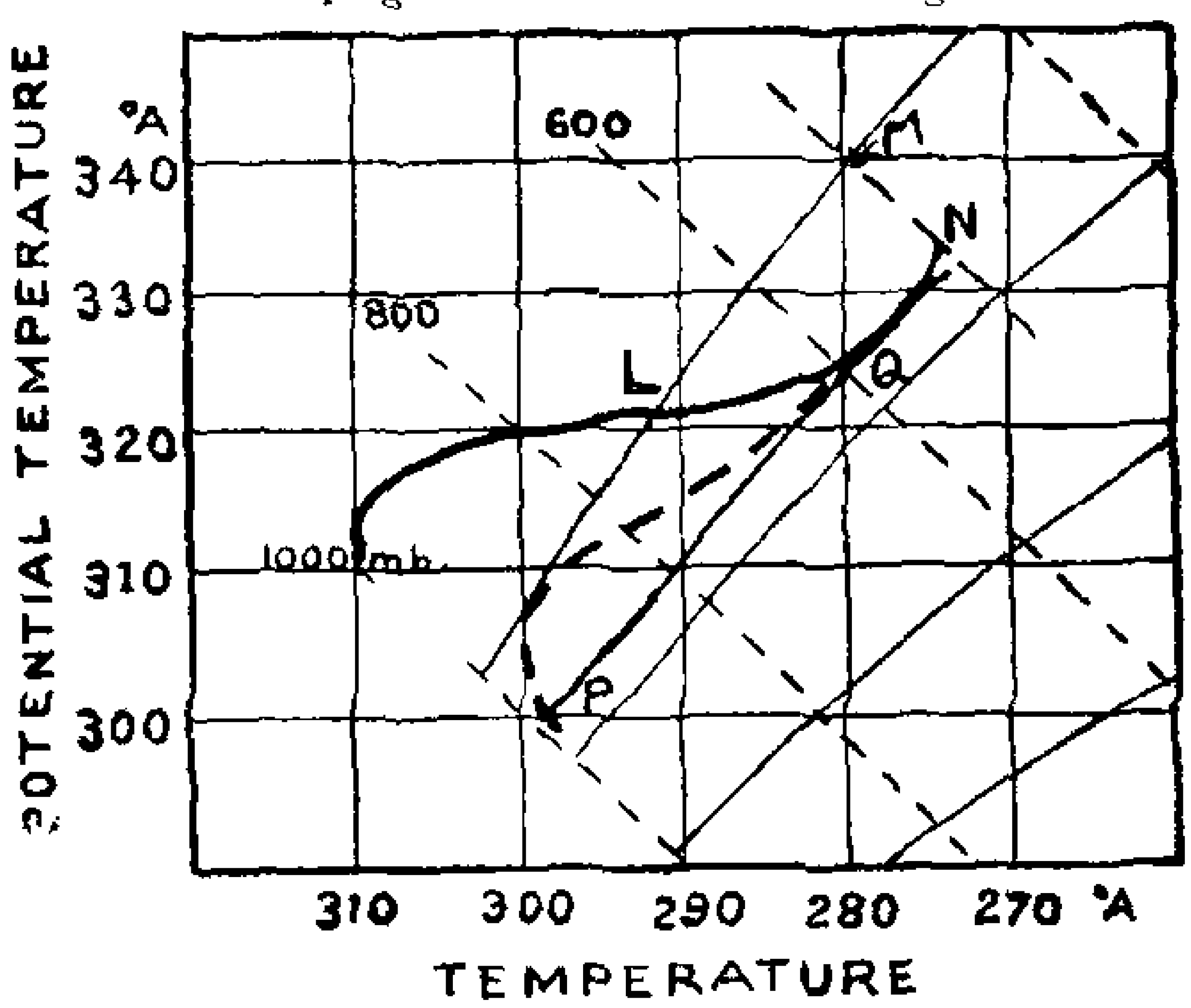

Fig 2
Tephigram of the Sounding at $16^h\ 15^m$ on 28-6 32
—— Tephigram ---- Estegram.

lie to the left of the lowest saturation adiabat touching the tephigram, while the 'environment of latent instability' is given by points on the tephigram which lie to the right of the highest saturation adiabat touching the estegram Thus in Fig 1, a particle in the layer between the heights represented by D and E can become unstable if raised to a point in the environment between X and Y Similarly in Fig 2, the environment of latent instability extends from L to the highest point reached by the balloon while the layers of latent instability extend from P to Q

An examination of the available records of soundings of duststorm conditions from the point of view of latent instability shows that the occurrence of duststorms is mostly associated with the existence of a state of latent instability in the atmosphere The mere existence of latent instability is not, however, sufficient to cause the phenomenon, a suitable agency or trigger is needed to give the initial displacement necessary to lift the layer of air possessing latent instability into that part of the environment where it will gain energy For instance in a case like that of Fig 1, the instability in the layer between surface and 0 9 km is itself sufficient to lift a layer from A to H On the other hand, in a case like that of Fig 2, some other outside agency is needed for lifting up the lower layers As discussed by Normand in a recent paper,[4] several factors like insolation, the rising of air over hill or over another colder air mass, convergence, can act as agencies for bringing about the release of the stored up energy The present authors have examined some soundings of duststorm conditions in detail with a view to finding out the trigger in each case, evidence being sought from the general synoptic weather situation, changes in upper winds and air sources, isochrones of occurrence of duststorms in the neighbourhood and a comparison of wet bulb temperature at the ground after duststorm with the wet bulb potential temperatures obtaining in the upper air before duststorm Two out of the six cases so far examined point to insolation and the resulting superadiabatic lapse rate of temperature in the lower layers as the exciting cause for the release of energy while in four other cases, the undercutting and uplifting action of a cold air mass appears to have been the agency responsible for this In 3 out of these 4 cases, the cold air mass came in the rear of a low pressure area passing across the station In the remaining case it was apparently associated with a locally developed cold front of a neighbouring thunderstorm As a typical instance of the analysis, the case of the duststorm of 28-6-1932 is discussed below —

On this day a duststorm occurred at 15 hours 38 minutes accompanied with thunder and light rain Two meteorographs were sent up, one at 14 hours 57 minutes, *i e*, before the duststorm, and the other at 16 hours 15 minutes, *i e*, after the duststorm Both have been retrieved. The tephigrams (with estegrams) relating to the ascents have been reproduced in Figs 1 and 2 It will be seen that at 14 hours 57 minutes, layers of latent instability extend from the surface to about 5 km while the environment of latent instability comprises the atmosphere above 2 5 km (up to the highest level reached by the balloon) Fig 1 shows that a considerable amount of energy could be realised on this day if air layers from below were forced into the environment of latent instability The particle from A, for example, would have had a speed of 35–40 miles per hour when it reached K

Duststorms occurred at some stations in North West India on this day, but did not reveal any regular time sequence which one should naturally expect if a regular frontal passage was responsible for these Upper winds and sources of air did not undergo any material change between the 28th and 29th Also, the wet bulb temperature on the ground (as recorded by a thermograph) is of the same order as, and not lower than, the wet bulb temperatures which would be attained by descent of air from above There is therefore no positive evidence of a cold air mass having come from elsewhere and acted as a trigger On the other hand, the tephigram shows a layer with a superadiabatic lapse rate of temperature between surface and 0 9 km caused, apparently, by the strong sunshine which existed up to 14 hours 30 minutes on this day Making allowance for variation of vapour pressure with height[5], the lapse rate should be more than 10 9° C /gkm in this layer in order to make it unstable Actually, the sounding shows a larger lapse rate, *viz*, 11 5° C /gkm As has already been explained, air rising from this layer on account of instability can, without expenditure of energy, reach a level beyond its condensation level and get into the environment of latent instability Thus the trigger in this case should be considered to be insolation causing the high lapse rate

Fig 2 which is the tephigram of the record after the duststorm shows some striking differences from the first record In the first place, the superadiabatic gradient in the lower layers has now given place to a weak inversion between surface and 600 metres The agency which acted as trigger for the phenomena is thus now absent Although latent instability is shown by this record for certain layers, the layers of latent instability do not extend to the surface, the lower limit of the environment of latent instability has gone up and is 0 5 km higher than before, i e, particles have now to be raised higher up in order to manifest instability For layers below the 930 mb level, the work which has to be done on the particles in order to raise them to the environment of instability is comparable to or larger than the energy that the particles can gain after reaching that environment So far as these particles are concerned, therefore, the case is one of pseudo instability No instability phenomenon occurred on the 28th after 16 hours 15 minutes

The conditions depicted would however be favourable for development of instability as soon as insolation again brought in a super adiabatic gradient in the lower layers or other suitable trigger intervened It is interesting to note that a duststorm did again occur on the next day

With regard to the seasonal variation of duststorms it may be added that, with the progress of the hot season, the tephigram tends to become more and more horizontal, thus increasing the area enclosable between it and a saturation adiabat If with this favourable background, the introduction of moisture takes place on a particular day, the wet bulb curve and the tephigram close up, and this increases the depth of the layer of latent instability, lowers the base of the environment of latent instability and increases further the area enclosable between the tephigram and a saturation adiabat These conditions favour greater and easier release of energy The fact that duststorms do not occur more frequently than they do, although the temperature gradients near the ground may be superadiabatic day after day in summer is probably due to the absence of real latent instability on all these days If and when moist air is brought in, perhaps by a western disturbance, conditions become favourable and if the superadiabatic gradient helps by acting as a trigger, instability occurs

A fuller account of this investigation will appear elsewhere

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3 Normand C W B *Nature* 1931 **128,** 583

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Whale-marking Voyage of the R.R.S. *William Scoresby*.

THE Royal Research Ship *William Scoresby*, the Discovery Committee s smaller ship, which is now used mainly for whale marking, has already sailed, the purpose of her early start being to search for whales in sub Antarctic waters before they have reached the Antarctic feeding grounds The route to be taken depends largely on the abundance and movements of whales Fuel will be taken, however, at South Georgia in November, and it is probable that operations will then be extended eastwards towards Bouvet Island if ice conditions are suitable. In the second part of the season the ship will move to more westerly regions, near the South Shetland Islands and in the eastern part of the Pacific sector

The *William Scoresby* sailed on September 16 and is expected to return about April 15, 1938 Mr G W Rayner is in charge of the operations and Lieut R C Freaker in executive command

Some four thousand whales have now been marked and more than ninety marks have so far been returned —(*Nature*, 1937, **140,** 572)