SUNSPOTS

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SUNSPOTS have been known since the third century of the Christian Era. Oriental records contain observations of 45 sunspots made between A.D. 301 and 1205. But in the western world, soon after the invention of the telescope, the discovery of sunspots appears to have been made in the year 1610 independently by Galileo, Fabricus and Schneir-Fabricius being the first to publish the fact. Scheiner at first maintained that the dark spots were due to the transit of small planets across the sun's disc, but Galileo and Fabricius from the very outset of their observations correctly recognised that they are objects on the sun. The thought of blemishes on the sun was, however, repugnant to medieval society dominated by theological philosophy and it was a long time before the existence of sunspots was grudgingly accepted as a scientific fact. From then onwards observations of sunspots have been fairly continuous, but really systematic observations, visual as well as photographic, have been made only during the last sixty years or so leading to many important discoveries concerning the nature of these objects.

Sunspots can be observed through a very small telescope of even an ordinary field or opera glass. The safest way to observe them is to point the instrument at the sun and focus the eye-piece until a sharp image of the solar

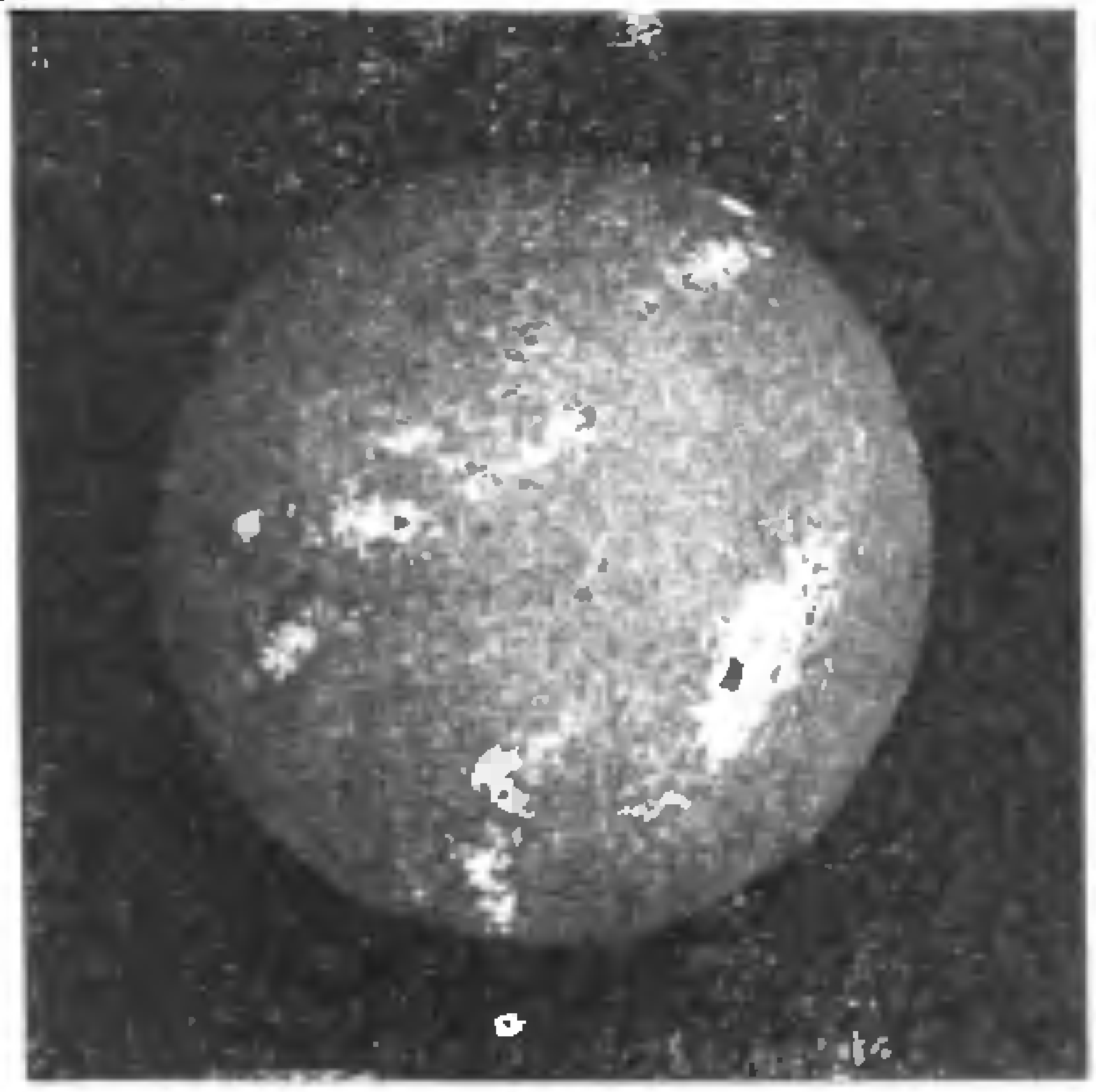

FIG. 1

disc, several inches in diameter, is projected on a white cardboard. A careful examination of this projected disc reveals that the sun has a mottled appearance, particularly near the edges. Now and then, on the mottled background dark spots appear, occasionally several times larger than the earth. They often occur in groups and many groups of sunspots have been observed covering areas of one hundred thousand square miles or more. Recently, a large group of spots, about twenty times the size of the earth in area, was observed between 30th January and 12th February 1946 (Fig. 1).

Spot areas are usually measured in millionths of the sun's visible hemisphere. If the area of a spot is more than 1000 units or about 25,000 miles in diameter, it can be seen by the naked eye when the brightness of general sunlight is reduced by the use of a shade-glass, or by thin clouds, or by nearness to the horizon. Evidently, the ancient Oriental records of sunspots refer to those observed with the naked eye and, therefore, contain no details of their structure. Modern telescopic observations, particularly those made by exceptionally skilful observers like Langley, Nasmyth, Secchi and a few others, have revealed a wealth of detail in the structure of sunspot which has gone a long way towards elucidating their real nature.

Although the structure of a solar spot varies very considerably during the period of its growth, a well-formed sunspot consists of two characteristic portions—a central, more or less circular and very dark region called the *umbra* and a surrounding fringe called the *penumbra* which is less dark and consists largely of filaments directed radially inwards. As Young has said the general appearance of a mature sunspot is "as if the umbra were a hole and the penumbral filaments overhung and partly shaded it from our view, like bushes at the mouth of a cavern". Fig. 2, which is a copy

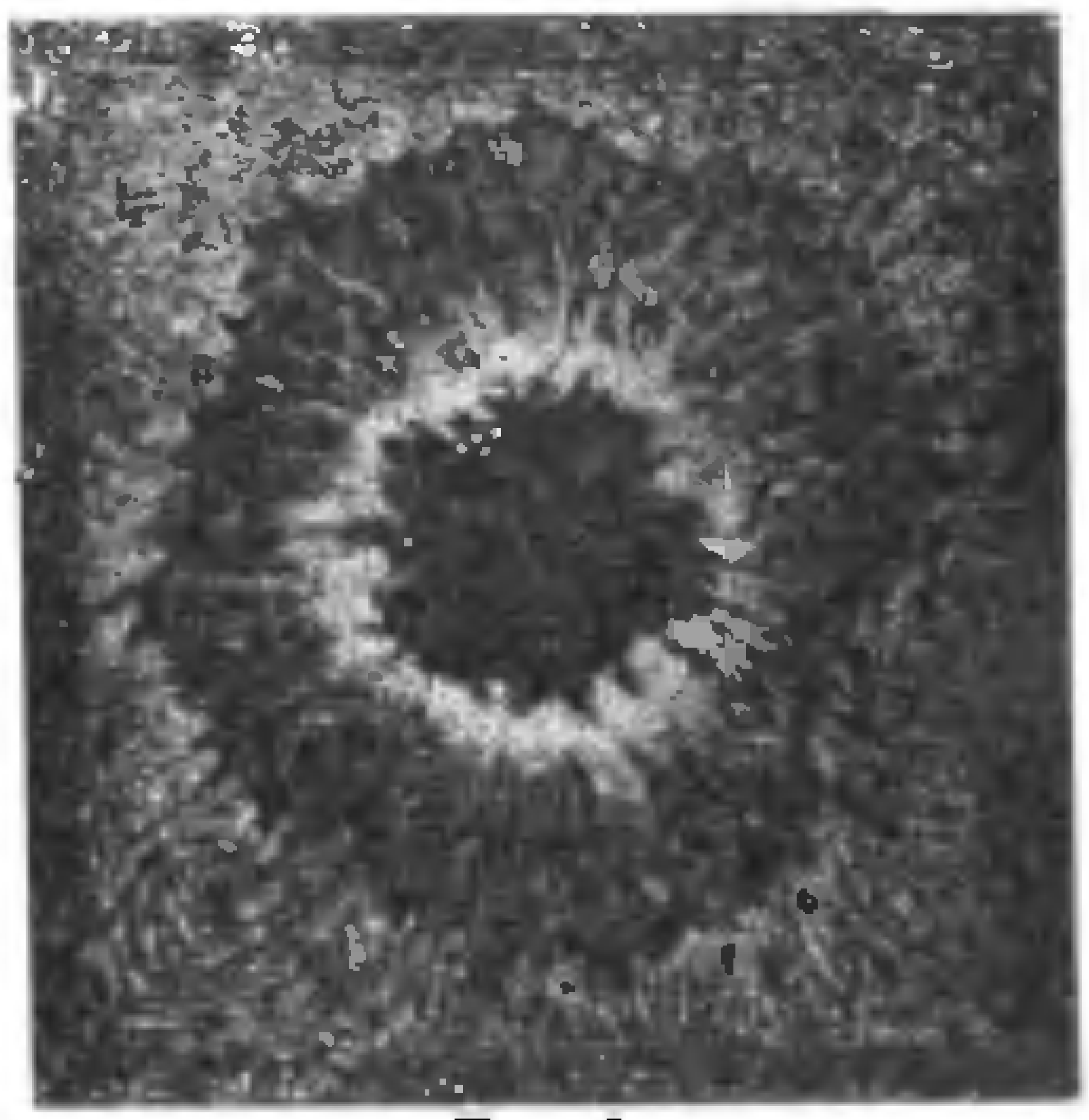

FIG. 2

of a drawing by Secchi, is a fair representation of such a spot under ordinary conditions of seeing. It will be noticed that the form of the spot in the drawing is nearly circular which is the ordinary form of a middle-aged sunspot, but during periods of formation and of dissolution a spot usually has a much more irregular shape. It will be seen also that there is no gradual shading off, either between the umbra and the penumbra or between the penumbra and the surrounding photosphere; in fact, the penumbra is clearly separated from the umbra by a bright ring and on the photospheric side it has a strongly marked dark boundary. These and many other details visible through a good telescope under good circumstances of seeing make the observation of sunspots one of the most fascinating experiences of astronomers.

If we watch a sunspot for some time we see it move steadily from east to west in a circle parallel to the sun's equator until it disappears at the western limb and if it is a long-lived one we see it reappear at the eastern limb after about a fortnight and sensibly at the same parallel of solar latitude. This movement is, however, only apparent because in reality the spot has very little proper motion of its own and is carried along by the east to west rotation of the sun about its polar axis. This apparent east to west movement of the solar spots is so regular and so largely independent of their individual characteristics that it affords a very convenient and fairly reliable method of measuring the period of rotation of the sun. Since spots are found to occur at all solar latitudes from 5° to 45° north and south of the solar equator it has been possible by this method to determine the periods of rotation of the sun at latitudes between 5° and 45° and it has been found that the sun's rotation is quite unlike the rotation of a solid body, for example the earth or the moon; for, the sun's rotation period is about 25 days near the equator increasing steadily at higher latitudes to about 27½ days at 45°. This curious feature of solar rotation has been verified also by several other methods of measurement which have also shown that the period of rotation continues to increase steadily right up to the poles where it is about 30 days. Of course, a spot in order to be suitable for the measurement of solar rotation must be visible for a fairly long time and the longer the life of a spot the more usable it must be for the unrpose. The life of a sunspot varies from a few hours to many months, the longest duration so far recorded being 18 months. The average life of a spot may, however, be taken as two or three months. We have said above that a spot has very little proper motion; this statement is, however, true only for a spot in its middle life, for a spot in the early stages of its life as well as when it is nearing dissolution shows very considerable proper motions. It must be mentioned also that when a large spot breaks up into two or more parts, as often happens, the parts fly asunder with velocities of the order of hundreds of miles per hour. But apart from the large and irregular proper motions which actively changing spots show, even the stable sunspots have a regular proper motion which is very small, but by no means quite negligible. According to the observations of Carrington spots between 20° north and south latitudes have a slight tendency to approach the equator, the movement amounting to a minute or two of arc per day, and outside these latitudes their tendency to approach the poles is much more pronounced.

As already stated in the preceding paragraph a sunspot can appear at any latitude between 5° and 45° latitudes north and south of the colar equator, but within these belts, often called sunspots belts, the distribution of spots is quite irregular. Between latitudes 10° and 30° the frequency of spots is highest, while beyond 40° and in the neighbourhood of the equator sunspots are rarely observed. Also between the sun's northern and southern hemispheres there is often a great inequality with regard to the number of spots, although over a very long period of years this inequality practically disappears. If one observes sunspots regularly for a number of years, one is bound to be struck by the fact that the total number of sunspots observable at any time and their areas vary not only from day to day, but from month to month and from year to year. A little more careful examination of observations ranging over a long period of years shows further that this variation is not irregular. In fact as early as 1776 Horrebow had already noticed it and had expressed the view that it was periodic. But the definitive discovery of the periodicity of sunspots and the determination of the length of the period we owe to Schwabe, a German pharmacist who, in 1843, announced his results after studying sunspots with unremitting patience for eighteen years and who continued his observations almost daily until 1868. Schwabe gave about ten years as the length of the sunspot period, that is, the time that elapses between one maximum of spot activity and the next. This figure was modified by later workers who used also data prior to Schwabe's observations as well as later data. The accepted figure for the length of the sunspot period is at present 11·13 years. But a Fourier analysis of all available data has revealed at least three more periods, viz., 8·36, 4·8 and 13·5 years. Not only do the number and the areas of spots show this periodicity, but also the position and the distribution of sunspots over the sun's surface vary in a periodic manner. This was demonstrated by Spoerer who, in 1880, discovered an empirical law, sometimes called *Spoerer's Law*, according to which the mean heliographic latitude of spots from one minimum of the sunspot cycle to the next steadily decreases; this, of course, is in agreement with Carrington's observations mentioned earlier. At a sunspot minimum the solar disc may be entirely free fro mspots for weeks and even months. But broadly speaking, about two years before the occurrence of a minimum some spots begin to appear in the neighbourhood of latitudes 30° north and south; these zones of maximum spot frequency drift towards the lower latitudes and by the time they reach about latitude 16° in both hemispheres, the next maximum of the sunspot cycle occurs. The zones of maximum spot frequency continue to drift towards the equator until the spots completely disappear in the neighbourhood of latitude 3° north and south of the equator. By this time already two more zones of spot activity have appeared in the neighbourhood of latitudes 30° north and south. Thus, at a sunspot minimum there are four spot belts—two near the equator due to the expiring cycle and two more at latitudes 30° north and south belonging to the next cycle. The cause underlying these peculiarities of distribution of sunspots must be intimately connected with the origin of the spots themselves, but at present it must be regarded as one of the unsolved mysteries of solar physics in spite of many attempts at its elucidation, notably those of Bjerknes and Rosseland.

From the practical point of view, the question whether the periodicity of sunspots has any notable influence on the earth is even more important than the problem of the cause of sunspot periodicity. There are undoubtedly several kinds of terrestrial phenomena which are closely associated with sunspots and are characterised by the same periodicity as sunspots. Among such phenomena may be mentioned the auroras, the changes in the earth's magnetic field and the frequency of short-wave radio fade-outs. Various claims to the discovery of a parallelism between sunspot periodicity and the periodicity of other terrestrial phenomena have been made from time to time; some of them may eventually prove to be correct, but at the present state of our knowledge we must regard them as unestablished.

The most obvious characteristic of a sunspot is, of course, its darkness; but this darkness is not of the same type as the darkness of a piece of coal compared to a sheet of white paper. If the light from the rest of the solar disc could be completely screened off, the darkest sunspot would shine as brightly as a powerful arc lamp. It has been found by radiometric methods that the temperature of a sunspot is of the order of 4,500°, while the temperature of the background or photosphere is about 6,000 and, therefore, the darkness of a sunspot is only apparent. This is confirmed also by spectroscopic data, for the spectrum of a sunspot differs from that of the photosphere in exactly the way one would expect considering the difference in temperaturee. For example, a large number of Fraunhofer lines which are strong in the photospheric light are weakened in the spot spectrum, while a number of other lines which are weak in the spectrum of the photosphere become considerably stronger in the spectrum of sunspots. Among these characteristic differences the most outstanding ones are the following: the lines of hydrogen are weaker in the spot spectrum than in the spectrum of the photosphere ; on the other hand, the line due to the neutral calcium atom (4227 A°) is very much more intense in the spectrum of spots than in that of photosphere. These and many other similar differences between the photospheric and spot spectra indicate that the temperature of the sunspot is considerably lower than that of he photosphere. The conclusion is also supported by the appearance in spots of certain molecular band spectra, such as those of titanium oxide, calcium and magnesium hydrides, which are scarcely perceptible or even non-existent in the spectrum of the photosphere.

Apart from the information regarding the physical state of matter in sunspots, the spectrograph and its variant, the spectroheliograph, have yielded information regarding the state of motion of the material of sunspots which is quite inaccessible to the ordinary telescope visual or photographic. Fig. 3 is a photograph by Mt. Wilson Observatory of a portion of the sun's surface containing a pair of spots taken in H-alpha light with the help of a spectroheliograph. A glance at the figure shows that there are curved formations strongly suggestive of spiral motion and strikingly reminiscent of the lines of force in the neighbourhood of a pair of magnetic poles. The occurrence of such remarkable features in spectroheliograms made Hale suspect that a sunspot might be a variable magnetic pole and that it might at the same time be a gigantic whirl in which electrified particles were in a state of circular motion thereby causing a magnetic field. In 1908 Hale confirmed his suspicion by his brilliant discovery that many lines of the spot spectrum show widening and even doubling or tripling similar in every way to Zeeman-effect. He also proved that in a spot pair (which is the common type of spot formation) the two constituents have opposite polarities. The intensity of the magnetic field varies from one spot to another; in some spots fields up to 4,000 gauss have been observed. The measurement of such weak fields by means of the Zeeman-effect is naturally a very difficult process, so that our knowledge about many important questions concerning the magnetism of sunspots, such as the direction of rotation and the sign of the charge of the electrified particles supposed to be responsible for the magnetic field, is necessarily very meagre. Our knowledge of motion of matter in sunspots, however, made a great step forward when Mr. Evershed at Kodaikanal Observatory made the discovery known as the Evershed-effect which ranks as one of the outstanding contributions to solar physics. In 1909 Evershed showed that in the lower levels of sunspots there is a movement of matter in a direction radially away from their centres and parallel to the sun's surface. He also found that this movement from the umbra towards the exterior is accelerated and attains a speed of about 2 km/sec. at the outermost edges of the penumbra. Evershed's discovery was followed by the works of St. John at Mt. Wilson Observatory who confirmed Evershed's conclusions and showed besides that in the higher levels of spots the movement of matter is precisely the opposite; i.e., matter flows towards the centre of the spots. The general picture (Fig. 4) of the motion of matter in sunspots which emerges from the researches of Evershed and St. John is that above a certain level in the

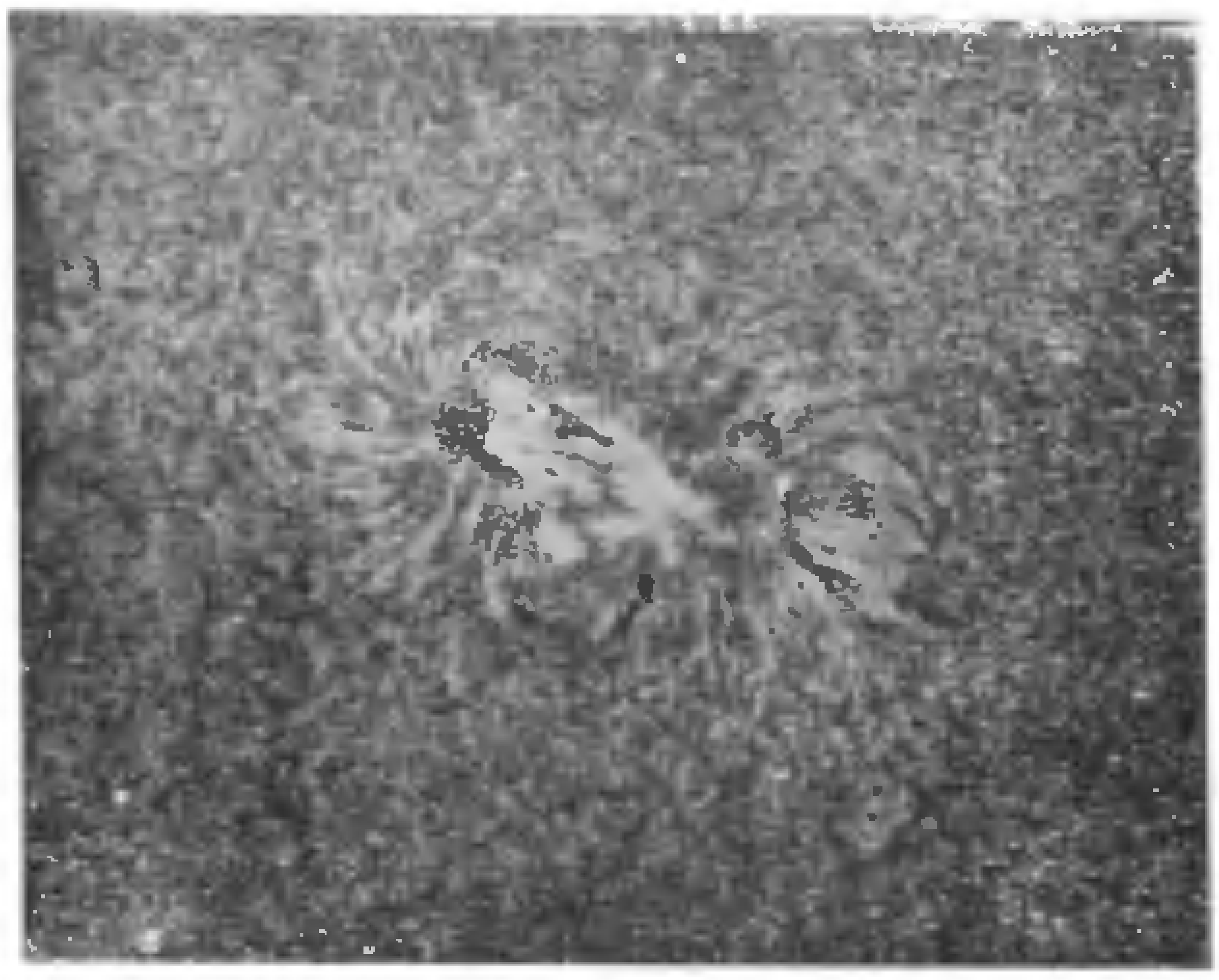

FIG. 3

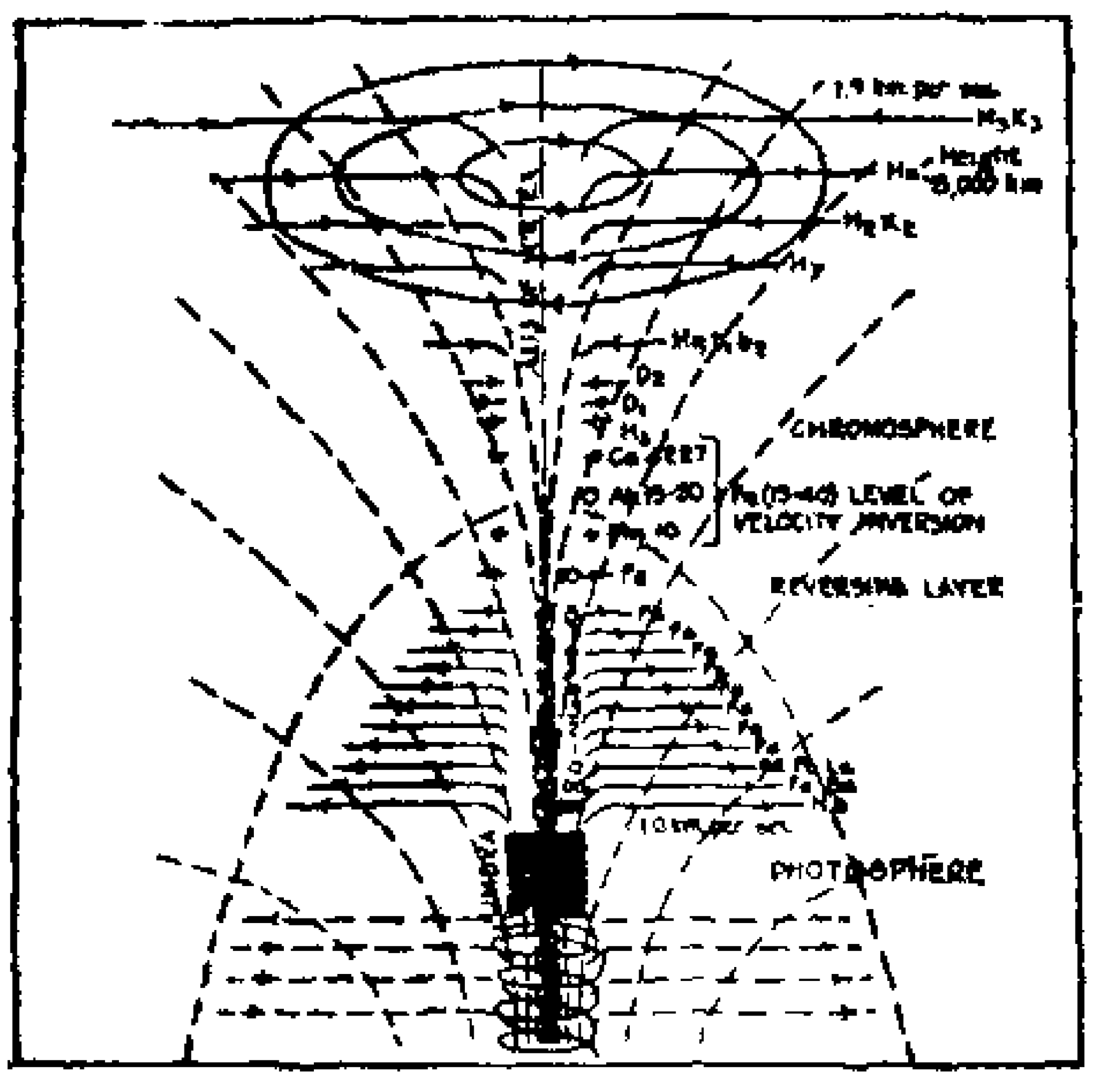

FIG. 4

interior of a sunspot (which may be called the inversion level) the motion is inwards (that is, towards the axis of the spot) and downwards, the speed increasing with height above the inversion level where the velocity is zero; while below the inversion level the motion is outwards and upwards, the speed increasing with distance below the inversion level. Thus although even in scientific literature sunspots are often likened to terrestrial cyclones on a gigantic scale, the motion of matter in a sunspot is the very opposite of what one finds in a terrestrial cyclone. Indeed the motion of matter in sunspots is very complex and although some of its details have been revealed by spectroscopic technique a great many more have yet to be discovered before one can hope to unravel the mysteries of the origin and the maintenance of these whirlpools of immense dimensions.

D.D.T., 666 AND INSECT PESTS OF STORED GRAINS

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THE axiom 'Necessity is the mother of invention' holds true, especially during the days of war when problems not seriously attended to before are solved quickly. The Entomologists too kept pace with other scientists in the second World War and were able to demonstrate the utility of substances like Dichloro-diphenyl-trichloroethane (D.D.T.) and Benzene hexachloride (666) for the control of insect pests. These substances have been known from 1874 and 1825 respectively and are highly poisonous to insects but are not so to animals and as such are undoubtedly of great value in the control of insects infesting fruits, vegetables and stored grains. The low volatility of these substances unlike naphthalene and camphor, keeps them effective for a longer period. Thus they embody one of the important properties which an ideal insecticide should possess. Another advantage which renders them the champion of all insecticides is that they act both as stomach and contact poisons and are insoluble in water. They dissolve readily in petroleum oils and do not react with strong acids, however, the alkalies do affect their composition but alkalies in traces as found in dry ashes, coal ash clinker, lime, etc., have little deleterious effect upon their efficiency at room temperature; this was ascertained from mixing experiments where different dusts were used for diluting these insecticides. They act as nerve poisons affecting the muscles and causing death by paralysis.

Benzene hexachloride is non-poisonous to human beings and animals in quantities recommended against insects. Recently Dr. Slade stated that the 'gamma' isomer of benzene hexachloride known as 'Gammexane' is about five times more toxic than D.D.T. and that 30 milligrams of 'Gammexane' per day for five weeks or 100 milligrams of the mixture of isomers for two months could be fed to rats without any untoward effect, while the actual amount of 'Gammexane' required to give 50 per cent. kill in six days in case of *Calendra oryzæ* was 0·7 parts per million of the weight of grains. Although there appears to be little or no danger to animals by the use of 666, care must be exercised in handling it. D.D.T. on the other hand is somewhat toxic to animals and hence needs special care in treating materials meant for human consumption. Prolonged smelling of the two substances causes giddiness and the brain gets fagged, but these conditions disappear in three to four days' time. The substances when handled in the form of solutions in vegetable oils without proper precautions, get absorbed through the skin and cause slight shivering of the portion of body which remains exposed for a longer period.

As regards insects, the effect was noticed to be greatly pronounced in case of adults of *Sitotroga cerealella* and *Corcyra cephalonica*. The moths soon after coming in contact with the treated grains, appear very much disturbed and excited. They struggle in vain to penetrate deep into the grains. The whole body appeared to be shivering till the insects found apparently dead were seen with their genitalia pulled out and moving in a characteristic fashion.

In coleopterous insects, the effect in its initial stages is in the form of 'paresis'. The senses are benumbed and the legs are paralysed first and rendered of little use to have firm hold on any object. The effect is more pronounced in case of *C. oryzæ* and *Bruchus affinis* where the wings also get paralysed and shortly after the stupor increases considerably. The insects behave somewhat like an intoxicated man; they stagger and fall frequently as the 'paresis' increases. The insects are incapable of feeding