CHAPTER 10

SUNSHINE

10.1 GENERAL

The routine measurement of the recorded duration of bright sunshine, either in hourly or daily totals, is required from some stations for climatological purposes. The type of sunshine recorder approved and used by the Meteorological Office utilizes the heat from the sun's rays, focused by a solid glass sphere to an intense spot, to char a trace on a specially manufactured card. This was originally known as the Campbell–Stokes recorder.

For accuracy in both recording and measuring sunshine duration from an exposed card it is necessary for sunshine recorder to be correctly installed and adjusted. Full details are given in I.10 of Appendix I (page 190). It is essential that the recorder should be mounted on a rigid support, such as a concrete or brick pillar, so that any necessary adjustments may be considered reasonably permanent.

The Meteorological Office sunshine recorder Mk 2 was designed for use in latitudes between 45° and 65°, north or south. It has gradually been superseded by the Mk 3C. The Mk 3B is for use specifically between latitudes 25° and 45°, north or south. The Mk 3A recorder is for use generally in latitudes within 40° of the equator.

10.1.1. Sunshine recorder Mk 2 (Plate XXIX) has a main base on which the instrument is mounted. The base has three lugs which are drilled to take screws for fixing purposes. Carried on the main base is a sub-base, consisting of a triangular plate, which in turn carries the bowl mounting and the seating for the glass sphere. The sub-base is supported on three adjusting screws so that it can be levelled accurately, and provision is made for it to be moved relative to the main base over a small range of azimuth. The solid glass sphere is seated on a cup on the top of a short pillar which is adjustable over small ranges of level and azimuth, permitting the glass sphere and bowl to be concentrically positioned. The card is held in one of three sets of overlapping grooves, one set appropriate to winter, another to summer, and a third to the equinoctial periods. The sunshine cards are held firmly in position by means of a clamping screw which is attached to a chain to prevent loss. The bowl is supported on a bracket which is slotted to provide an adjustment for latitude. A sphere-retaining clip can be fitted to prevent the displacement of the sphere by high winds or by other means, e.g. by large birds.

10.1.2. Sunshine recorders Mk 3A, 3B and 3C each consist of a solid glass sphere mounted concentrically within a portion of a spherical bowl (Mk 3C is illustrated in Plate XXX). The sphere support is a semicircular brass bar of nearly rectangular cross-section, attached symmetrically to the back of the bowl and concentric with it. The sphere is held by means of two brass screws, one fitted into a cup-shaped boss and the other fitted into a ball-ended boss, diametrically opposite on the sphere. Three overlapping pairs of grooves in the bowl accept the three types of sunshine card, the cards being secured by a clamping screw. The arc sphere support is mounted in a grooved slide to permit adjustment for latitude, and the slide is mounted on a T-shaped metal base which is supported for levelling on a fixed metal sub-base. The sub-base has three lugs which are drilled to take screws for fixing purposes.

10.2. SUNSHINE CARDS

There are three types of card; the type to be used varies with the season of the year, but otherwise any card is appropriate to any latitude and to any Mark of recorder. Figure 16 shows a cross-section of the bowl, and indicates the grooves to be used at a particular time of the year.

In the northern hemisphere the cards are used as follows:

(*a*) Long curved cards during the summer, from 12 April to 2 September inclusive; the card is inserted, with its convex side uppermost, beneath the flanges which are marked 'summer card' in Figure 16.
Note. At latitudes of 25° or less, the long curved summer cards are trimmed at each end (as instructed on the back of card) before insertion into the recorder.

(*b*) Short curved cards during the winter, from 15 October to the last day of February inclusive; the card is inserted, with its concave edge uppermost, beneath the flanges which are marked 'winter card' in Figure 16.
Note. At latitudes greater than 40°, the short curved winter cards are trimmed at each end (as instructed on the back of the card) before insertion into the recorder.

(*c*) Straight cards about the times of the equinoxes, from 1 March to 11 April inclusive, and again from 3 September to 14 October inclusive; the card is inserted beneath the central pair of flanges which are marked 'equinoctial card' in Figure 16. When inserting the equinoctial card, care must be taken to see that the hour figures are the right way up (otherwise the morning sunshine will be recorded on the portion of the card intended to receive the afternoon record, and vice versa).

In the southern hemisphere the short curved cards are for use in the winter period, 12 April to 2 September, and the long curved cards during the summer period, 15 October to the last day of February.

Before bringing a new type of card into use it is advisable to clean away any dirt which may have accumulated in the grooves into which the card will be placed.

10.3. CHANGING THE CARD

A new card is inserted into the recorder bowl each day, even when there has been no sunshine during the past 24 hours. If, after rain, the old card cannot be withdrawn without tearing it, it should be cut out carefully by drawing a sharp knife along the edge of one of the flanges.

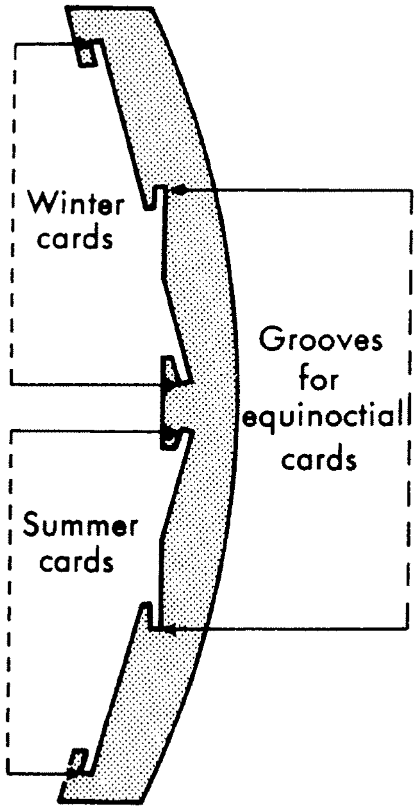

Figure 16. Cross-section of a sunshine bowl

Ideally, the card is changed between sunset and sunrise; at stations where this done the following details are entered on the back of the card before insertion: the station name, year, month, and date of the following day. No other entries are required.

At many climatological stations the cards are changed during the day, either at 0900 GMT or (at Health Resort stations) at 6 p.m. clock time. Practices at these stations are:

(*a*) If the sun is shining at changing time, make a pencil mark from the sun's image to the lower edge of the old card before removing it.

(*b*) Slacken the clamping screw, remove the card by a sliding action along the grooves, and enter the date and time OFF on the back.

(*c*) On the back of the new card enter the station name, year, month, date and time ON. Insert the new card by sliding it along the appropriate grooves and adjust the 12 time line to coincide with the noon line engraved on the bowl, then tighten the clamping screw.

(*d*) If the sun is shining, make a pencil mark from the sun's image to the upper edge of the new card.

The pencil marks on the old and the new cards are to help in allotting the two parts of the burn to the appropriate day, and to identify any overlap of the burns.

10.3.1. Local Mean and Local Apparent Time. It should be noted that the time indicated by the image of the sun on the sunshine card does not, in general, coincide with an hour line printed on the card. This apparent discrepancy arises for the following reasons. When the centre of the sun is due south of an observer the time is called 12 hours or noon, Local Apparent Time (LAT). The sun is said to 'transit' at this time, and the interval between two consecutive transits is conventionally divided into 24 equal parts. However, the orbit of the earth is elliptical and so the time interval between successive transits is not in fact constant throughout the year. Since it is inconvenient to have a 'day' of variable length for most practical purposes, a constant day has been defined for a mean sun whose apparent motion round the earth is uniform throughout the year. Time in this day of constant length is designated Local Mean Time (LMT); LMT at the Greenwich meridian is called Greenwich Mean Time (GMT). The difference in time between the earth's true behaviour and its conventional mean behaviour is expressed in terms of the 'equation of time'. Local Mean Time is obtained from Local Apparent Time by adding or subtracting the 'equation of time'; this varies from about −15 minutes in mid-February to about +17 minutes in mid-November for the observer on the Greenwich meridian.

Table III on page 208 gives the time GMT at which the sun will be due south (local apparent noon) at a particular longitude, east or west of Greenwich, on a particular date.

10.4. MEASURING THE TRACE

The correct method of measuring the daily duration of sunshine recorded on a card is to place the edge of a reversed card of the same type along the length of the burn and to mark on it lengths equal to those of the successive burns. The card is moved along the trace so that the lengths are added automatically, the line marking the end of one burn being used to mark the beginning of the next. The total duration is then read off on the time scale of the measured card (special care being taken to make the measurement at the same level as the burn). When the burn is not parallel to the edges of the card, because of a faulty adjustment of the recorder, the measurement should be made at the level of the trace at noon.

10.4.1. Days of broken sunshine. On a day of broken sunshine the measurement is complicated because of the spread of the burn. When the sun is shining brightly the scorch is not a fine line but a broad burn up to 3 mm wide. This spreading exaggerates the duration of short bursts of sunshine and some allowance must be made for this when measuring the record. The separate burns have rounded ends and the standard practice is to measure from a point about half-way between the centre of curvature and the extreme visible limit of the burn (see Plate XXXI).

10.4.2. Small circular burns. Small circular burns may be caused by very short bursts of sunshine, sometimes lasting for as little as two or three seconds. Such burns, which on close examination show no signs of elongation, should be ignored unless they constitute the only record on an otherwise blank card, in which case a daily total of 0·1 hour should be recorded. Thus a tabulated daily total of 0·1 hour means that the day was not entirely sunless, rather than that the duration was one-tenth of an hour.

It is sometimes difficult to decide whether or not a small burn is truly circular. In most cases when the card is burnt right through it will be found, on closer inspection, that the burn is in fact slightly elongated. When a burn appears to be made up of a series of small circular burns joined together, it should nevertheless be measured as a continuous burn, provided of course that no uncharred card is included in the measurement.

10.4.3. Faint burns. On a day of uninterrupted sunshine the trace is a continuous burn, tapering off at the ends. This tapering off occurs because there is only a slow increase in the burning power of the sun's rays after sunrise, with a corresponding decrease before sunset. In these circumstances the measurement should be taken to the extreme ends of the tapering burn; the whole of the brown trace should be measured as far as it can fairly be seen. It should be noted that a slight discoloration of the card to light blue does not indicate bright sunshine and should therefore be ignored.

On occasions when the intensity of sunshine is diminished by haze, thin cloud or mist, periods of sunshine may be recorded as faint brown scorches similar to those seen at the ends of a record near sunrise and sunset. Because there is no spread of the burn on these occasions, the whole of each brown trace should be measured as far as it can be seen.

Under conditions of continuous weak sunshine it is possible for apparent breaks in the recorded trace to occur when the burn crosses an hour line printed on the card: these gaps should be ignored.

10.4.4. Hourly amounts. Certain stations are required to measure hourly amounts of sunshine and to tabulate them on Metform 3445. The rules in previous paragraphs should be followed, subject to the following additions. Measurements should be made in tenths of an hour and entered on the form in accordance with the instructions printed on it.

The daily totals should be obtained by the method described at the beginning of this section (page 156), not by adding up the hourly amounts. If necessary, the hourly amounts should then be adjusted so that their sum agrees with the daily total, but in carrying out any adjustments the following restrictions should be observed.

(*a*) Completely sunless hours and hours of unbroken sunshine should be left unadjusted.

(*b*) Hours with breaks amounting to less than one-tenth of an hour should NOT be rounded up to a whole hour: they should be tabulated as ·9.

Any adjustment should then be distributed among the remaining hours having incomplete burns, in approximate proportion to their sunshine duration.

Small circular burns are ignored unless they are the only record on an otherwise blank card. In such cases the daily total is recorded as 0·1 hour, and the entry is credited to the hour in which the greatest number of circular burns occurred. If this greatest number occurred in more than one hour, the entry is credited to the hour with the most prominent burn.

10.4.5. Checking the measurements. Consistency checks are made on all sunshine data returned to the Meteorological Office. When problems arise from either overestimates or underestimates, guidance on the correct procedures to be followed is offered to the observer concerned.

10.5. WRITING UP THE CARDS

The name of the station and the date (day, month, year) will already have been written on the back of the card. At stations where the card is changed after sunset the measurement of duration is entered in either of the two spaces provided.

10.5.1. At stations where the card is changed between sunrise and sunset, usually at 0900 GMT, the following procedure should be followed:

(*a*) Measure the amount of sunshine recorded between sunrise and time off; (the time off should have been marked with a pencil line below the trace if the sun was shining at the time). Turn the card over and enter this amount on the back in the left-hand space provided.

(*b*) Measure the duration from time on (pencil mark above the trace) to sunset. Reverse the card again and enter this duration in the right-hand space provided.

After measurement, each card will bear two amounts, each with the date to which they refer. Daily totals for entry on return forms are then obtained by adding the parts from two cards appropriate to a particular date.

10.5.2. At stations where the card is changed after sunset, but measurements of sunshine are required from sunrise to 6 p.m. clock time, and from 6 p.m. till sunset, the following routine is carried out.

When the sun is shining at 6 p.m. the position of the image of the sun is marked on the card by means of a short pencil line so that portions of the trace before and after 6 p.m. are clearly differentiated. (Since the time indicated by the recorder is Local Apparent Time, this line will not usually coincide with the printed hour line, 18 or 17, on the card.) If the two amounts are entered separately on the reverse of the card, only one date should be entered: the date on which the sunshine occurred.

10.6. CARE OF THE RECORDER

Once the instrument has been installed and properly adjusted it requires little attention beyond changing cards each day. The glass sphere should be cleaned with a soft lint-free cloth whenever necessary, and not with any material likely to abrade the surface. Excessive vigour in polishing should be avoided; impairment of the surface due to excessive polishing may result in a substantial loss of record in weak sunshine. The sphere of the Mk 2 recorder can easily be removed for cleaning. If the sphere of a Mk 3 recorder has to be removed, care must be taken to unscrew only the female (socketed) screw; if both screws are loosened the concentricity of the sphere and bowl may be lost.

The recorder should be examined each morning and any deposit, such as snow, frost, dew, bird-droppings, should be removed immediately. Hard deposits should never be chipped off since the sphere may become scratched or

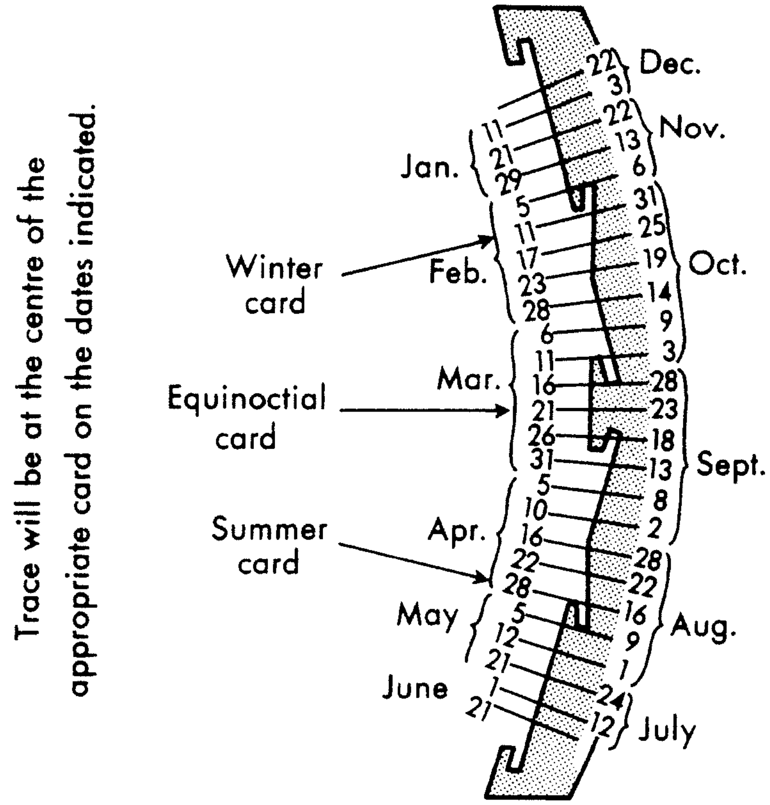

Figure 17. Diagram showing position of sunshine trace at different times of the year when the latitude setting of the instrument is correct

pitted. An aerosol of windscreen de-icing fluid is recommended for defrosting the sphere which is then wiped clean. The need for adjustment may arise owing to the settlement or warping of the support and will be necessary if

(*a*) the trace is not parallel to the centre line of the card, or

(*b*) the trace is either too high or too low on the card when compared with the position of the trace on Figure 17.

Fault (*a*) is most likely to be due to an error in the level in the east–west direction. Check this first and correct the level as necessary by means of the front levelling screws. If this level is, however, found to be correct, then the fault must be due to an error in the meridian adjustment.

Fault (*b*) can be caused by incorrect latitude setting or by the recorder being out of level in the north–south plane. If the latitude setting is correct for the station, check that the sub-base is level in the north–south plane with the aid of a spirit level (a machined flat is provided on the sub-base for this purpose) and adjust by means of the rear levelling screw only. If any adjustment to either the latitude setting or the north–south level is made, it is essential to check the east–west level again.

The adjustments necessary to correct either or both of these faults are explained in I.10.3 of Appendix I (page 195). Observers are warned particularly against attempting to correct a faulty record on the card by altering the centralizing of the sphere. If an error of centralizing is suspected, the matter should be reported to the Meteorological Office which, if necessary, will make arrangements for the adjustment to be checked and corrected.

CHAPTER 11

SPECIAL PHENOMENA

11.1. GENERAL

A number of interesting luminous phenomena, for which the generic term 'photometeor' has been adopted, some special clouds and the two electrometeors, aurora and St Elmo's fire, are described in this chapter.

The *International cloud atlas* defines a photometeor as 'a luminous phenomenon produced by the reflection, refraction, diffraction or interference of light from the sun or moon'. Photometeors may be observed in more or less clear air (mirage, shimmer, scintillation, green flash and twilight colours), on or inside clouds (halo phenomena, coronae, irisation, glory) and on or inside certain hydrometeors* or lithometeors* (glory, halo phenomena, coronae, rainbow, Bishop's ring and crepuscular rays).

Refraction is a process which involves the bending of light when it passes through media of different densities. Since the degree of bending is wavelength-dependent, some separation of individual wavelengths will occur and, in the case of white light, sometimes results in the display of its constituent colours.

Diffraction is a phenomenon whereby the spectrum of colours is observed in the geometrical shadow of an obstacle. It is caused by the differential bending of the constituent wavelengths of white light which results in the spectrum. It is explained by the wave theory of light and not by the simple assumption that light travels in straight lines. Diffraction gives rise to several phenomena (see 11.2.8 to 11.2.11) arising from either a suspension of dust or water drops in the atmosphere.

Some of the phenomena described, such as the rainbow and the halo of 22°, are quite common; others are rare. An observer who is fortunate enough to see phenomena of the latter class is encouraged to make as accurate and as detailed a record as possible, including any measurements, sketches or photographs (see 11.6). Any phenomenon thought to be of exceptional interest should be reported to the Meteorological Office (Met O 15).

11.2. PHOTOMETEORS

11.2.1. Halo phenomena: a group of optical phenomena in the form of rings, arcs, pillars or bright spots produced by refraction and reflection of light by ice crystals suspended in the atmosphere (cirriform clouds, diamond dust etc.).

These phenomena, when formed by the refraction of light from the sun, may show colours, but halo phenomena produced by the light of the moon are

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*Hydrometeors and lithometeors are defined in 4.2.1 and 4.2.2, pages 58 and 63.

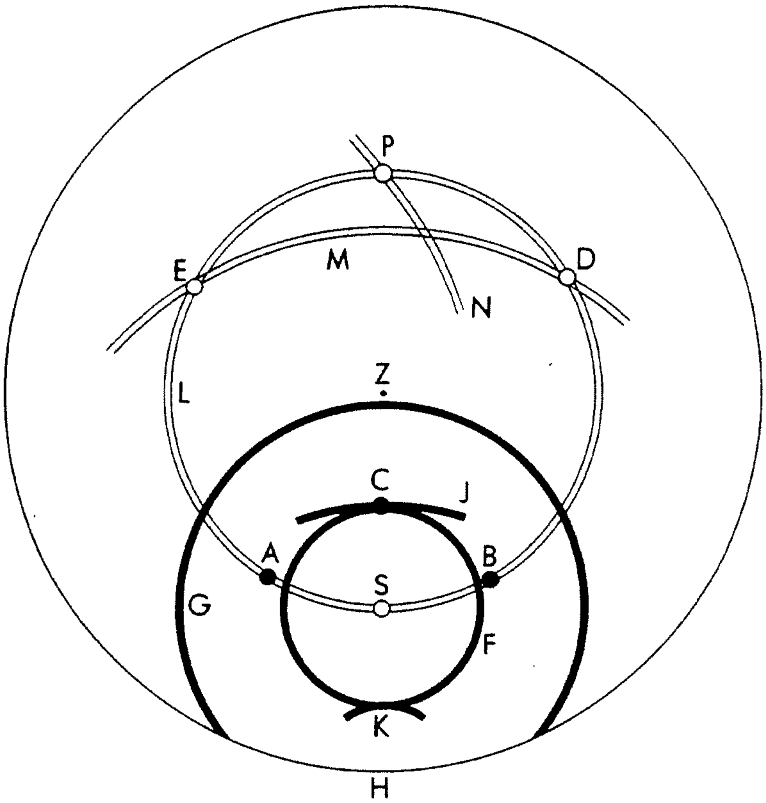

Figure 18. Halo phenomena

An unusually complete halo display seen about midday on 6 March 1941 in the west Midlands; composite diagram based on observations from various localities.

Appearances due to refraction, which may be brilliantly coloured, as on this occasion, are shown black; appearances due to reflection, which are always white, are shown by the finer lines. The outer circle, H, is the complete horizon, with Z, the zenith, in the centre; S is the sun, P the anthelion, A, B, C, D, E are parhelia or mock suns; F is the 22° halo, G the 46° halo, J and K are upper and lower arcs of contact of F; L is the parhelic circle or mock-sun ring (parallel to the horizon), M the arc through the mock suns at 120° (usually a pair of arcs not joined in the middle), and N the oblique arc through P (one of a symmetrical pair which may sometimes be seen together).

always white. The many different kinds of halo which have been observed are shown in Figure 18 which is a composite diagram made up from a number of drawings of an unusually complete halo display seen about midday on 6 March 1941 in various localities in the west Midlands.

11.2.1.1. *Halo of 22°* (small halo) is the most frequent halo phenomenon and appears as a luminous ring, F in Figure 18, with the sun or moon, S, at its centre and having a radius of 22° of a great circle (90° is the measurement of the arc extending from the zenith to the horizon). The space within the ring appears less bright than that just outside. The ring, if faint, is white; when more strongly developed it shows coloration: the edge nearest the sun is red and this is followed by yellow and, in some rare cases, a green or violet fringe can be detected on the outside.

The angle of 22° is the angle of minimum deviation for light passing through a prism of ice with faces inclined at 60°, and this halo is probably due to the refraction of light through hexagonal prisms among ice crystals in cloud.

11.2.1.2. *Arcs of contact to the 22° halo.* Tangent arcs are sometimes seen on the outside of this halo at its highest and lowest points. The lower arc of contact (K in Figure 18) is very rare; the upper arc, J, is more common. Both may be reduced to a bright spot at the point of contact. Depending on the altitude of the sun, the arcs present either their convex sides to the sun (low solar elevations) or their concave side (high solar elevations) and are generally very luminous and may display brilliant colour effects.

It is very rare indeed for the upper and lower arcs to join to form an elliptical circumscribing halo or for two further arcs of contact to appear at the sides of the 22° halo.

11.2.1.3. *Halo of 46°* (large halo). This large halo (G in Figure 18) is occasionally seen, though it is seldom complete. It is much less common than the halo of 22° and is always less bright. This halo also has arcs of contact; in fact these arcs occur more frequently than the halo itself and are sometimes mistaken for it. This halo requires crystals with faces at right angles.

11.2.1.4. *Parhelic circle* (the mock-sun ring). Occasionally a white ring which passes through the sun parallel to the horizon may be recognized. This is called the parhelic circle or the mock-sun ring and is shown in Figure 18 in its rare complete form, L. The minor arc, passing through the sun to the points of intersection with the 22° halo, may at times be distinct, faint or invisible when the major arc, or parts of it, can be clearly seen. Bright spots may be observed at certain points of the parhelic circle. These bright spots occur most commonly a little outside the halo of 22° (parhelia, at A and B), occasionally at an azimuthal distance of 120° from the sun (paranthelia, at E and D) and, very rarely, opposite the sun (anthelion, at P). When they are particularly bright they are called mock suns.

The corresponding phenomena produced by the moon are called paraselenic circle, paraselenae, parantiselenae, and antiselene; when they are bright they are called mock moons.

Mock suns shown at A and B in Figure 18 are very luminous and brilliantly coloured. Red is on the side nearest to the sun, with yellow, green, blue and violet following; the blue is generally indistinct and the violet usually too faint to be distinguished. These mock suns are situated approximately on the 22° halo when the sun's altitude is 10° or less; with increasing altitude they are formed further outside the halo, being 14° outside when the sun's altitude is 55°. They cannot be formed when the sun's altitude exceeds 60° 45′. They lie on the parhelic circle which may or may not be visible at the time. Mock suns at E and D are white. The image of the sun occasionally observed at P is a brilliant white and is sometimes termed the 'counter-sun'.

Through the mock suns D and E, two separate arms, the paranthelic arcs, may rarely be seen and they are sometimes (though very rarely) observed to join and appear to form the continuous arc M. The oblique arc N, through the anthelion P, is one of a pair; on some occasions one may be seen clearly while the other is invisible. These arcs, being caused by reflection, are white.

11.2.1.5. *Halo of 90°*. A fourth ring, the halo of 90°, is exceedingly rare; it is not shown in Figure 18. The ring is white and cannot be seen in its entirety unless the sun is at the zenith.

11.2.1.6. *Circumzenithal arc.* Occasionally the upper and lower circumzenithal arcs may be observed; they appear to lie in horizontal planes. The upper circumzenithal arc (brightly coloured, with red on the outside and violet on the inside) is a rather sharply curved arc of a small horizontal circle near the zenith; the lower circumzenithal arc is a flat arc of a large horizontal circle near the horizon. The upper arc occurs only when the angular altitude of the luminary is less than 32°; the lower arc occurs only when the angular altitude of the luminary is more than 58°. The upper arc touches the large halo, if visible, when the angular altitude of the luminary is about 22°; the lower arc touches the large halo when the angular altitude of the luminary is about 68°. The arcs become increasingly separated from the large halo as the angular altitude of the luminary departs from the above values. Circumzenithal arcs may be observed without the large halo being visible.

11.2.1.7. *Sun pillar.* This may be seen occasionally, particularly at sunrise or sunset, and will frequently extend about 20° above the sun and generally ends in a point. At sunset it may be entirely red, but is usually a blinding white and shows a marked glittering. If the sun is high in the heavens the pillar may appear as a white band vertically above or below the sun, but it will not be very brilliant and is often short. Occasionally, however, these white columns appear simultaneously with a portion of the white mock-sun ring, and so form another remarkable phenomenon, the cross. Sun pillars are due to reflection of sunlight from ice crystals.

11.2.1.8. *The undersun.* This is a halo phenomenon produced by reflection of sunlight on ice crystals in cloud. It appears vertically below the sun in the form of a brilliant white spot, similar to the image of the sun on a calm water surface. It is necessary to look downward to see the undersun; the phenomenon is therefore only observed from aircraft or from mountains.

11.2.2. Rainbows: a group of concentric arcs with colours ranging from violet to red, produced on a 'screen' of water drops (raindrops, droplets of drizzle or fog) in the atmosphere by light from the sun or moon.

This phenomenon is mainly due to refraction and reflection of light. When rainbows are produced by the sun their colours are usually brilliant; when produced by the moon their colours are much weaker or sometimes absent.

A primary rainbow is a coloured bow which appears on a 'screen' of water drops when light from the luminary falls upon them. The coloured bow is opposite the luminary by which it is produced and its centre is on the extension of the line joining the luminary and the observer. Thus the rainbow may form a complete ring when seen from an aircraft. Close inside the primary bow there may appear one, two or more supernumerary bows with the colours in the same order but with each inner bow becoming progressively much fainter. These supernumerary bows, usually narrow with green, violet or orange colours, are due to interference, and on rare occasions may also occur outside the secondary bow (see below).

It is rarely that all the 'colours of the rainbow' (red, orange, yellow, green, blue, indigo and violet) are observed. The size of the drops or droplets determines which colours are present and the width of the band occupied by each of them. Drops larger than 1 mm in diameter yield brilliant bows with violet on the inside (radius of the arc 40°) and red on the outside (radius of the arc 42°). With drops about 0·3 mm in diameter the outside limiting colour is orange, and inside the violet there are bands in which pink predominates. With smaller drops supernumerary bows appear to be separate from the primary bow. With still smaller drops about 0·05 mm in diameter the rainbow degenerates into a white fogbow with faint traces of colour at the edges. The variations of colour with drop size are due to diffraction. No primary bow can form if the altitude of the luminary is higher than 42°.

Outside the primary bow there may be a secondary bow, much less bright than the primary and with a breadth about twice that of the primary. The red is on the inside (radius of the arc 50°) and the violet is on the outside (radius of the arc 54°). No secondary bow can form if the altitude of the luminary exceeds 54°.

Reflection rainbows are occasionally seen on calm days when a sheet of water lies in front of or behind the observer when standing with his back to the sun. Such bows are formed by rays of light illuminating the falling raindrops after reflection at the surface of a sheet of water. The centre of a reflection above is thus as high above the horizon as the sun, or the same angular distance above the horizon as the centre of the direct bow is below the horizon; consequently the arc, when complete, exceeds a semicircle. The direct and reflection rainbows intersect on the horizon, and the colours have the same sequence.

11.2.3. Mirage: an optical phenomenon consisting mainly of steady or wavering, single or multiple, upright or inverted, vertically enlarged or reduced, images of distant objects.

Mirages are produced by refraction of light in the layers of air close to the earth's surface due to large temperature gradients in the vertical and associated changes of refractive index. Objects seen in a mirage sometimes appear appreciably higher or lower above the horizon than they really are; the difference may amount to as much as 10°. Objects located below the horizon or hidden by mountains may become visible ('looming'); objects which are visible under normal circumstances may disappear during the occurrence of a mirage.

An inferior mirage (or lower mirage) may occur over a flat strongly heated surface, for example a desert, and may often be seen over road surfaces heated by the sun. Rays of light from distant objects, impinging on the heated surface at grazing incidence, are bent upwards in traversing the strongly heated layer of air on the surface, just as if they were reflected by a mirror lying horizontally on the surface. An inverted image of the object is therefore seen and the illusion of a sheet of water is created. The images are often elongated vertically or otherwise distorted.

A superior mirage (or upper mirage), in which the light rays are bent downwards from a warm stratum of air resting on a colder one, is seen most frequently in polar regions. The distances involved are greater, so that the details can hardly be observed without telescopic aid. With such assistance a distant ship, for instance, may sometimes be seen in triplicate, one of the images being inverted. As the stratification which produces a superior image is stable, the images are clear and well defined in contrast to the shimmering images of the inferior image.

The images produced by a superior mirage are not always exactly in the same vertical. The separation is explained by a slight departure of the strata of equal density from horizontal planes. Lateral refraction of this kind is to be distinguished from the phenomenon which can be observed sometimes near a heated wall when objects appear to be reflected in the wall.

Fata Morgana is a complicated form of mirage in which multiple images of an object are produced by several layers of air of different refractive indices.

11.2.4. Shimmer: the apparent fluttering of objects at the earth's surface, when viewed in the horizontal direction.

Shimmer occurs chiefly over land when the sun is shining brightly. It is due to short-period fluctuations of the refractive index in the surface layers of the atmosphere. Shimmer may reduce the visibility appreciably.

11.2.5. Scintillation: rapid variations, often in the form of pulsations, of the light from stars or terrestrial light sources. Scintillation, or twinkling, is the more or less rapid change of apparent brightness of a star, sometimes accompanied by colour changes at altitudes less than about 50°. It is due to minor variations in the refractive index of the atmosphere, mainly in the low atmosphere. The amount of twinkling is always greatest towards the horizon and least at the zenith.

Scintillation is also observed in terrestrial lights. Shimmer seen near the ground on a hot day is akin to it.

The bright planets do not usually appear to twinkle as they have discs of definite size. Each point on the disc twinkles independently of the others, so that on the average the light is steady.

11.2.6. Twilight colours: various colorations of the sky and of the peaks of mountains at sunrise and sunset.

Twilight colours are produced by refraction, scattering or selective absorption of light rays from the sun in the atmosphere.

When clouds, particularly high-level and middle-level clouds, occur about the time of sunset or sunrise, or in bright twilight, their coloration is often very beautiful, The cloud colours are mainly shades of orange, rose or red, since the direct sunlight illuminating the cloud has passed through a great length of the lower layers of the atmosphere. Shades of purple are sometimes seen, since a cloud may at the same time be indirectly illuminated by scattered blue light from higher atmospheric levels.

Colour phenomena also occur in a cloudless sky during the twilight periods. These vary considerably and are best developed in arid or semi-arid land regions. Some of those which occur most commonly everywhere are mentioned here. The *primary twilight arch* appears, after the sun has set, as a bright but not very sharply defined segment of reddish or yellowish light resting on the western horizon. After the sun has set, a pink or purple glow may be seen covering a considerable part of the western sky; this is the *first* *purple light*. It reaches its greatest extent and luminance when the sun is about 4° below the horizon, and disappears when it is about 6° below.

At sunset, a steely-blue segment, darker than the rest of the sky, begins to rise from the eastern horizon. This is the shadow of the earth thrown by the sun on to the earth's atmosphere. The *earth shadow* is bordered by a narrow band of rose or purple colour, called the *counterglow*. The whole rises fairly quickly in altitude, the shadow encroaching on the counterglow and soon obliterating it. With increasing general darkness the edge of the shadow weakens, but may sometimes be traced up to its passage through the zenith. In the later stages of twilight, this shadow edge comes down nearly to the westerly horizon, leaving a slightly more luminous segment between it and the horizon; this is the *secondary twilight arch*. Just before the ending of astronomical twilight (which ends when the sun's centre is 18° below the horizon), it is sometimes seen as a fairly well-defined whitish arch on the horizon, with an altitude of only a few degrees at its apex. This might be confused with an auroral arc visible at very low altitude.

Other colours are often seen in the cloudless twilight sky, portions of which may be green, yellow, orange, or red, according to the amount of dust and water vapour present in the air. Instead of the purple light after sunset, the sky very often shows some shade of clear green, probably when the air is relatively free from dust.

Analogous phenomena, in the reverse order, occur before sunrise.

11.2.7. Alpine glow: a series of phenomena seen in mountainous regions about sunrise and sunset. Two principal phases are generally recognized:

(i) The true alpine glow. At sunset the phase begins when the sun is 2° above the horizon; snow-covered mountains in the east are seen to assume a series of tints from yellow to pink, and finally purple. As this phase is due mostly to direct illumination by the sun, it terminates when the mountain tops pass into the shadow of the earth. The alpine glow is most striking when there are clouds in the western sky and the illumination of the mountains is intermittent.

(ii) The afterglow. This begins when the sun is 3° or 4° below the horizon. The lighting is faint and diffuse with no sharp boundary and occurs only when the 'purple light' is manifest in the sky.

11.2.8 Green flash: a predominantly green coloration of short duration, often in the form of a flash, seen at the extreme upper edge of a luminary (sun, moon, or sometimes even a planet) as it disappears below or appears above the horizon.

Flashes up to an altitude of several degrees have sometimes been observed. Although the colour of the phenomenon is predominantly green, blue and violet may also be visible, particularly when the air is very transparent. The colour lasts two or three seconds at the longest.

No completely satisfactory explanation has so far been given for the green flash but it is most probable that the greater refraction of the short waves (violet, blue, green) than of the long waves (red) of white sunlight, coupled with the greater degree of Rayleigh scattering experienced by the violet and blue rays, plays the most important part. It is possible that the flash may appear blue or violet in a hazy atmosphere when such differential scattering may not be appreciable. It is probable that an unusual degree of refraction, such as occurs with a low-level inversion of temperature, is required for the phenomenon.

Differential refraction of white light is also the cause of the analogous very rare 'red flash' which may occur when the sun's disc appears just below a bank of clouds near the horizon.

11.2.9. Coronae: one or more sequences (seldom more than three) of coloured rings of relatively small diameter, centred on the sun or moon. In each sequence the inside ring is violet or blue and the outside ring is red; other colours may occur in between. The innermost sequence usually shows a distinct outer ring of reddish or chestnut colour called the 'aureole', the radius of which is generally not more than 5°. Often the aureole alone appears.

Coronae are due to the diffraction of light by very small water drops. The smaller the drops the greater the radii of the aureole and of the successive, approximately equidistant, red rings. The more uniform the size of the drops the purer are the colours of the coronae.

The diameters of coronae are generally considerably smaller than that of the halo of 22° so that they are very near the luminary and can be seen around the sun only when its brightness is very much dimmed. Coronae are seen most often round the moon though no doubt they occur as frequently round the sun. Sometimes they may be more favourably observed round the sun by using a reflector (such as a pool of water or black glass) to reduce the intesity of the light.

Coronae may be distinguished from haloes by the reversal of colour sequence, the red of the halo being inside, that of the corona outside. Size of the rings should not be used as a criterion because the diameter of a corona may occasionally be quite as large as that of a halo. As coronae are produced by diffraction they occasionally show the sequence of colours two, three, or even four times over. This cannot happen with haloes.

11.2.10. Bishop's ring: a whitish ring, centred on the sun or moon, with a slightly bluish tinge on the inside and reddish-brown on the outside.

In the middle of the day the inner radius of the ring is about 10°, the outer 20°; when the sun is low the ring is larger. Bishop's ring was first seen after the great eruption of Krakatoa in 1883 and could be seen until the spring of 1886. It was also seen after the eruptions of Soufrière in St Vincent and Mt Pelée in Martinique in 1902, after the north Siberian meteorite in 1908, and at the time of nearest approach to the earth of Halley's Comet on 18 and 19 May 1910. The phenomenon is attributed to diffraction associated with fine dust in the high atmosphere. The colours of a Bishop's ring are not very distinct; they are particularly faint in rings observed around the moon, showing only a pale red fringe.

11.2.11. Glory: one or more sequences of coloured rings seen by an observer around his own shadow on a cloud consisting mainly of numerous small water drops, on fog or, very rarely, on dew.

It happens frequently on mountains that there is a mist on one side of a ridge and not on the other. In such circumstances an observer standing with his back to the sun will sometimes see coloured rings of light round the shadow of his own head on the mist. The coloured rings, called 'glory', have no direct connection with the shadow, but are caused by light diffracted backwards in the same way as the coronae are caused by light diffracted forwards. The colour order is the same as that for a corona.

When the shadow seems to be very large, because the cloud or fog are near the observer, it is called a 'Brocken spectre' whether a coloured glory is seen or not. A large outer ring, known as 'Ulloa's ring', which is essentially a white rainbow, is sometimes seen at the same time.

Airborne observers sometimes see a glory around the shadow of the aircraft in which they are flying.

11.2.12. Irisation (iridescence): colours appearing on clouds, sometimes mingled, sometimes in the form of bands nearly parallel to the margin of the clouds; green and pink predominate, often with pastel shades.

Irisation colours, often brilliant, resemble those observed on mother-of-pearl. Within about 10° from the sun, diffraction is the main cause of irisation. Beyond about 10°, however, interference is usually the predominant factor. Irisation extends at times to angles exceeding 40° from the sun and even at this angular distance the colours may be brilliant.

Irisation is occasionally seen on the edges of some species of cirrocumulus, altocumulus, and stratocumulus clouds. The coloured patches may be parts of coronae probably due to the local occurrence of exceedingly small water droplets. The point to note is the angular distance from the sun or moon of the patches which show irisation. This may be judged by holding a centimetre rule at arm's length when each centimetre will approximate to 1°.

11.3. SPECIAL CLOUDS

Nacreous and noctilucent clouds occur at high altitudes and may be observed from comparatively restricted geographical locations. Both may be seen from the British Isles but usually only in the higher latitudes.

11.3.1. Nacreous clouds: clouds resembling cirrus or altocumulus lenticularis and showing very marked irisation, similar to that of mother-of-pearl; the most brilliant colours are observed when the sun is several degrees below the horizon.

Nacreous clouds are a rare type of stratospheric cloud and were previously termed 'mother-of-pearl clouds'. The nature of the cloud particles is not yet known, but the associated optical effects suggest diffraction by spherical particles of diameter less than 2·5 micrometres; it has been suggested that the particles may be water droplets or spherical ice particles.

These clouds have been observed mainly in Scotland and Scandinavia but have occasionally been reported from Alaska and from France during periods of a strong west to north-west airstream. Measurements by Professor Störmer in southern Norway and Dr D. H. McIntosh in Scotland indicate that the clouds occur at an altitude between 21 and 30 km and require a temperature approaching −90 °C to form. Such a temperature is only likely to be approached occasionally during December, January and, less likely, February in the northern hemisphere.

The clouds are somewhat lenticular in form, very delicate in structure, and show brilliant irisation at angular distances up to about 40° from the sun. Irisation reaches its maximum brilliance when the sun is several degrees below the horizon. Later, with the sun still further down, the various colours are replaced by a general coloration which changes from orange to pink and contrasts vividly with the darkening sky. Still later, the clouds become greyish, then the colours reappear, though with greatly reduced intensity, before they finally fade out. Up to about two hours after sunset, the nacreous clouds can still be distinguished as tenuous grey clouds standing out against the starry sky. If there is moonlight, they may be visible throughout the night. Before dawn, this sequence is repeated in reverse order.

By day, nacreous clouds often resemble pale cirrus. If, after sunset, cirrus and nacreous clouds coexist, the nacreous clouds still show bright colours after the cirrus has already turned grey. Nacreous clouds show little or no movement; this fact, together with the circumstances of their occurrence strongly suggests that they are in the nature of mountain wave clouds.

11.3.2. Noctilucent clouds: clouds resembling thin cirrus, but usually with a bluish or silvery colour, or sometimes orange to red; they stand out against the night sky. Most of the information in this section is based on a review by the late J. Paton.

These clouds occur at great heights, about 80 km, and they remain sunlit long after sunset. They are visible only at night in that part of the sky where they are directly illuminated by sunlight and when the sky background is dark enough to permit their weak luminescence to be seen.

Noctilucent clouds have been observed only in latitudes higher than 45°N. The northern limit is uncertain because of prevailing cloudiness and the lack of observing sites but is probably at least 80°N. At about latitude 55°N the clouds are seen most frequently in late June and early July. They are usually observed only in the summer months.

Because of their great height it had been assumed that they consisted of volcanic or meteoric dust but sounding rockets fired in northern Sweden during the summer of 1962 successfully collected noctilucent cloud particles which on examination provided strong indications that the clouds consisted of ice crystals.

Noctilucent clouds usually appear in the form of thin cirrus-like streaks, sometimes only one or two isolated filaments being visible while at other times the cloud elements are closely compacted into an almost continuous mass resembling cirrocumulus or altocumulus undulatus. Weaker and more tenuous displays have the form of decayed cirrus and there is often a structureless background (nebula) rather similar to cirrostratus.

The noctilucent clouds can usually be distinguished from ordinary clouds by the fact that they remain brighter than the sky background and glow with a pearly, silvery light, generally showing tinges of blue coloration. They sometimes appear reddish in the immediate vicinity of the horizon.

11.3.3. Observations of nacreous and noctilucent clouds. When nacreous or noctilucent clouds are observed, observers should record (i) the night of occurrence specified by two dates, e.g. 11–12 July 1982, and the latitude and longitude of the place of observation; (ii) the period(s) of time, GMT, during which the clouds were observed; (iii) the horizontal and vertical extent, expressed in degrees of azimuth and elevation, at specified times, say every quarter-hour, half-hour or hour, and (iv) general notes on the nature and behaviour of the clouds.

It is most useful to draw a rough sketch showing the configuration of the cloud elements and the co-ordinates, elevation and azimuth of the visible boundaries of the cloud, i.e. the maximum elevations in different azimuths and the limiting azimuths, east and west of north. Advice on using a pilot-balloon theodolite, and also the use of a centimetre scale as a rough guide, in deriving the values of elevation and azimuth is given in 11.6 on page 175.

When stars are present in the vicinity of the clouds their position in relation to the clouds should be noted, thereby providing reference marks from which the altitude of the clouds may be determined. The horizon provides another useful reference mark.

If monochrome or colour photographs can be taken, a record should be made of the time to the nearest minute of each photograph, the focal length of the lens, and the azimuth and angular elevation of any landmarks from which the direction of the optical axis may be determined. With fast monochrome film, exposure times are of the order of 10 seconds at f/3.5; with colour film of rating ASA 25, exposure times are 40–60 seconds at f/3.5. It is advisable to take several photographs at different exposures.

Meteorological Office Headquarters are always interested in receiving photographs and reports of such clouds.

11.4. ELECTROMETEORS

11.4.1. St Elmo's fire (or corposant): a more or less continuous, luminous electrical discharge of weak or moderate intensity in the atmosphere, emanating from elevated objects at the earth's surface (lightning conductors, wind vanes, masts of ships) or from aircraft in flight (wing-tips etc.).

It is also seen on projecting objects on mountains. This phenomenon may be observed when the electrical field near the surface of objects becomes strong. According to some observations, the character of St Elmo's fire varies with the polarity of the electricity being discharged. The negative 'fire' is concentrated so that a structureless glow envelops an elongated object such as a mast or an aerial; the positive 'fire' takes the form of streamers about 10 cm long. It may also appear as luminous globes, a number of which are sometimes seen along the aerial. The colour of St Elmo's fire can be violet or greenish.

The phenomenon is also termed 'corposant' (*corpo santo:* holy body) because of its once-supposed supernatural nature.

11.4.2. Aurora: a luminous phenomenon which appears in the high atmosphere in the form of arcs, bands, draperies, curtains or rays.

Aurorae are due to electrically charged particles ejected from the sun and acting on the rarified gases of the high atmosphere. As the charged particles spiral towards the earth, their visible interaction with the gases reaches its maximum frequency in the 'auroral zones'; these zones are centred on the geomagnetic poles with a radius of approximately 20° and aurora is visible near them on almost every clear night. The northern auroral zone lies just north of Norway, south of Iceland and Greenland, over northern Canada and north of Siberia.

Measurements have indicated that the altitude of the lower limit of polar aurorae is approximately 60 to 100 km and can extend to as high as 1000 km. The frequency of aurora varies markedly with solar activity, tending to occur at times of maximum sunspot number; at times of minimum sunspot number the auroral displays seem to recur at 27-day intervals, these being the periods of rotation of the sun. The extent of auroral activity is also much enhanced during a major solar flare or storm when aurora may be visible far to the south of its normal position. The estimated annual frequency of nights of visible aurora, ignoring the intervention of cloud, twilight or moonlight, is about 150 in northern Scotland and about 10 in southern England. The corresponding frequencies of overhead displays are about 10 and 1 respectively. The terms 'aurora borealis' or 'northern lights' and 'aurora australis' or 'southern lights' apply respectively to the northern and southern hemispheres. Aurora is usually pale and grey but sometimes, during more active periods, it will become yellow-green or red.

The common forms of display and their descriptions are given in the drawings of Figure 19. Aurora often appears as a *glow* (a) on the poleward horizon; such a glow is the upper part of some other auroral form whose lower edge is below the horizon. A common form, particularly in high altitudes, is an *arc;* this may be *homogeneous,* i.e. uniform in brightness (b), or *rayed,* i.e. with vertical ray structure (c). Multiple arcs, running parallel to one another across the sky, are not uncommon. When an arc has folds along its length it is called a *band;* this also may be *homogeneous* (d) or *rayed* (e). Rayed bands in which the rays are long look like curtains or draperies. Single *rays* (f) or bundles of rays are often seen after the break-up of a rayed arc or band. If the display passes overhead, the parallel rays along the lines of force appear, by perspective, to converge at the magnetic zenith, thus producing *coronal rays* (g). The magnetic zenith is not coincident with the observer's zenith but is displaced towards the equator by an amount depending on the distance of the observer from the geomagnetic pole. In the British Isles the magnetic zenith is about 20° south of the observer's zenith. During a display brighter patches may occur and move along the arc or drapery and the process of 'flaming' may be seen in which light surges upwards from the lower edge of the arc or drapery to the zenith. As a display fades the aurora will degenerate into *patches* (h) which are like diffuse clouds without any arc or ray structure.

The distribution of aurorae in time and space has been determined by visual observation and by simultaneous photography from a number of stations, some of which have been equipped with automatic 'all-sky' cameras. Radio-echo techniques have also been used in investigating aurorae.

The observer should give a description of the aurora and note the direction in which it appears most intense, the position and angular height above the

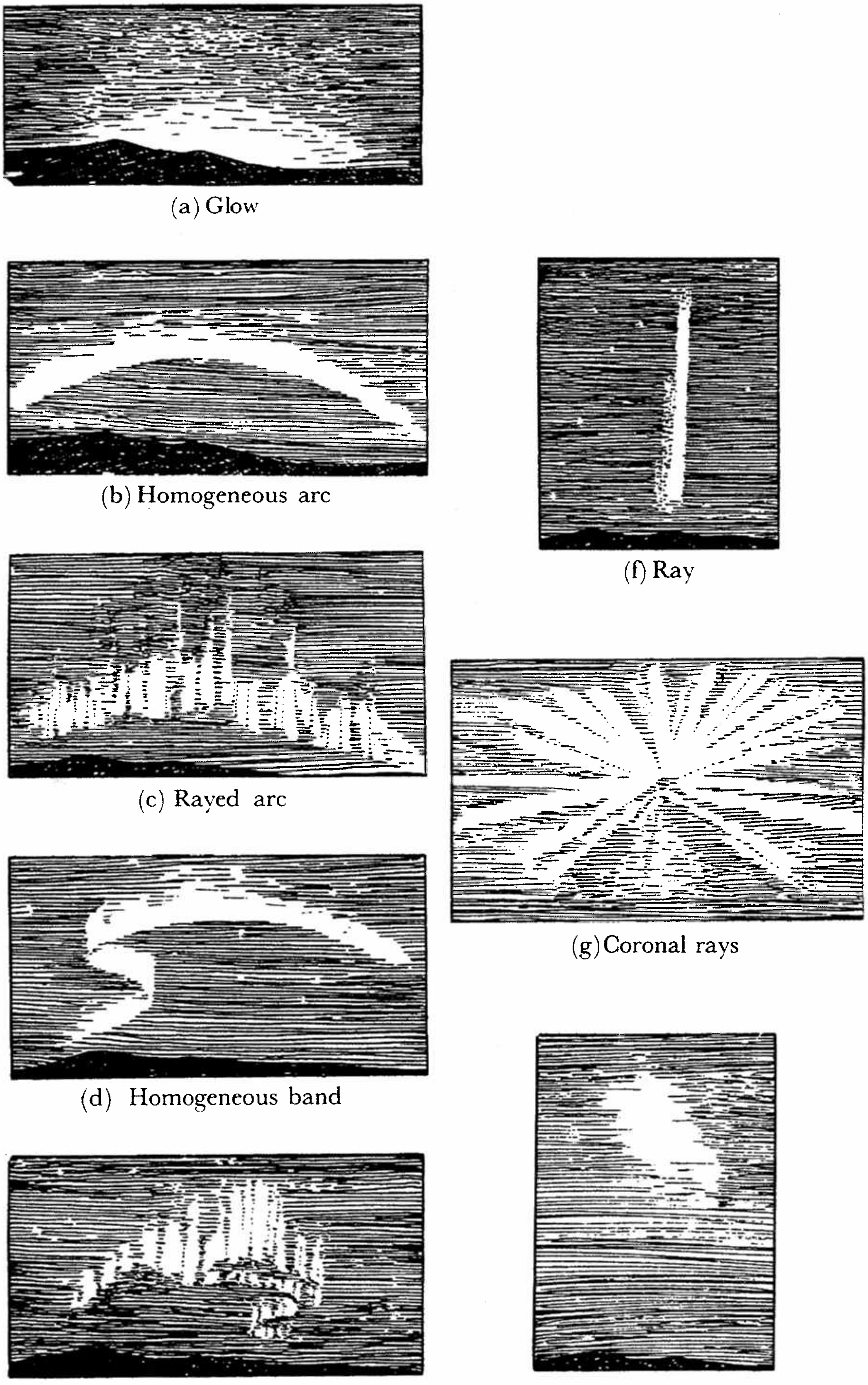

Figure 19. Auroral forms

horizon of particular features, and colour effects. The advice about sketches and photographs given in 11.3.3 for nacreous and noctilucent clouds also applies to aurorae.

11.4.2.1. *Dating of aurorae.* Auroral displays are dated according to the date of commencement of the night on which the display occurs. For example, an aurora beginning on the 25th of the month and ending on the 26th is described as 'the aurora of the 25th'. An aurora occurring after midnight may, however, be referred to as 'the aurora of the early hours of the 26th' in a case where ambiguity may otherwise arise. In statistical summaries, statements referring to frequency are in the form 'aurora was observed on X nights'.

11.5. MISCELLANEOUS PHENOMENA

11.5.1. Crepuscular rays. Three similar phenomena are included under the term 'crepuscular rays'. These are:

(*a*) Sunbeams penetrating through gaps in a layer of low cloud and rendered luminous by water or dust particles in the air (phenomenon termed 'sun drawing water' or 'Jacob's ladder').

(*b*) Pale blue or whitish beams diverging upwards from the sun hidden behind cumulus or cumulonimbus clouds. The well-defined beams are separated by darker streaks which are the shadows of parts of the irregular cloud.

(*c*) Red or rose-coloured beams, diverging upwards at twilight from the sun below the horizon. The light is scattered to the observer by atmospheric dust; the beams are separated by greenish-coloured regions which are the shadows of clouds or hills below the horizon.

In classes (*b*) and (*c*) the beams and shadows may persist across the sky before converging at the 'antisolar point' (anti-crepuscular rays). The apparent divergence and convergence is an optical illusion produced by perspective.

11.5.2. Day darkness. The term 'day darkness' or 'high fog' describes a state of gloom caused by a concentration of smoke at no great height (a few hundreds of metres or feet) above ground level. In the British Isles it is a winter phenomenon, now relatively infrequent, characteristic of large conurbations. Although the darkness may be comparable with that of night, the visibility near the ground may not be seriously impaired.

The 'special phenomenon' group for reporting day darkness (Regional Code 668 in *Handbook of weather messages,* Part II) provides for three degrees of day darkness, 'bad', 'very bad' and 'black' (Regional Code 624) which are self-explanatory, and also provides for reporting the direction in which the day darkness is worst. The phenomenon is different from the ordinary gloom of a murky day caused by dense low cloud and poor visibility. The darkening of the sky is abnormal and often shows a dirty greenish or reddish coloration even when the darkness is no worse than 'bad'. In 'black' day darkness there is no coloration and the pall appears impenetrable by the sun's rays.

11.5.3. Zodiacal light and associated phenomena. The zodiacal light is observed as the cone-shaped extremity of an elongated ellipse of soft whitish light. It extends from the sun as centre and appears above the westerly horizon after sunset or above the easterly horizon before sunrise. The light retains its apparent place among the stars, as it gradually sets in the evening or rises in the morning. It is most brilliant and most readily seen in the tropics, and it may sometimes be conspicuous in temperate latitudes provided that it is observed away from the glare of large towns. It is then often sufficiently bright to be visible to some extent in faint twilight or faint moonlight.

The light is pearly and homogeneous, and differs markedly in quality from that of the Milky Way, the brightest part of which it may considerably exceed in luminance. Its luminance decreases with altitude, since its brightness is greater the nearer the observed point is to the position of the sun below the horizon. It appears, however, to fall off in brightness very near to the horizon on account of the greater thickness of the atmosphere its light has to traverse. At any particular altitude the axis of the light is brighter than its lateral parts. The best time for observation is just after the last traces of twilight have disappeared in the evening, or just before the first traces appear in the morning, the greatest extent of the light being visible.

The axis of the light lies very nearly, but not quite, in the plane of the ecliptic, and the whole phenomenon is thus confined to the zodiacal constellation. In temperate latitudes the ecliptic is often inclined at such a small angle to the horizon that the light is rendered invisible by the additional extent of the atmosphere traversed. In the latitudes of the United Kingdom it is best seen in the evenings of January to March and in the mornings of September to November; only about the time of the winter solstice is it possible to observe it on the morning and evening of the same day. In February the light lies between the constellations of Pegasus and Cetus, the apex being near the Pleiades. Just after dark in this month, in the latitudes of the United Kingdom, the altitude of the apex of the light is about 50°, the cone lying obliquely with regard to the horizon. The breadth near the horizon at this time is 25° to 30°, and the altitude of the brightest part 20° to 30°. At this time the light has a fairly clear-cut boundary on the side towards the south; on the side towards the north it is more diffuse, and is often seen to have an extension to the north for some distance above the horizon. Observations in other latitudes, and especially in the tropics, have not been frequent enough to determine whether this difference of the two edges and the extension to the north are seen everywhere.

The zodiacal light is generally believed to be caused by the scattering of sunlight from a cloud of particles lying in the ecliptic. The composition and origin of these particles is not yet certain but they are believed to be of interplanetary dust which is the debris of comets.

11.5.3.1. *Zodiacal band and Gegenschein.* Associated with the zodiacal light are two other phenomena, the zodiacal band and the Gegenschein. Joining the apexes of the morning and evening zodiacal lights is an extremely faint luminous band, a few degrees wide, lying along or nearly along the ecliptic; this is called the zodiacal band. On it at a point nearly, or perhaps exactly, 180° from the sun's position in the ecliptic, is a somewhat brighter and larger, though rather ill-defined, patch of light, 10° or more in diameter, known by the German name Gegenschein (literally 'counterglow', but this term in English is applied to a meteorological phenomenon of twilight, see 11.2.6.). When they are at a sufficient altitude, the zodiacal band and the Gegenschein may be observed in temperate latitudes on the clearest moonless nights. The position and width of the band and the size, shape and exact position of the Gegenschein should be noted, together with variations of brilliancy and any special features seen, but the observation will be found difficult even for the keenest eyesight. The Gegenschein is usually invisible for the few nights on which it is projected upon the Milky Way in its annual journey round the ecliptic.

11.6. RECORDING PHENOMENA

For the more unusual phenomena an observer may record such information as the times of occurrence at different stages or phases, angular diameters of circles or arcs, notes on their colouring, angular elevation, movement, etc. Such information is part of the record of a station and should be retained so that it can be referred to by any interested party. Some notes are given here on the best way to measure angles both accurately and approximately. Photographs provide a suitable means of recording some phenomena and advice is included on exposure, but this must be considered as providing only a rough guide.

If a pilot-balloon theodolite is available, the elevation scale can be used to measure angles in the vertical plane. Caution must be exercised, however, in using the azimuth scale to measure the angular radii of haloes etc. If A_1 and E are the azimuth and elevation of the sun and A_2 is the azimuth of the limb of the halo at the same elevation, the angular radius (α) of the halo is not $A_2 - A_1$ but may be derived from the expression

$$\sin \alpha = \cos E \sin (A_2 - A_1).$$

Rough angular measurements may be made by holding a centimetre scale at arm's length and taking one centimetre as equivalent to one degree. The exact distance for which this is true is 57·4 cm (22·6 inches).

11.6.1. Photographing phenomena. Advice on photographing nacreous and noctilucent clouds is given in 11.3.3.

Colour transparencies are ideal for recording clouds and many optical phenomena. It is essential that the correct light setting is used, and the photographer should not be surprised if a very high light value is measured. The light from clouds and halo phenomena is very intense, and fast shutter speeds with small apertures are frequently required even with slow colour film. When photographing clouds it is often helpful if the horizon or some foreground feature can be included to give perspective to the picture. Part of a nearby tree may be ideal. If a halo is to be photographed it is necessary to obscure the sun's disc with some intervening object unless the sun is low in the sky. A slender tree, a chimney stack or small amounts of any lower cloud of sufficient optical thickness may be utilized. The standard lens of a 35 mm camera will not photograph a complete halo on one frame.

Cloud photography on black and white film is also possible but here again the correct exposure setting must be used. In addition an orange (×5) or red (×10) filter will accentuate the blue tones when blue sky is visible and give a better picture for scientific purposes. Even a yellow (×2) filter will help in this respect. The recording of optical phenomena is more difficult with black and white film than with colour, and unless one is experienced in this work a more reliable result will be obtained by making a sketch. It must be remembered too that colours do not record well on monochrome film; for example, a bright red will appear black on the print.

Whenever a photograph is taken, the observer should record the time, place, direction the camera was pointing, aperture, shutter speed, type of film and filter (if used) together with suitable notes of the special points observed.