Iron Nickel Titanium Manganese Chromium Cobalt Carbon Vanadium Zirconium Cerium Calcium Scandium

Neodymium Lanthanum Yttrium Niobium Molybdenum Palladium Maçnesium Sodium Silicon Hydrogen Strontium Barium

Aluminium Cadmium Rhodium Erbium Zinc Copper Silver Germanium Glucinum Tin Lead Potassium

Bismuth (?) Tellurium Indium Oxygen Tungsten

Mercury (?)

Helium Ytterbium Europium

The spectrum taken near the limb of the sun shows increased general absorption, but also definite peculiarities of great interest in connexion with the spectra of the spots, which it will be convenient to describe first.

When the slit of the spectroscope is set across a spot, it shows, as might be expected, a general reduction of brightness as we pass from the photosphere to the penumbra ; and a still greater one as we pass to the umbra. This is not a uniform shade over the whole length of the spectrum, but shows in bands or flutings of greater or less darkness, which in places and at intervals have been resolved by Young, Dunér and other unques­tionable observers into hosts of dark lines. Besides this the spectrum shows very many differences from the mean spectrum of the disk, the interpretation of which is at present far from clear. Generally speaking, the same absorption lines are present, but with altered intensities, which differ from one spot to another. Some lines of certain elements are always seen fainter or thinner than on the photosphere, or even wholly obliterated; others sometimes show the same features, but not always; other lines of the same elements, perhaps originating at a level above the spot, are not affected; there are also bright streaks where even the general absorption of the spot is absent, and sometimes such a bright line will correspond to a dark line on the photosphere; most generally the lines are intensified, generally in breadth, sometimes in darkness, sometimes in both together, sometimes in one at the expense of the other; certain lines not seen in the photosphere show only across the umbra, others cross umbra and penumbra, others reach a short distance over the photosphere. A few of the lines show a double reversal, the dark absorption line being greatly increased in breadth and showing a bright emission line in its centre. The umbra of a spot is generally not tormented by rapid line-of-sight motions; where any motion has been found G. E. Hale and W. S. Adams make its direction down­wards; but round the rim and on bridges the characteristic distortions due to eruptive prominences are often observed. There appears to be some connexion between prominences and spots; quiescent promi­nences are sometimes found above the spots, and W. Μ. Mitchell records an eruptive prominence followed next day in the same place by the appearance of a small spot. It docs not appear that the affected lines follow' in any way the sun-spot cycle. The radiation from a spot changes little as it approaches the sun's limb; in fact Hale and Adams find that the absorption from the limb itself differs from that of the centre of the disk in a manner exactly resembling that from a spot, the same lines being strengthened or weakened in the same way, though in much less degree, with, however, one material exception : if a line is winged in the photosphere the wings are generally increased in the spot, but on the limb they are weakened or obliterated. If the spot spectrum is compared with that of the chromosphere it appears that the lines of most frequent occurrence in the latter are those least affected in the spot, and the high level chromospheric lines not at all; the natural interpretation is that the spot is below the chromosphere. As to whether the spots are regions of higher or lower temperature than the photosphere, the best qualified judges arc reserved or discordant, but recent evidence seems to point very definitely to a lower temperature. Hale and Adams have shown that the spectrum contains, besides a strong line-spectrum of titanium, a faint banded spectrum which is that of titanium oxide, and a second banded part remarked by Newall has been identified by A. L. Fowler as manganese hydride. The band spectrum, which corresponds to the compound or at least to the molecule of titanium, certainly belongs to a lower temperature than the line spectrum of the same metal. Hence above the spots there are vapours of temperature low enough to give the banded spectra of this refractory metal, while only line spectra of sodium, iron and others fusible at more moderate temperatures are found (see also Spectroheliograph).

The chromosphere, which surrounds the photosphere, is a cloak of gases of an average depth of 5000 m., in a state of luminescence less intense than that of the photosphere. Hence when the photosphere is viewed through it an absorption spectrum is shown, but when it can be viewed separately a bright line spectrum appears. Most of the metallic vapours that produce this lie too close to the photosphere for the separation to be made except during eclipses, when a flash spectrum of bright lines shines out for, say, five seconds after the continuous spectrum has disappeared, and again before it reappears (see Eclipse). F. W. Dyson has measured some eight hundred lines in the lower chromo­sphere and identified them with emission spectra of the following

elements: hydrogen, helium, carbon with the cyanogen band, sodium, magnesium, aluminium, silicon, calcium, scandium, tita­nium, vanadium, chromium, manganese, iron, zinc, strontium, yttrium, zirconium, barium, lanthanum, cerium, neodymium, ytterbium, lead, europium, besides a few doubtful identifications; it is a curious fact that the agreement is with the spark spectra of these elements, where the photosphere shows exclusively or more definitely the arc lines, which are generally attributed to a lower temperature. In the higher chromosphere the following were recognized: helium and parhelium, hydrogen, strontium, calcium, iron, chromium, magnesium, scandium and titanium.

In the higher chromosphere on occasions metallic gases are carried up to such a level that without an eclipse a bright line spectrum of many elements may be seen, but it is always possible to see those of hydrogen and helium, and by opening the slit of the spectroscope so as to weaken still further the continuous spectrum from the photosphere (now a mere reflection) the actual forms of the gaseous structures called prominences round the sun's rim may be seen. In the visual spectrum there are four hydrogen lines and one helium line in which the actual shapes may be examined. The features seen differ according to the line used, as the circumstances prevailing at different levels of the chromosphere call out one line or another with greater intensity. The helium formations do not reach the sun’s limb, and it is another puzzling detail that the spectrum of the disk show's no absorption line of anything like an intensity to correspond with the emission line of helium in the chromosphere. The promi­nences are of two kinds, quiescent and eruptive. Some of the former are to be seen at the limb on most occasions; they may hang for days about the same place; they reach altitudes of which the average is perhaps 20,*000* m*.,'* and show the spectral lines of hydrogen and helium. Sometimes they float above the surface, sometimes they **are** connected with it by stems or branches, and they show delicate striated detail like cirrus cloud. The eruptive prominences, called also metallic, because it is they which show at their bases a complete bright line spectrum of the metallic elements, rush upwards at speeds which it is difficult to associate with transfers of matter; the velocity *often* exceeds 100 m. a second; W. Μ. Mitchell watched one rise at 250 m. a second to the height of 70,000 m., and in five minutes after it had faded away and the region was quiet. This is remarkable only in point of velocity. Much greater heights occur. Young records one which reached an elevation of 350,000 m., or more than three-quarters of the sun’s radius. Since identification of spectral lines is a matter of extreme refinement, any cause which may displace lines from their normal places, or otherwise change their features, must be examined scrupulously. We have seen above numerous applications of the Doppler effect. Two other causes of displace­ment call for mention in their bearing on the solar spectrum— pressure and anomalous dispersion. The pressure which produces a continuous spectrum in gases at a temperature of 6000° must be very great. Recent experiments on arc spectra at pressures up to 100 atmospheres by W. J. Humphreys and by W. C. Duffield show several suggestive peculiarities, though their bearing on solar phenomena is not yet determined. The lines are broadened (as was already known), the intensity of emission is much increased, but some are weakened and some strengthened, nor is the amount of broadening the same for all lines, nor is it always symmetrical, being sometimes greater on the red side; but besides the effect of unsymmetrieal broadening, every line is displaced towards the red; different lines again behave differently, and they may be arranged somewhat roughly in a few groups according to their behaviour; reversals are also effected, and the reversed line does not always correspond with the most intense part of the emission line. For example, in the iron spectrum three groups about wave-length 4500 are found by Duffield to be displaced respectively 0∙17, 0∙34, 0∙66 tenth-metres, at 100 atmospheres. This shift towards the red J. Larmor suggests is due to relaxation of the spring of the sur­rounding ether by reason of the crowding of the molecules; a shift of 0∙17 tenth-metres would, if interpreted by Doppler’s principle, have been read as a receding velocity of 11 km. per second. It is clear that these results may give a simple key to some puzzling anomalies, and on the other hand, they may throw a measure of uncertainty over absolute determinations of line-of-sight velocities.

The possible applications of anomalous dispersion are. varied and interesting, and have recently had much attention given to them. W. H. Julius holds that this sole fact robs of objective reality almost all the features of the sun, including prominences, spots, faculae and flocculi, and even the eleven-year period. Though few' follow him so far, an ex­planation of the principle will make it clear that there are numerous possible opportunities for anomalous dispersion to qualify inferences from the spectrum. Theoretically anomalous dispersion is insepar­able from absorption. When a system vibrating in a free period of its own encounters, say through the medium of an enveloping aether, a second system having a different free period, and sets it in vibration, the amplitude of the second vibration is inconsiderable, except when the periods approach equality. In such a case the two systems must be regarded as a single more complex one, the absorbed vibration becomes large, though remaining always finite, and the transmitted vibration undergoes a remarkable change in