The Blue Sun of September 1950

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Abstract

Two causes for a coloured sun are discussed, namely refraction and absorption. The importance of integrating the refraction effects arising from different parts of the sun's disk as light sources is emphasized. It is shown that by such integration of ring phenomena around the sun, many observed peculiarities may be explained. Important conditions for that some types of coloured suns shall arise are homogeneity of the particles of the scattering medium, and also that the particles shall be large enough to give rise to rings of sufficiently small radius. Transfer of air masses at long distances but without a sideward mixture taking place is in favour of the creation of dust sheets of homogeneous character, as the vertical sedimentation has then time to come into action.

The sun, when seen through some absorbing medium — it may be clouds or dustlayers of different origin — generally takes on colour more or less different from the normal one. Absorption, as well as scattering, being in general different for different wave lengths, this effect is a natural one. Another possible cause for a change in the apparent colour of the sun may be found in the effects of refraction. During the end of September 1950 the sun appeared more or less distinctly blue to a number of European observers and also at many stations in the eastern parts of North America. As the blue sun represents a very unusual phenomenon it attracted great attention and aroused considerable interest. A number of rather exhaustive papers have already appeared on the subject.

According to generally accepted view, the colour effect resulted from cloud or smoke layers created in connection with great forest fires which had previously taken place in Canada during the period 17—25 Sept. 1940. An analysis of the upper air charts for the period 20—27 Sept. seemed to suggest this cause.

It is not the authors intention to repeat here large parts of the descriptions and observations published by others. For these, the reader is referred to the interesting material presented by JENNE (1951) in this issue of Tellus, and to a few other papers listed among the references. In making the following suggestions as regards the possible explanation, I simply presume that the essential facts are known. Before entering into a more theoretical discussion, I wish to add some few facts based upon observations in Sweden.

Table 1

Reports from Swedish Meteorological Stations on the "Blue Sun" of 17th September 1950

Piteå $\left\{ \begin{array}{l} \text{lat. } 65°19' \\ \text{long. } 21°28' \end{array} \right\}$ On the 27th the sun broke through the clouds between 15 h and 15.30 h. It was blue in colour (cobolt blue), as seen by several observers in the vicinity.

Koskats $\left\{ \begin{array}{l} \text{lat. } 66°29' \\ \text{long. } 20°18' \end{array} \right\}$ Wednesday 27th Sept. the sun was strongly shimmering blue, in a very uncanny way.

Öjebyn {lat. 65°21′, long. 21°23′} Blue sun. The sun appeared silvergrey to blue. No glare from it.

Bruksvallarna {lat. 62°39′, long. 12°25′} The 27th September, the sun was bluish between about 8.45 h to 9.15 h; the light from it was feeble and could be looked at with the naked eye.

Kåreslätt {lat. 57°25′, long. 14°29′} The 27th Sept. at 9.30 h the sun appeared bluish.

Singshult {lat. 56°44′, long. 13°22′} The 27th Sept. the sun blue in colour at 8.50 h.

Törneryd {lat. 56°14′, long. 15°01′} The 27th Sept. the sun bluish "like a day light lamp".

Kristianstad {lat. 56°02′, long. 14°09′} The 27th Sept., the sun blue-white.

Lyngsjö {lat. 55°56′, long. 14°05′} Cobolt blue sun 9.10 h to 11.20 h, Sept. 27th.

Malmö airport {lat. 55°36′, long. 13°03′} The 27th September a peculiar phenomenon was observed between 9 h and 9.30 h. The disk of the sun appeared a clear light-blue colour through the cloud sheet, which consisted of Cist, Cu and Scu. It seems doubtful, however, but whether the Ci-Str did not actually consist of a sheet of dry haze. At about 9.15 h the cloud elements at about 10° distance from the sun showed a dusky red colour. At 15.35 h—15.55 h a similar phenomenon was observed, but the solar disk was then not so decidedly blue but had more the colour of a flame used for welding. The colour of the clouds had by then disappeared.

Lund {lat. 55°42′, long. 13°12′} Sun blue 8.30 h—10.30 h the 27th.

Björka {lat. 55°39′, long. 13°38′} Sun bluish grey, most conspicuously at 9.40 h the 27th Sept.

Alnarp {lat. 55°39′, long. 13°05′} The 27th: Sun blue between 9 h and 10 h.

Svalöv {lat. 55°55′, long. 13°07′} The 27th, sun blue between 8 h and 9.30 h.

Ven {lat. 55°55′, long. 12°44′} The 27th: Sun clearly light blue at 8.10 h—9.15 h.

Hörby {lat. 55°51′, long. 13°40′} Sun blue behind light cloud sheet at 9 h—10 h, the 27th.

Morups tånge {lat. 56°55′, long. 12°22′} The 27th, sun appeared blue between 8.30 h to 9.15 h.

The Table 1 gives a complete list of the reports on the "blue sun" received from the Swedish meteorological stations. It ought to be noted that the first appearance of the phenomenon occurred almost simultaneously at all stations from Bruksvallarna at lat. 62° 39 N, down to Malmö airport at lat. 55° 36 N. The slightly later observation at Piteå, 65° 19 N, can possibly be due to the fact that the sun broke through the lower cloud layers first at 15^{h} in the afternoon at that station.

In Table 2 are given the results of some actinometric observations at Stockholm. These observations were taken at a considerably later date than the first appearance of the blue sun, because of the fact that earlier observations were made dubious by a rather large variability of the sun's radiation. However, during the actinometric observations the sun appeared decidedly blue at times. From the measurements of the total radiation together with those determined with aid of red and yellow filters, the quantities β and α are computed according to the method devised by myself and later further developed by SCHÜEPP (1949). It may be remembered that the scattering by dust and other solid or liquid particles in the air, is in the fundamental considerations on which this method is based, expressed by the empirical formula:

$$I = I_0 \cdot e^{-\frac{\beta}{\lambda^{\alpha}} \cdot m}$$

where I_0 and I are the incoming and outgoing radiations respectively, β is the scattering coefficient and α an exponent, which reflects the dependence of the scattering upon wave length. In the case of purely molecular scattering, α has a value equal to 4.015. The scattering by ordinary dust in the atmosphere is characterized by a value of α of about 1.3; after volcanic outbreaks (like that of Mount Katmai in 1912) α goes down to values as low as about 0.5 or even less, showing the particles to be considerably larger than normal. Over the deserts, especially after sand storms, values of α have been found which are also very low (see for instance F. ALBRECHT 1941).

It is evident that for a value of $\alpha > 0$ the scattering is larger the shorter the wave length, viz. a larger detoriation for instance in blue than in red. If on the other hand α assumes a

Table 2
Place: Stockholm 59° 11′ N, 18° 4′ E

Date	Hour	Radiation from sun gr cal/cm²				
		Total	OG 1	RG 2	α	$10^3\,\beta$
1950						
29/9	13.12	0.622	0.452	0.376	—0.8	163
	13.20	0.622	0.452	0.372	—0.5	160
	13.28	0.717	0.523	0.427	0.3	124
	13.36	0.780	0.562	0.460	—1.2	99
	13.44	0.897	0.658	0.532	0.2	82
	13.53	1.031	0.748	0.602	—0.5	46
30/9	10.03	0.963	0.727	0.604	0.6	107
	10.11	0.978	0.738	0.620	0.3	93
	10.46	1.070	0.793	0.653	0.5	83
	10.54	1.098	0.799	0.658	—0.8	70
	11.42	1.070	0.789	0.645	0.5	84
	11.50	1.070	0.790	0.643	1.1	83
	12.40	0.991	0.737	0.606	0.6	105
5/10	12.37	1.192	0.866	0.682	2.3	29
	12.45	1.210	0.881	0.702	1.4	30

negative value, the dependence of the scattering effect upon wave length is reversed, viz. the red is reduced more rapidly than the blue. Apart from the question of whether the supposition of a constant α throughout the spectrum is valid here (and probably it is not), we may however conclude from the way in which the computation is made that the observations on which it is based have given a much larger reduction for waves longer than 0.525 than for shorter wave lengths. The blue has consequently been represented in the sun light more strongly than is normal. From Table 2 in the doctorate thesis of SCHÜEPP, a table based on the theoretical considerations of MIE (1908), it is clear that while the ordinary scattering particles in the atmosphere have a diameter less than 2.0 μ, the particles in this actual case must have had a much larger diameter, probably greater than 15 μ. I will return to this subject later on.

From what has been said above it seems evident, that the bluish colour of the sun *can* have arisen through the scattering and absorption by a cloud or dust layer containing rather large particles compared with those present in the clear atmosphere. But the question is whether this statement represents the whole truth. A silverblue or grayish blue sun light might have arisen in this way, but can it explain the rather clear blue sun observed at many places? Before attempting an answer it may be worth while to consider for a moment the possible effects of refraction.

As has been shown theoretically as well as practically, the refraction of the light from a luminous point source, under certain conditions, gives rise to luminous ring phenomena: circular spectra with the light source as the centre. The radii of these rings are in general inversely proportional to the diameter of the particles and directly proportional to the wave length. Kämtz (PERNTER-EXNER 1922) has made a large number of measurements on such rings round the sun, when the sun light is passing through thin cloud sheets consisting of water droplets. Similar measurements have also been made by Hilding Köhler. The largest drops found by Kämtz in this way have a diameter of 61 μ, giving rise to rings which for red light (about 0.65 μ) had a radius of 0°39'. For blue light these particles would consequently be expected to give rings with radii of just the same order of size as the diameter of the sun itself (about 0°32').

What will now occur if the radii of these rings get so small as to be comparable with the sun's diameter itself? It seems evident that colour effects in the neighbourhood of the sun must then result as an integral effect of all the rings which we can imagine to be produced with the different elements of the sun's disk as centres. Let us take a simple case with the radius of the first ring of blue light equal

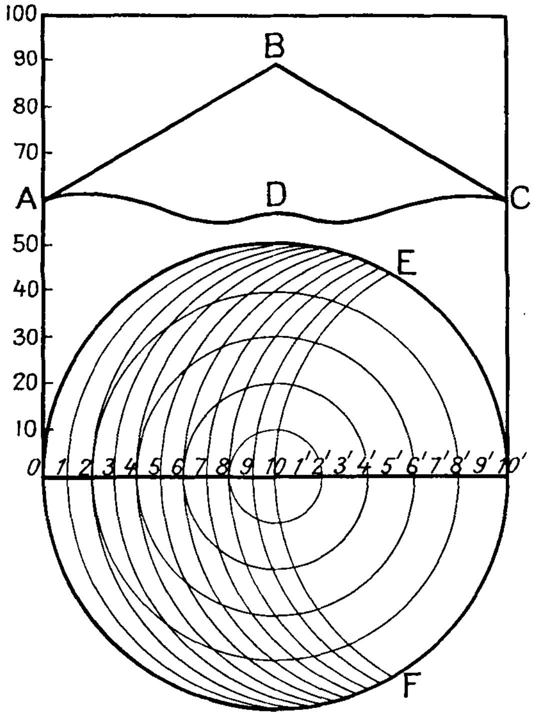

Fig. 1

Colour distribution of "additional" refracted light over the sun's disk under the assumption that first blue ring has the same radius as the sun's disk. If the blue light (wave length 4,200 Å) in sun radiation would be uniformly distributed over the sun's disk, the *additional* light at point 10′ would be proportional to the length of the arc EF, the light at point 9′ proportional to the arc through 9 and so on. The distribution of additional blue light over the sun's disk would then be according to the line ABC, the intensity being largest at the centre and uniformly decreasing against the edges. If due regard is also taken to the fact that the blue light in the direct sun radiation is subjected to a rapid decrease from the centre to the edges the distribution of the additional blue light will be given through the curve ADC showing the blue to be strongest at the periferic parts of the disk. A tendency to a blue ring thus is apparent also in this case. (Distribution of radiation over sun's disk, see Smithsonian Physical Tables 1910, p. 179).

to the sun's radius (r). Then a point at the distance a from the centre of the sun will additional blue light from all elements on a segment AB of a circle which has a radius r and the point in question as a centre. The apparent illumination with blue light of the various points of the sun's disk may for this simple case simply be expressed by $I \simeq \arccos \gamma$; where $\gamma = \frac{a}{r}$.

Fig. 1 demonstrates how this extra illumination of blue light is distributed over the sun's disk. It falls off from the centre to about 20 per cent at edges. If we take account also of the fact that the blue light of the sun's disk is decreasing from centre to edges and that the integral "additional" light on the points far from the centre has its source, to a larger extent, at elements near the sun's centre than is the case for points near the sun's centre, we find an almost uniform distribution of additional blue light over the sun's disk. On the other hand additional red light can only occur at points for which γ is larger than about 0.60, which means that the central parts of the sun up to about 0.6 of the radius must appear decidedly blue or green.

If the radius of the first blue ring is larger than the radius of the sun, a peculiar phenomenon ought to occur. Then the central parts of the sun can not obtain additional blue light from any parts of the sun. A darker spot ought to occur in the centre of the sun's disk and around it a clear blue circle ought to appear. As no red light probably in that case will add itself to the direct light from the sun's disk, the sun will appear blue or blue green as a whole, with exception for the dark centre.

To these considerations we may add from a paper by GELBKE (1951) the following description taken from Pernter-Exner of some experiments by Kiessling who, in view of some peculiar light phenomena following the eruption of Krakataua, made experiments on the optical effect of dust and powders on sun light: "In einem Glaskolben wurden nach Belieben, Staub- oder Dampfwolken verschiedenster Art erzeugt. Die künstlich durch Zerkleinern fester Stoffe hergestellten Staubmassen waren nicht geeignet, im durchfallenden Licht besondere Farbenphänomene zu erzeugen... offenbar weil die Grösse der Teilchen sehr ungleich war ... Mit den Sporen von *Boletus cervini*, die einen Durchmesser von 0,026 bis 0,031 mm haben, also recht gross sind, gelang es hingegen, sehr farbenprächtige Beugungerscheinungen zu erzielen, offenbar deshalb, weil alle Teilchen die gleiche Grösse hatten. Ebenso zeigten verschiedene Kondensationsprodukte, wie Salmiaknebel und Wassernebel sehr schöne Farben, desgleichen alle durch Verbrennung entstandenen Raucharten..." "Aus der Veränderung der Farben in kurzer Zeit nach Entstehen des Nebels — die Sonne erschien durch denselben zu Anfang rot oder braunrot, dann trat ein violetter Farbenton hinzu, und nach wenigen Minuten ging die Farbe in ein reines, zuletzt blendend leuchtendes Azurblau über — lässt sich auf eine Änderung der Grösse der Nebelteilchen schliessen."

Further I also wish to cite from the paper af Gelbke the following description of early observations of blue- or green-coloured suns.

"1465 In diesem Jahre ist die Sonne um den heiligen Creuztag gar dunkel am Himmel gestanden und ein blauer Cirkel (vgl. Greifswalder Beobachtungen.) rings umher/so blau als ein Kornblume gesehen worden.

1554 Grüne Sonne und auffallenden Dämmerungserscheinungen in Thüringen.

1571 Grüner Mond am 27. Oktober. (Ohne Ortsangabe)

1815 Nach dem Ausbruch des Tambora grüne Sonnenfärbung im Indischen Ozean."

The first of these cases, the one of 1465, seems to present an instance where the peculiar case of a dark centre with a blue ring has actually been observed.

It is evident that we can not further apply the theoretical considerations holding for small droplets to the particles giving rise to these phenomena. On the other hand the experiments of Kiessling and others show that quite similar phenomena of refraction occur when light is passing through powder and dust sheets from solid substances. From theory and experiments and from what is known from earlier observations, it may be proposed that two conditions ought to be fullfilled in order to produce the blue- or green coloured sun, namely:

(1) The particles ought to be of rather uniform size,

(2) The particles ought to be large enough, probably of a size larger than 0,050 mm in diameter.

It is perhaps doubtful whether the first condition is really necessary for producing the blue colour of the sun's disk or of rings around it. It is clear that if particles of rather different size are present in the cloud or dust sheet, the smallest blue ring arising through refraction must result from the largest particles present and that the blue colour must be rather pure, since no other particles can produce a mixture with other longer waves just at that angular distance from the centre. If the particles are not of uniform size the other colours, as for instance red, must appear rather dusky and be spread out over a wider area around the sun. Compare here the figure published by Gelbke in his paper mentioned above. The only condition necessary that a clear blue colour shall be produced at the disk or in its immediate surroundings seems then to be that particles large enough shall be present in sufficient amount to produce a visible effect.

Since it seems evident that refraction can produce effects very similar to those observed, it may be asked whether the observed surplus of blue in the transmitted radiation does not simply result from the refraction effect and the apparent high transmission of blue simply is a result of the fact that only blue refracted light falls within the opening angle of the actinometer. As, however, the opening angle of the Michelson actinometer is 8°—20°, and consequently covers the essential part of the area within which the refraction phenomenon takes place, I think that in the present case this explanation does not include the whole truth. It seems therefore safe to conclude that an abnormal transmission of blue light has taken place. On account of the fact that the difference in transmission between short and long waves is not very large, I doubt on the other hand that the transmission conditions alone would have been able to produce the optical sensation observed. We have here probably a case where the *two causes together* have been necessary to produce the impression of a clearly blue sun.

Finally some few words concerning the origin of the refracting and scattering particles. Evidently they have been abnormally large and they have occured at a level where in general such large particles seldom occur, namely at a height of 10,000 to 13,000 meters. The explanation that they have originated from the large and intense forest fires in Canada seems acceptable, even if it appears quite remarkable that smoke from these fires should have been able to rise to such a height. The possibility of some other origin should not, however, be overlooked. The trajectories of the air masses which passed over Europe during the period 27—30 September also pass over the Canadian forest fire region at the proper time, but it seems possible to extrapolate them further back in time to the region of the Japanese Islands. The unsafety and scarcity of observations from the Pacific Ocean makes the extrapolation not very dependable. In Japan, however, there was observed a violent outbreak of the Volkano Asama on September 23. *Hamburger Abendblatt*, on Sunday, September 24, carried the following notice from Associated Press: "Eine 10000 m hohe Rauchsäule stieg zum Himmel auf, als der 2780 m hohe Vulkan *Asama*, etwa 110 km nordwestlich von Tokio am Sonnabend früh ausbrach. In dem Naheliegenden Kurort Karnizama wurden von der Gewalt der Explosion zahlreiche Fensterscheiben eingedrückt."

It is perhaps doubtful whether dust particles from this volcano could have reached Europe already by the 27 of September, but on the other hand there are indications of other volcanic activity in the Japanese region at a somewhat earlier time. The wind reports from the upper air layers over the Pacific, however, do not permit conclusive statements concerning these possibilities. In this respect it would be highly interesting to know whether reports of a blue sun have come in from any points west of Canada. If the answer is negative, the volcanic hypothesis, as regards the origin of the causative particles, is eliminated. That it should be seriously considered, however, seems evident from the fact that in most cases where "blue suns" have been earlier reported heavy volcanic outbreaks (for instance that of Krakataua) had recently taken place in the same region.

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