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THE USE OF LIGHT FILTERS IN THE OBSERVATION OF PILOT BALLOONS.

BY

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THE USE OF LIGHT FILTERS IN THE OBSERVATION OF PILOT BALLOONS.

By R. A. WATSON WATT, B.Sc.

In Pilot Balloon work at the Branch Meteorological Office, South Farnborough, it has been for some years the writer's practice to make considerable use of that nondescript light filter, a " dark glass " over the eye-piece, to reduce eye fatigue in long or difficult ascents. It was obviously desirable that a more rational system of filtering should be tried, and it is proposed to describe here a series of experiments begun in October, 1919, and now absorbed into routine practice.

The functions of such filters for visual observation are threefold: (1) to absorb the glare-producing ultra violet light, although this is probably adequately performed by the glass of the optical system, (2) to absorb the short-wave scattered light from haze and mist, (3) to improve contrast by cutting off light from one of two contrasting sources. In pilot balloon work the conditions of the problem depend on choice of colour of balloons to suit the circumstances. This is largely a matter of personal taste and judgment. The writer has a strong prejudice in favour of a light orange coloured balloon for use against a cloudless blue sky, but undyed and light red balloons are quite satisfactory for this case; while for a background of white cloud (Ci-St) cutting off direct sunlight, a very dark blue balloon is moderately good.

The case of cloudless sky is the more interesting from the present point of view, since it offers a clear field for long trajectories. With favourable conditions of illumination (sun, balloon and observer all approximately in one vertical plane) the balloon, after passing through the turbid lower strata, shows up as a brilliantly shining speck on a blue background. If the balloon is rubbed free of adhering French chalk before launching, its high reflection coefficient gives extremely good visibility. In such a case a single light filter accomplishes a triple purpose: it cuts off the diluting scattered light from intervening haze, it reduces the amount of scattered light from the sky background, and it selectively transmits the light received from the balloon after absorption. Thus the unfiltered system of bright white or orange balloon image against a comparatively bright blue sky will be converted by a red filter into a balloon image of undiminished brilliancy against a dark red background, the contrast being much sharper, while the "fuzziness" from haze is also eliminated. The advantages accruing from this improved image system are, of course, only marked after conditions would otherwise have become difficult; under average conditions this would be the case when the balloon is some twenty kilometres distant, but in haze the improvement would appear much earlier. Eye fatigue is almost eliminated, the risk of failing to pick up the image after reading the scales is much reduced, and, as will be seen from results quoted below, the filtered image remains visible long after the unfiltered image has disappeared.

After preliminary trials with the ordinary K and G screens* of photography, a test set of filters was assembled. Two discs of glass of 5·5 cm. diameter carried between them sectors of stained gelatine film, and this system was mounted rotatably in front of the eye-piece so that any one sector could be interposed between eye-piece and eye at will. The eye-piece position was selected in preference to the objective for various reasons: (1) ease in changing filters, (2) elimination of need for "optical flats", (3) economy of film. The sectors are so small that five can be cut from one square inch of film. The first filter group prepared was uncemented, the sectors being merely clamped between the discs, and despite the six reflecting surfaces excellent results were obtained. Later filters have been cemented with Canada Balsam in the usual way.

Table I. gives the names of the filters tried together with approximate transmission data. Figure 1 gives the absorption curves of the seventeen types. It will be seen that the filters fall into two groups, thirteen forming a yellow-orange-red transmitting series of increasing density, the remaining four being red-absorbing. The red-absorbing set is of minor importance, and the most useful filters are the drastic reds E, A and F, since these serve the triple purpose enumerated, haze penetration, reduced transmission of the blue of the sky, and selective transmission of light from the balloon. The latter, whether reflected by or partially transmitted through the balloon fabric, contains a high proportion of the longer waves left over after the selective absorption of short waves by the undyed or orange-red pigmented fabric. In the main test set fifteen sectors were used, K_2 and C_3 being rejected as insufficiently different from their neighbours.

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* *See* "Wratten Light Filters," published by Kodak Ltd.

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Table I.—Approximate Percentage Transmission Data of Filters Used.

Wratten List No.	6.	8.	9.	10.	15.	19.	21.	27A.	23A.	27.	25.	29.	70.	60.	44A.	48A.	49A.
Name	K_1.	K_2.	K_3.	K_4.	G.	Mandarin Orange.	Monobromo Fluoresceine.	Stage red light.	E red light.	Stage Red.	A.	F.	α	P.	Minus red 5.	C_3.	C_4 light.
Wave Length.																	
4,500	37	·8	·3	0	0	0	0	0	0	0	0	0	0	·6	43	37	21
5,000	75	65	36	41	0	0	0	0	0	0	0	0	0	49	40	7	1
5,500	75	69	72	80	75	52	17	·8	·6	0	0	0	0	35	11	0	0
6,000	75	78	80	80	71	80	98	66	63	55	53	0	0	1	0	0	0
6,500	79	85	84	72	67	87	100	80	72	79	76	64	·4	0	0	0	0
7,000	82	90	88	70	73	90	100	75	77	75	72	71	45	3	0	0	0
Stability ...	Quite Stable.					Moderately Stable.		Stable.	Moderately Stable.	Stable.	Moderately Stable.			Stable.	Moderately Stable.	Stable.	

Quite stable = no change on 12 months' exposure to daylight.
Stable = no change on 6 months' exposure to daylight.
Moderately Stable = possible slight change on 3 months' exposure to daylight.

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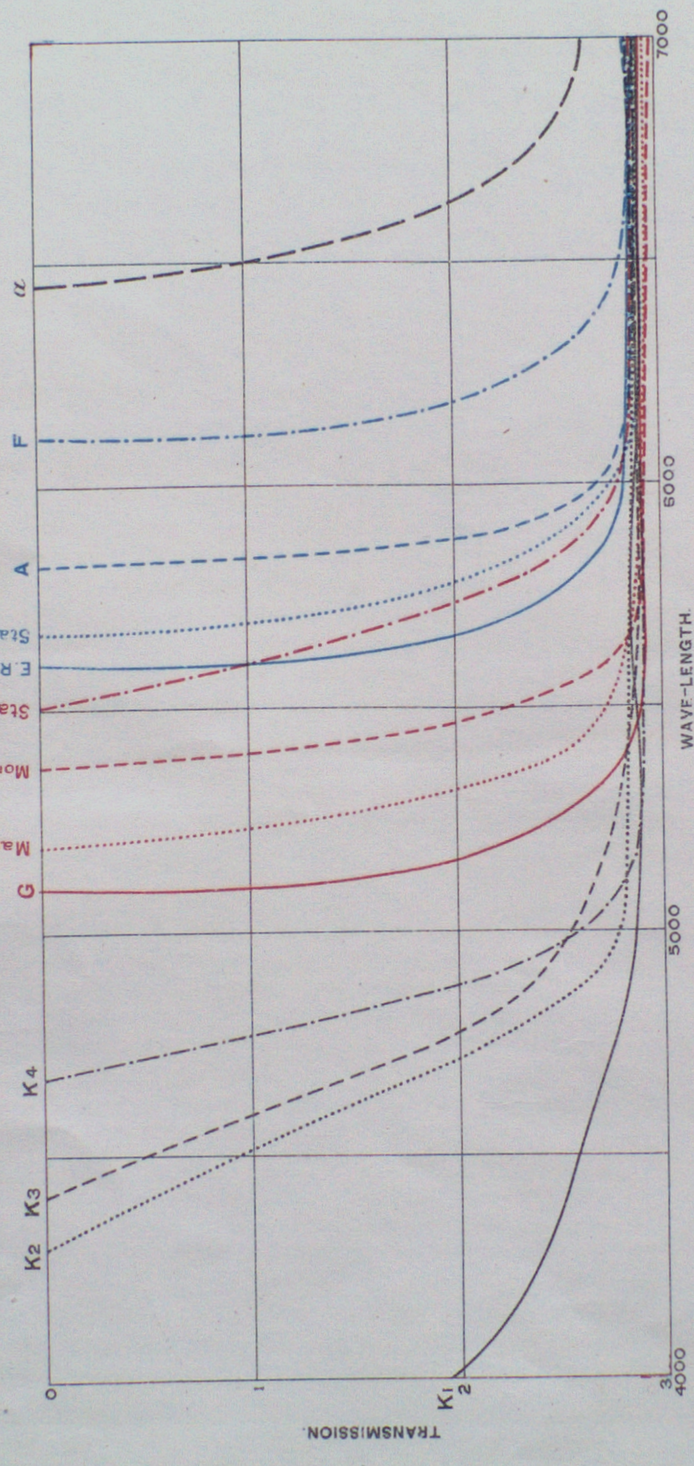

Figure 1 (a).

RED-TRANSMITTING FILTERS.

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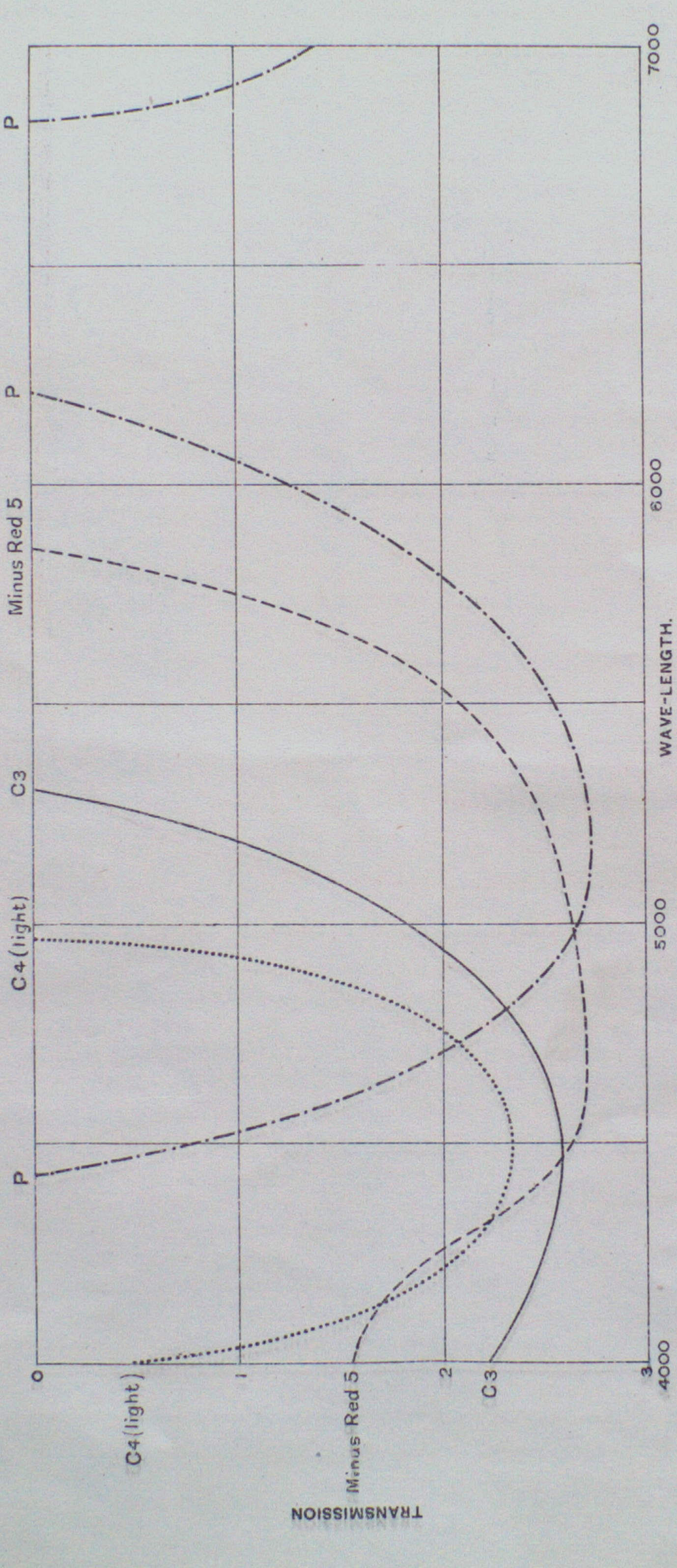

Figure 1 (b).

RED-ABSORBING FILTERS.

In the minor case of ascents with dark blue balloons against white cloud no satisfactory technique has yet been attained. The best that can be done is to use the haze penetrating properties of the yellow-red filters, and leave the contrast to look after itself. One trial has been made with a matt-black pigment on the balloon, it showed a marked improvement over the dark blue which is obviously a rough approximation only to the ideal contrast of dead black against white which is called for. Low cloud coming up prematurely obscured the black balloon and time has not yet been found to continue the trials.

The three red-absorbing filters are mainly limited in use to transitional conditions during ascents with white, orange or red balloons. When not in bright sunlight, as for example in the frequent case of an ascent just before sunrise, these balloons show up dark against a comparatively bright sky background, even when a red filter is used. After sunrise, at the level of the balloon, the conditions are reversed, the balloon is bright, the background relatively dark. Between these two phases is a brief period when there is, with no filter or with a red-transmitting filter, practically no contrast whatever, and the balloon is extremely difficult to see. Interposition of a "minus red" filter, however, will cut off the light received from the balloon, and continue the first phase--dark balloon on light ground—until the intensity of illumination is sufficient for easy visibility in the second phase.

The very dense "monochromatic" filter *a* is occasionally useful when the balloon is in a region of intense sun glare; it can, in fact, be used to retain the balloon image until the sun's disc actually enters the field of view. The writer has only once succeeded in following a balloon across the solar disc, the experience is a trying one.

It is a matter of some little difficulty to give quantitative data as to the improvement of conditions by filters. Reduction of fatigue, increase of comfort, reduced risk of failing to pick up the image after looking away, are not readily measurable quantities. It is therefore proposed to adduce quantitative evidence of only one effect—the increase of total observed trajectory, on the assumption that the unfiltered image could have been held until, knowing its exact position in the field, the observer could no longer detect it, and that the filtered image might be lost in any manner whatever. The values of the trajectories on these assumptions were obtained in several ascents by repeated reversion from use of filter to direct observing, and noting the point of disappearance of the unfiltered image. Since the removal of a filter could be effected in less than a second, the conditions were very favourable for the detection of the unfiltered image; the ratio of trajectories thus obtained therefore will be a very considerable under-estimate of the improvement due to the filter in cases where bad visibility gave a high risk of failure to locate the unfiltered image after looking away.

Table II. (*a*) gives the computed values (one theodolite method) of the trajectories, and their ratio, in the eight cases in which the comparison was carried out.

Thus the eight ascents in which this ratio was measured give a mean increase of trajectory amounting to 62 or 68 per cent. The results are so consistent that it was not considered necessary to continue the comparison, particularly in view of the fact that on several occasions the search for the unfiltered image led to the premature loss of the filtered image—clearly visible before reversion to no filter. One such case was that of February 6th, when a 31·6k trajectory was cut short by checking back. This, and other cases of interest, are included in the Table II. (*b*) which shows the ratio of trajectories obtained with filter to estimated trajectories without filter, the estimate being based on an exceedingly strong probability that the unfiltered image would have been lost in haze or mist at, or near, an easily estimated time. This indicates to some extent how far Table II. (*a*) favours the "unfiltered" trajectory in special cases.

Lastly, notes appended to Table II. give details of notable ascents, whether in length of trajectory or in height sounded.

The ascent of 26th November provided a convenient occasion for intercomparison of filters, and the ratio of trajectories obtained by use of G, A and E filters to the "unfiltered" trajectory were 1·40, 1·50 and 1·61 respectively.

It appears, then, that the use of appropriate filters will in many cases give an improvement of trajectory amounting to from 50 to 100 per cent., and in difficult working conditions to some 400 per cent. It will also reduce the physical and mental strain of observation by greatly improving visibility and contrast, by reducing risk of losing sight of the balloon, and it will reduce eye fatigue by cutting down the integral amount of light required to give good visibility.

All the practical needs of pilot balloon work will be met by the use of a set of six types of filter, viz., K_2, G, A, F, α, and "minus red 5," preferably mounted in some such form as is shown in fig. 2 (see Appendix). This represents the filter cell now in use at Farnborough with balloons of two standard colours : (1) bright orange, for use against a blue sky ; (2) matt black, or the nearest obtainable approximation, for use against white cloud. The bright orange balloon with a "minus blue" filter has all the advantages and none of the disadvantages of the undyed balloon, and may, in cases where change of conditions or error of judgment calls for reverse of contrast in the course of the ascent, be made virtually black by the use of the "minus-red" series.

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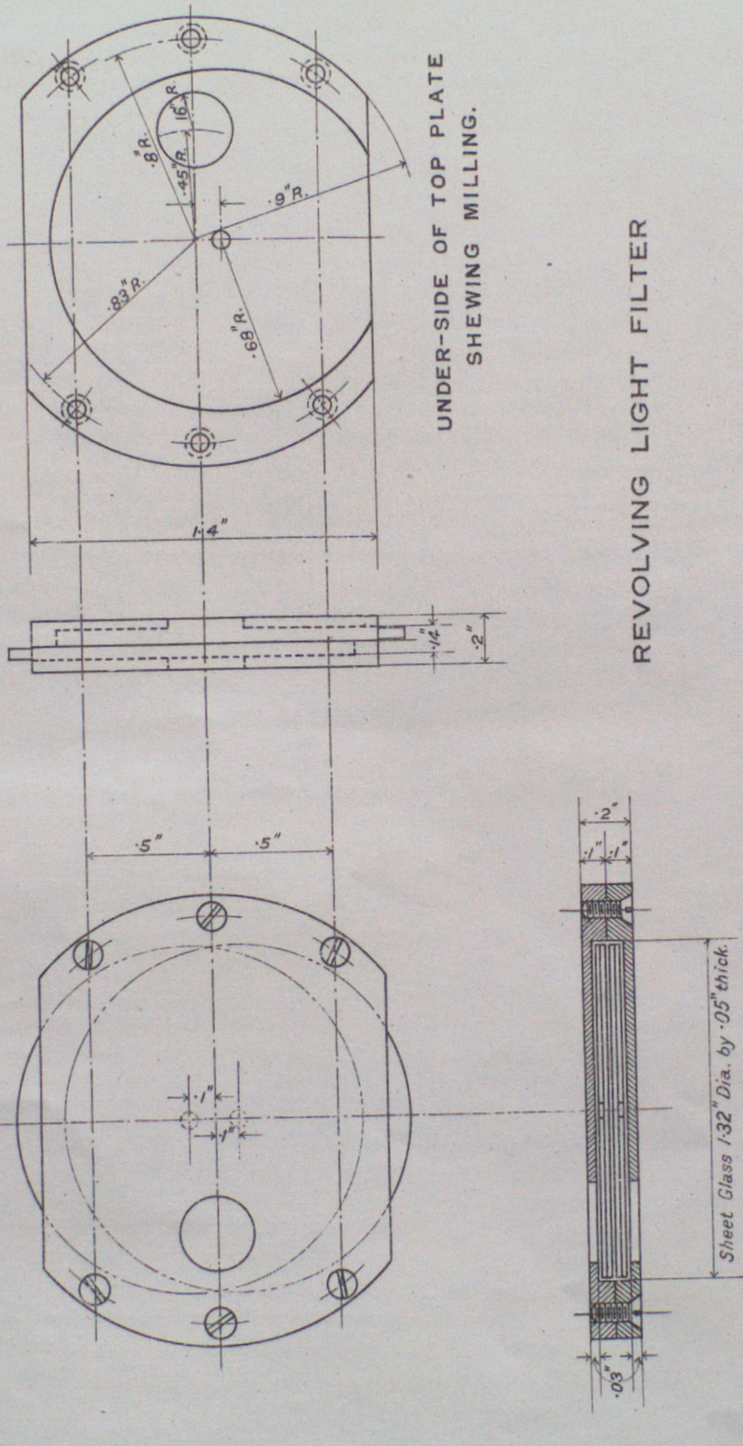

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TABLE II.—INCREASE OF TRAJECTORIES OBTAINED BY USE OF FILTERS.

(*a*) *Unfiltered image invisible at* k_1 *though position in field known.*

Date.	Time.	Colour of Balloon.	Background.	Unfiltered image lost at distance k_1	Filter in use at end.	Filtered image lost at k_2.	Ratio $\frac{k_2}{k_1}$.	Remarks
1919.								
Nov. 25 ...	1157	Orange	Blue sky	16·7	A	26·9	1·61	Pilot balloon observed to burst while easily visible.
„ 26 ...	0731	Orange	Blue sky, mist increasing.	13·3	A	21·0	1·58	Pilot balloon lost in increasing mist.
„ 26 ...	1033	Undyed	Blue sky	58·9	E	95·0	1·61	*See* note.
Dec. 8 ...	0747	Orange	Blue sky, hazy	16·0	—red 5	28·0	1·85	
„ 17 ...	0920	Orange	Ci	14·8	Stage red	23·4	1·58	Unfiltered image very faint, *see* 11 (*b*).
1920.								
Jan. 29 ...	0813	Undyed	Blue sky	12·9	F	24·8	1 92	Unfiltered image very faint, *see* 11 (*b*).
Feb. 9 ...	0748	Orange	Ci	24·2	Green	30·4	1·26	Error of judgment in choice of pilot balloon partly corrected by filter.
„ 11 ...	0814	Orange	Ci	13·3	A	21·0	1·58	
						Mean	1·62	Or omitting Feb. 9th, in which wrong colour of balloon used 1·68.

Table II.

(*b*) *Unfiltered image would probably have been lost at k_1 (estimated).*

Date.	Time.	Colour of Balloon.	Background.	Unfiltered image lost at distance k_1.	Filter in use at end.	Filtered image lost at k_2.	Ratio $\frac{k_2}{k_1}$.	Remarks.
1919.								
Dec. 17 ...	0920	Orange	Ci	11·5	stage red	23·4	2·1	
1920.								
Jan. 9 ...	0746	Deep red	Ci	17·5	F	84·0	4·8	
„ 21 ...	0815	Undyed Orange	White haze	5·0	—	—	} 4·4	Undyed pilot balloon first sent up invisible in any filter beyond 5k, orange kept by *α* filter till sun entered field. Improvement due to correct choice of balloon and filter.
„ 21 ...	0830				*α*	21·8		
„ 29 ...	0813	Undyed	Blue sky	8·0	F	24·8	3·1	
Feb. 6 ...	1458	Orange	Misty	6·0	F	31·6	5·3	Pilot balloon would almost certainly have been lost in shallow surface mist. Still easily visible in F filter when lost by search for unfilterd image (which had become more easily visible after rising through mist).

Exceptional trajectories.—Nov. 26, 95k ; Jan. 9, 84k.
Considerable heights sounded.—Nov. 26, 25·5k ; Feb. 6, 12·8k ; Feb. 7, 13·8k.

Summary.

Filters are required to absorb scattered light from haze, and to alter the relative intensities of balloon and background. An experimental eye-piece filter set, containing fifteen filters, twelve "minus blue" and three "minus red" was used.

A mean improvement of from 60 to 70 per cent. was obtained on the trajectories. This improvement was actually measured under conditions which were unfavourable to filters.

Improvement is estimated at 100 to 400 per cent. in five special cases.

Trajectories of 95 and 84k, and heights of 25·5, 13·8, and 12·8k were obtained by use of filters in winter.

Standardisation of the use of filters, and of two colours for pilot balloons is suggested.

The writer is indebted to Mr. F. H. Baker and Mr. G. L. Smith, of the Royal Aircraft Establishment, for advice and assistance in the preparation of the filters, and to Messrs. Kodak Ltd., for the technical data on filters, extracted from their booklet on "Wratten Light-Filters."

APPENDIX.

Description of the Eyepiece Filter System.

The filter system, of which working drawings are given in figure 2, consists of a double set of filters in a brass cell, which is attached to the theodolite eyepiece cover by a single screw. Each set of filters consists of five sectors of a size sufficient to cover the eyepiece aperture, the first set consisting of filters K_2, G, A, F, α, and the second K_2, G, A, F, "-red 5" cemented to a glass disc which is bored in the centre to rotate on a short pin (length less than thickness of glass) in cell. A large microscope cover glass is cemented over each set of sectors. The pin centres are arranged so that the two filter discs are eccentric, one projecting slightly above top, the other slightly below the bottom of the cell, so that they may be rotated independently, and any pair of filters superposed if necessary. Actually, however, superposition is seldom required, and a single disc in a suitably modified cell could be used.

It will be clear that the dimensions shown in figure 2 will require modification to suit the theodolite in use and the thickness of glass available for carrying the filters,