Color Glass Standardization*

A Study of 129 Lovibond Red Glasses with Respect to the Reliability of Their Nominal Grades**

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I. Introduction

PREVIOUS experience and investigations have shown that the grading of red Lovibond glasses[1] between 7.0 and 8.0, as supplied by the proprietors of the system, is inconsistent by several tenths of a unit. That is to say, glasses marked with numerals differing by several tenths of a unit may be alike in color; and, vice versa, glasses marked with the same numeral may differ in color by an amount corresponding to several tenths of a unit[2].

The purposes of the examination and sorting to be described are:

(1) To investigate these irregularities at 7.0 to 8.0 on the red scale somewhat more extensively and carefully than has been done heretofore, and

(2) To select from a large group of glasses of nominal values between 7.0 and 8.0 the ones which should truly be graded as 7.6 ± 0.1.

II. The Glasses

The glasses with which we are concerned in the present report were collected and submitted by the American Oil Chemists' Society[3]. It is understood that nearly all of them are glasses which have been in use in the grading of vegetable oils by members of that Society. When submitted, the glasses had already been labeled with numbers which will be used to identify them in the present report[4].

III. Methods of Examination and Sorting

The original intent of the present examination was merely to sort these glasses into the following groups:

(1) Those which are so nearly the standard 7.6 as not to be distinguished from it by the most careful direct comparison of color.

(2) Those which are probably greater than 7.6 but certainly not greater than 7.7,

(3) Those which are probably less than 7.6 but certainly not less than 7.5,

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**This work was carried out under the direction of Mr. Irwin G. Priest who also outlined the form which this report has taken. The authors acknowledge their indebtedness to him and also to Mr. J. O. Riley who acted as an observer.

[1]Tintometer, Ltd., Salisbury, Eng., Descriptive Circular and Price List. J. W. Lovibond, Measurement of Light and Colour Sensations, George Gill and Sons, London, Chapter II.
The Lovibond Color System—A Spectrophotometric Analysis of the Lovibond Glasses; K. S. Gibson and F. K. Harris, B. S. Sci. Paper 547, (Government Printing Office, Washington, February 17, 1927).

[2]B. S. Sci. Pap. 547, p. 9.

[3]Submitted to the Bureau of Standards by Harry P. Trevithick, President, A. O. C. S., No. 2 Broadway, New York, N. Y., as follows: Identification numbers (See table 1, first column) 1 to 187, August 4, 1927; Identification numbers 188 to 190, August 27, 1927; Identification numbers 192-195, September 24, 1927.

[4]It is understood that Mr. Trevithick has a key to the numbers showing the ownership of the glasses.

Miss Geraldine K. Walker, Research Associate of the American Oil Chemists' Society, comparing Lovibond Glasses by means of the Martens Photometer at the Bureau of Standards

Upper: Placing glass in the comparator

Lower: Adjusting brightness match and comparing hues of two glasses

(4) Those which are greater than 7.7[5], and

(5) Those which are less than 7.5[6].

As the work progressed it appeared desirable to extend it to include the actual regrading of each of the glasses to an accuracy of about 0.1 or 0.2; and, in the end, this has also been done. To imitate as closely as possible the condition under which the calibration is of most critical interest, the classification has been made with the glasses in combination with 35-yellow.

Their classification has been based solely on hue and saturation in a direct comparison of the color of the submitted glasses with the color of the standards. Brilliance has been varied and equated in judging the equality of hue and saturation; possible differences in brilliance have not, however, been regarded in this classification[7].

The color comparisons have been made by means of a Martens photometer[8], used essentially as follows:

(1) A piece of milk glass standing in a vertical plane between a north window and the photometer is illuminated by the light from the sky.

(2) The photometer, with its axis horizontal, is placed so that its photometric field is evenly illuminated by light transmitted by the milk glass.

(3) The glasses to be compared are held in a black chamber between the milk glass and the photometer so that one half of the photometric field is illuminated by light transmitted through the standard glass, or standard combination of glasses[9], and the other half by light transmitted through the glass under test. In all cases the effective portion of each glass is symmetrical about the geometrical center of that glass.

(4) The exit pupil of the photometer is covered by a 35Y glass through which the observer looks in comparing the standard glass and the glass being tested.

(5) The observer can match the brilliance of the two halves of the field by adjustment of the photometer itself.

(6) The positions of the standard and test glasses are reversed before final judgment is made.

The initial procedure was to sort the glasses into groups. First, each glass was compared with the standard 7.6 and placed as a result of this comparison into one of three groups: (1) less than 7.6, (2) indistinguishable from 7.6, and (3) greater than 7.6. Then the sorting was carried out with reference to a combination of two glasses the first glass being the standard 7.6; the second, a Lovibond red glass whose value is known to be very close to 0.1 Lovibond red unit. This combination may be thought of as a standard 7.7. Then, each submitted glass in combination with the 0.1 glass was compared to the standard 7.6. It is apparent that this procedure is

[5]In this class, glasses which are so near 7.7 as to make their classification doubtful are indicated by a question mark (?) in Table 1.

[6]In this class, glasses which are so near 7.5 as to make their classification doubtful are indicated by a question mark (?) in Table 1.

[7]For significance of these terms, see: "Report of Colorimetry Committee," Optical Society of America, J.O.S.A. & R.S.I., 6, pp. 534-535, (August, 1922). (Separate copies of this report may be purchased at 50 cents each of Professor F. K. Richtmyer, Bus. Mgr., J.O.S.A. & R.S.I., Cornell University, Ithaca, N. Y.)

[8]As exhibited to the American Oil Chemists' Society and used in testing the color discrimination of members at Memphis, Tenn., May, 1927. For original technical description of the instrument, see: Phys. Zeitschrift, 1, pp. 299-303· (1900).

[9]When the standard was a combination of two or more glasses, clear glasses were added so that the light illuminating one half the field passed through as many reflecting surfaces as that illuminating the other half.

equivalent to the comparison of each submitted glass with a standard 7.5 Lovibond red glass, the standard 7.5 being produced by negative combination with the standard 7.6. In effect, then, each submitted glass was compared to three standards, the standard 7.6, the standard 7.7, and the standard 7.5. The glasses were independently sorted against these three standards by three observers (DBJ, IGP, JOR).

The actual regrading (by GKW verified in part by DBJ) of the submitted glasses was accomplished by sorting the glasses in the same way against a large number (instead of just three) of standard combinations so chosen that each glass submitted was a close color match for one of them. The additional standard combinations were obtained by adding, either positively or negatively, other Lovibond red glasses of small known denomination to the standard 7.6. The grade of the standard combination (Table 1, *third column*) which was found to match a given submitted glass was taken as the regrade numeral (on the scale of Priest and Gibson, Cf. Section IV,) for that glass.

The results from the four observers have been compared; and doubtful or contradictory findings have been verified or corrected. The final findings of the four observers have been interpreted in the following way in order to place the glasses in the groups indicated above:

(1) A glass belongs to group 1 (indistinguishable from 7.6) provided all observers on every trial failed to distinguish it from 7.6.

(2) A glass belongs to group 2 (probably greater than 7.6 but certainly not greater than 7.7) provided, first, that one observer judged it greater than 7.6, and, second, provided also that no observer judged it greater than 7.7.

(3) A glass belongs to group 3 (probably less than 7.6 but certainly not less than 7.5) provided, first, that one observer judged it less than 7.6, and, second, provided also that no observer judged it less than 7.5.

(4) A glass belongs to group 4 (greater than 7.7) provided one observer judged it greater than 7.7.

(5) A glass belongs to group 5 (less than 7.5) provided one observer judged it less than 7.5.

IV. Standards and Accuracy

The standards are those recently established by Priest and Gibson at the Bureau of Standards[10]. The particular 7.6 glass used as standard is identified by the mark "B.S.9940"[11]. It was obtained directly from the Tintometer, Ltd., Salisbury, England, and delivered to the Bureau, December 11, 1912[12]. It was graded 7.6 by the Lovibond establishment. Its computed value is 7.59 on the scale established by Priest and Gibson from the set of glasses identified by the mark "B.S.9940." This computation is uncertain by 0.01 or 0.02 but these small differences

[10] Complete description of this standardization has not yet been published. A brief description was given orally by Priest at the Convention of the A. O. C. S., Memphis, May, 1927, and at the Twelfth Annual Meeting of the Optical Society of America, Schenectady, N. Y., October, 1927 (For abstract see J. O. S. A. & R. S. I., 16, 1928). It is expected that a complete account of this standardization will be published later as a B. S. Sci. Paper.

[11] This is the Bureau of Standards inventory number for the complete set of glasses containing the 7.6 used as standard. The glasses of this complete set have, in a sense (See Gibson and Harris, loc. cit. p. 6) been adopted as standard by agreement with the Society of Cotton Products Analysts (now American Oil Chemists' Society).

[12] On B. S. Order No. 13644.

Table 1. - Complete Summary

Identification Number as submitted	Lovibond Numeral engraved on glass (Letters refer to notes, see last column)	Approximate Lovibond Numeral found by one observer (GKW)	Lovibond Numeral as graded in this examination	Notes
181	6.0 a	6.75@	less than 7.5	a This glass was submitted by mistake since the group was expected to consist of glasses of nominal grade between 7.0 and 8.0. The engraved marks are: "Lovibond, Colour Scale, 200 NT, 6.0,". (The commas within the quotation marks, in this note and in those which follow, indicate the end of a line of engraving. They are not a part of the engraved marks.)
11	7.0 b	6.98	less than 7.5	
38	7.0 c	6.98	less than 7.5	
64	7.0 d	6.75	less than 7.5	
65	7.0 d	7.16	less than 7.5	
73	7.0 e	7.21	less than 7.5	
93	7.0 f	6.96	less than 7.5	
120	7.0 g	6.98	less than 7.5	
121	7.0 f	7.07	less than 7.5	b The engraved marks, aside from the numeral, are: "Lovibond's, Colour Scale, 200 NT, R,".
128	7.0 h	7.30@	less than 7.5	
132	7.0 h	7.18	less than 7.5	
133	7.0 i	7.27	less than 7.5 (?)	c The engraved marks, aside from the numeral, are: "Lovibond's,Colour Scale, 200 NT, N ,".
142	7.0 f	7.49@	less than 7.5 (?)	
145	7.0 j	7.33@	less than 7.5	d The engraved marks, aside from the numeral, are: "Lovibond, Colour Scale, 200 NT,".
159	7.0 b	7.03	less than 7.5	
163	7.0 k	7.34	less than 7.5 (?)	e The engraved marks are: "Lovibond's, Colour Scale, 200 NT, 7.0 R,". A paper label on this glass was marked "7.5".
167	7.0 l	7.42	less than 7.5	
184	7.0 cc	7.34	less than 7.5	
185	7.0 d	7.74	greater than 7.7 (?)	
3	7.1 j	7.27	less than 7.5	f The engraved marks, aside from the numeral, are: "200 NT",.
21	7.1 j	7.07	less than 7.5	
24	7.1 j	7.08	less than 7.5	g The engraved marks, aside from the numeral, are: "Lovibond's, Colour Scale, 200 NT, F ,".
26	7.1 j	7.07	less than 7.5	
28	7.1 f	7.91	greater than 7.7	
34	7.1 j	6.89	less than 7.5	h The engraved marks, aside from the numeral, are: "Lovibond, Colour Scale, 200 NT, H,".
35	7.1 f	7.14	less than 7.5	
45	7.1 j	7.01	less than 7.5	i The engraved marks are: "Lovibond's, Colour Scale, 200 NT, 7.0 W,". A vertical line is scratched through the digit "0" of the "7.0". On the reverse side of the glass a "7.1" is deeply etched. A paper label on this glass was marked "7.1".
47	7.1 j	6.91	less than 7.5	
72	7.1 f	7.18	less than 7.5	
79	7.1 f	7.33@	less than 7.5	
85	7.1 g	7.31	less than 7.5	
86	7.1 j	7.14	less than 7.5	
94	7.1 f	7.08	less than 7.5	j The engraved marks, aside from the numeral, are: "Lovibond's, Colour Scale, 200 NT,".
112	7.1 j	7.44@	less than 7.5 (?)	
117	7.1 j	6.89	less than 7.5	
122	7.1 f	7.34	less than 7.5 (?)	k The engraved marks are: "Lovibond, Colour Scale, 200 NT, 7.0 H, England,".
123	7.1 f	7.49@	between 7.5 and 7.6	
126	7.1 f	7.07	less than 7.5	
138	7.1 f	7.31	less than 7.5 (?)	l The engraved marks, aside from the numeral, are: "Reg'd. No., 410631, 200 NT, W,S,".
154	7.1 j	7.27	less than 7.5	
168	7.1 f	7.01	less than 7.5	m A part of this glass is chipped off. The engraved marks might correspond either to note (d) or to note (j).
169	7.1 m	7.07	less than 7.5	
170	7.1 j	6.70	less than 7.5	
182	7.1 n	8.11	greater than 7.7	n Engraved as in note (f). The numeral is 7.1, the digit "1" of the "7.1" being somewhat indistinct. A paper label on the glass was marked: "7.9 LV,".
4	7.4 o	7.87	greater than 7.7	
52	7.4 p	7.66@	between 7.6 and 7.7	
171	7.4 h	7.33@	less than 7.5	
172	7.4 q	7.34	less than 7.5 (?)	o The engraved marks are: "NT, 200, E 7.4, 7.25,". Through the "7.25" two horizontal lines have been scratched.
2	7.6 c	7.44	less than 7.5 (?)	
6	7.6 q	7.52@	between 7.5 and 7.6	
7	7.6 r	7.44@	less than 7.5 (?)	p The engraved marks, aside from the numeral, are: "200 NT, L ,". The "L" is indistinct.
10	7.6 s	7.87	greater than 7.7	
17	7.6 t	7.91	greater than 7.7	
18	7.6 u	7.69	between 7.6 and 7.7	q The engraved marks, aside from the numeral, are: "Lovibond's, Colour Scale, 200 NT, g,".
19	7.6 b	7.72@	greater than 7.7 (?)	
20	7.6 j	7.59	7.6	r Engraved as in note (l) except that a "g" appears instead of the "W".
33	7.6 v	7.42	less than 7.5 (?)	
36	7.6 w	7.84	greater than 7.7	
39	7.6 ss	7.31	less than 7.5 (?)	s Engraved as in note (l) except that the "W" did not appear.
44	7.6 q	7.76	greater than 7.7 (?)	

are quite inappreciable in a direct comparison of color.[13]

The Bureau of Chemistry, N. Y. Produce Exchange, has a 7.6 Lovibond red glass which is an exact duplicate of this standard in so far as hue and saturation are concerned. The present standard agrees to within less than 0.1 R with the standard used by Priest and Wesson in calibrating sixteen glasses in October 1920[14].

[13]For the sake of brevity, then, we say simply the "standard 7.6" although the computation

Table 1 (continued)

48	7.6 g	7.31	less than 7.5 (?)	t The engraved marks are: "Lovibond, Colour Scale, 200 NT, L 7.6,".
53	7.6 x	7.84	greater than 7.7	
54	7.6 r	7.27	less than 7.5	
58	7.6 q	7.59	7.6	u The engraved marks, aside from the numeral, are: "Lovibond, Colour Scale, 200 NT, M,".
59	7.6 u	7.29@	less than 7.5	
67	7.6 y	7.87	greater than 7.7	v Engraved as in note (1) except that an "F" appears instead of the "W".
81	7.6 j	7.64@	between 7.6 and 7.7	
82	7.6 b	7.76	greater than 7.7	
87	7.6 x	8.10	greater than 7.7	w The engraved marks are: "200 NT, N 7.6,".
88	7.6 g	7.59	between 7.5 and 7.6	
92	7.6 j	8.11	greater than 7.7	x The engraved marks are: "200 NT, g 7.6,".
95	7.6 l	7.91	greater than 7.7	y The engraved marks, aside from the numeral, are: "Lovibond, Colour Scale, 200 NT, W,".
104	7.6 b	7.34	less than 7.5 (?)	
105	7.6 b	7.34	less than 7.5 (?)	
106	7.6 v	7.59	7.6	z The engraved marks are: "200 NT, 7.6, F,".
107	7.6 q	7.76	greater than 7.7	bb The engraved marks, aside from the numeral, are: "Lovibond's, Colour Scale, 200 NT, L
108	7.6 bb	7.59@	7.6	
111	7.6 d	7.91	greater than 7.7	
118	7.6 bb	7.33@	less than 7.5	cc The engraved marks, aside from the numeral, are: "Lovibond, Colour Scale, 200 NT, R,".
124	7.6 v	7.43@	less than 7.5 (?)	
144	7.6 p	7.69	between 7.6 and 7.7	dd The engraved marks are: "Lovibond, Colour Scale, 200 NT, 7.6 R,". A part of this glass has been chipped off so that the first line of engraving might have read "Lovibond's".
147	7.6 y	7.74	greater than 7.7 (?)	
149	7.6 dd	7.74	greater than 7.7	
152A	7.6 ee	7.54@	between 7.6 and 7.7	
155	7.6 j	7.46@	less than 7.5 (?)	ee The engraved marks are: "Lovibond, Colour Scale, 200 NT, F 7.6, England,".
160	7.6 b	8.00	greater than 7.7	
173	7.6 q	7.69	between 7.6 and 7.7	
174	7.6 g	8.39	greater than 7.7	ff The engraved marks are: "Lovibond's, Colour Scale, 200 NT, H 7.6,".
175	7.6 ff	7.52@	between 7.5 and 7.6	
176	7.6 g	8.43	greater than 7.7	
177	7.6 l	7.72@	greater than 7.7 (?)	gg The engraved marks are: "Lovibond's, Colour Scale, 200 NT, N 7.6,". In the last line of engraving the "N" is indistinct.
178	7.6 q	7.74	greater than 7.7	
179	7.6 l	7.84	greater than 7.7	
188	7.6 d	7.69	between 7.6 and 7.7	hh The engraved marks correspond to note (bb). There is also an "R" through which two lines have been scratched.
189	7.6 d	7.59	between 7.5 and 7.6	
190	7.6 d	7.75@	greater than 7.7 (?)	ii The engraved marks are: "200 NT, g 7.8,".
192	7.6 d	7.64@	between 7.6 and 7.7	
193	7.6 u	7.74@	greater than 7.7 (?)	
194	7.6 d	7.75@	greater than 7.7 (?)	jj Engraved as in note (ii). A paper label on the glass was marked: "7.5 Cudahy".
195	7.6 l	7.74@	greater than 7.7 (?)	
26	7.8 gg	7.84	greater than 7.7	kk The engraved marks are: "Lovibond's, Colour Scale, 200 NT, p 8.0,". A paper label on the glass was marked "7.6".
29	7.8 hh	7.87	greater than 7.7	
85	7.8 ii	8.11	greater than 7.7	
88	7.8 q	7.69@	between 7.6 and 7.7	
89	7.8 g	8.33	greater than 7.7	ll The engraved marks are: "200 NT, 8.0 E,". The "E" is in upper case script and is indistinct.
70	7.8 c	7.84	greater than 7.7	
80	7.8 jj	8.20	greater than 7.7	mm The engraved marks are: "Lovibond, Colour Scale, 200 NT, F 8.0,".
89	7.8 b	8.20	greater than 7.7	
90	7.8 j	7.75@	greater than 7.7 (?)	
113	7.8 q	8.39	greater than 7.7	nn The engraved marks are: "Reg'd No, 410631, 200 NT, L 8.0, England,". There is also a small engraved symbol roughly resembling a crown. *See note (a).*
139	7.8 q	7.74@	greater than 7.7 (?)	
1	8.0 d	8.11	greater than 7.7	
9	8.0 j	8.20	greater than 7.7	
40	8.0 kk	7.87	greater than 7.7 (?)	oo Engraved as in note (nn) except that the "L" is omitted.
60	8.0 g	8.15	greater than 7.7	
66	8.0 d	8.17	greater than 7.7	pp Engraved as in note (j). A paper label on the glass was marked "8.1 LJ".
74	8.0 j	8.20	greater than 7.7	
96	8.0 ll	8.15	greater than 7.7	
134	8.0 mm	8.11	greater than 7.7	qq Submitted by mistake; see note (a). The engraved marks are: "200 NT, F 8.2, Lovibond's, Colour Scale,". Two vertical lines have been scratched through the digit "2" of the "8.2".
136	8.0 nn	8.22	greater than 7.7	
145	8.0 c	8.02	greater than 7.7	
161	8.0 j	8.50	greater than 7.7	
164	8.0 oo	8.33	greater than 7.7	rr Submitted by mistake; see note (a). The engraved marks are: "200 NT, g 8.9,". A paper label on this glass was marked "8.0".
180	8.0 b'	8.20	greater than 7.7	
183	8.0 pp	8.11	greater than 7.7	
186	8.0 h	8.11	greater than 7.7	ss The engraved marks are: "Lovibond's, Colour Scale, 200 NT, F 7.5,". A paper label on the glass was marked "7.1".
187	8.0 y	8.52	greater than 7.7	
129	8.2 qq	8.17	greater than 7.7	
30	8.9 rr	9.03	greater than 7.7	

@ The average of three determinations

gives 7.59. Likewise we say the "standard 7.5" and the "standard 7.7" although the computation yields 7.49 and 7.69 respectively. This designation is used in the tables which follow wherever division into the groups (1) to (5) is meant. In the third column of Table 1, however, in which is given the regrade numerals found by one observer (GKW), the values of the corresponding standards are given as computed to 0.01 Lovibond red units. We do this because we wish to give the most probable regrade numeral for each glass; but this should not be taken to imply that the observations by GKW or even the standards are accurate to 0.01 Lovibond red units.

[14]"Report on Calibration of Sixteen Lovibond Red Glasses of Nominal Value 7.6," Cotton Oil Press, January, 1921. (Separate copies of this report may be had on application to Irwin G. Priest, Bureau of Standards, Washington, D. C.)

V. Results

The essential results are summarized in the tables (1, 2, 3, 4) and graph (Fig. 1)

VI. Discussion of Results

The experimental uncertainty of the results presented in Table 1 is such that we can certify the division into groups only to 0.05 Lovibond red units. The regrade numerals presented in the third column of Table 1 represent (except as noted) a single determination by one observer (GKW); they have been checked (by DBJ) for gross mistakes such as would result from purely clerical errors; hence, we can certify them to be within 0.20 Lovibond red units of the true numeral. We believe a great majority of them are within 0.10 units of the true numeral. Certain of these glasses have been independently graded twice by one observer (GKW) and at least once by another observer (DBJ); the regrade numerals (indicated by the symbol @, in the third column of Table 1) resulting from an average of these three or more determinations may, we believe, be regarded correct to 0.10 Lovibond red units.

TABLE 2

List of Glasses Accurately 7.6

20	106
58	108

TABLE 3

List of Glasses Not Less Than 7.5 Nor Greater Than 7.7 (Including those in Table 2)

6	52	81	108	152A	188
18	58	88	123	173	189
20	68	106	144	175	192

The information in Tables 2, 3, and 4 may be found from a study of Table 1 (fourth column). This information is assembled in tabular form to render it more readily accessible. Likewise has the distribution of glasses of constant nominal value according to regrade value (shown graphically, Fig. 1) been evaluated from the results presented in Table 1 (third column).

TABLE 4

Analysis of Group Regraded Between 7.5 and 7.7 With Respect to Their Grades as Submitted

Engraved Numeral	Number of Glasses Submitted	Number of Glasses Included in Regrade Group 7.5 to 7.7
6.0	1	0
7.0	18	0
7.1	25	1
7.4	4	1
7.6	52	15
7.8	11	1
8.0	16	0
8.2	1	0
8.9	1	0
Total	129	18

It will be observed from Table 4 that, of the 18 glasses graded be-

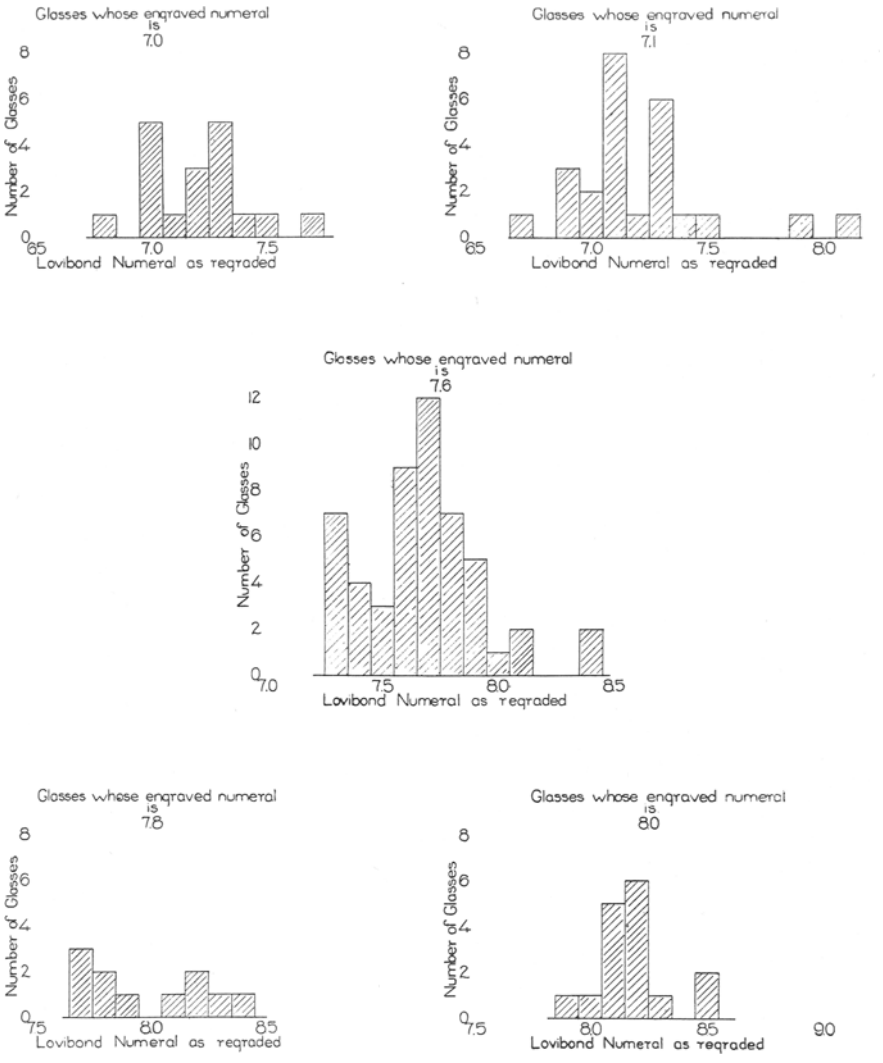

Fig. 1

The distribution of glasses of constant engraved numeral according to their regrade numerals

tween 7.5 and 7.7, 15 had been engraved 7.6. If the 129 glasses may be considered a fair sample, it may appear that a glass has little chance of being between 7.5 and 7.7 unless its engraved numeral is 7.6. Such a conclusion is not justified, however, because so few glasses of engraved numeral close to 7.6 were submitted (4 marked 7.4, none marked 7.5, none marked 7.7, and 11 marked 7.8). Indeed Table 4

does justify an expectation quite the contrary, since, of the 52 glasses engraved 7.6, only 29 per cent (15 out of the 52) were found to be between 7.5 and 7.7.

It is immediately apparent from Fig. 1 that the present regrading corroborates previous findings of inaccuracies in the engraved numerals of Lovibond red glasses between 7.0 and 8.0 if those engraved numerals are to be considered an index of color. As typical of these inaccuracies may be taken the occurrence of the regrade numerals for the glasses engraved 7.6. It is seen that these regrade numerals cover a range of 1.1 Lovibond red units. If these 52 glasses constitute a fair sample, the degree of inaccuracy to be expected in the maker's grading of Lovibond red glasses between 7.0 and 8.0 is such that two glasses having the same engraved numeral might really differ by an amount corresponding to more than 1.0 Lovibond red unit.

It may also be noted from Fig 1, without difficulty at least for glasses engraved 7.0, that the mean of the regrade numeral does not agree with the engraved numeral. In Table 5 the means of the regrade numerals (third column) are compared with the engraved numerals (second column).

It is found that the engraved numerals are consistently smaller than the mean of the regrade numerals, the differences (fourth column) ranging between 0.08 and 0.20 with an average (weighted according to the number of glasses) of 0.12. It seems safe to conclude, therefore, that, *if these* 122 *glasses can be considered a fair sample,* the scale established by Priest and Gibson departs by about 0.1 from the average Lovibond red glass between 7.0 and 8.0 in use in the United States; it is equally clear, however, that the deviation (0.12 Lovibond red units) of the scale established by Priest and Gibson is negligible in comparison with the variations which may apparently occur within a group of glasses of the same engraved numeral (See Fig. 1). To make possible a direct comparison, the average and maximum deviations from the mean regrade numeral have been computed for each group of constant engraved numeral (columns 5 and 6, Table 5). The average deviation from the mean ranges from 0.11 to 0.23 Lovibond red units with a

TABLE 5

Deviation of Grades as Submitted From the Priest-Gibson Scale Compared to Variations Among Glasses of the Same Engraved Number

Number of Glasses	Lovibond Numeral Engraved on Glass	Mean of Regrade Lovibond Numerals	Engraved Numeral Minus Mean of Regrade Lovibond Numerals	Average Deviation From Mean of Regrade Lovibond Numerals	Maximum Deviation From Mean of Regrade Lovibond Numerals
18.....	7.0	7.20	—0.20	0.17	0.50
25.....	7.1	7.20	—0.10	0.21	0.90
52.....	7.6	7.68	—0.08	0.19	0.72
11.....	7.8	7.98	—0.18	0.23	0.42
16.....	8.0	8.18	—0.18	0.11	0.32
122	Weighted Means:		—0.12	0.18	

grand average of 0.18 which is actually larger than the deviation (0.12) of the engraved numerals from the mean. The maximum deviation from the mean ranges from 0.32 to 0.90 Lovibond red units, compared to which the deviation of the engraved numerals from the mean is, of course, unimportant. The scale established by Priest and Gibson from the glasses of the Bureau set known as "B.S.9940" seems, then, to be, for red glasses between 7.0 and 8.0, a satisfactory evaluation of the average Lovibond glass in use in the United States for the grading of vegetable oils. Though not a matter of primary importance, it is perhaps fortunate that the limited number of glasses on which this scale was based happened to be a fair representation of glasses in use in this country rather than consistently high or low by 0.6 or 0.7 units as is shown in this report to be perfectly possible (See column 6, Table 5).

In investigating possible causes for these occasional large irregularities it was noted that a few of the glasses (26 out of 129, See Table 6) could easily be separated from the mass because of their abnormal shape, some being abnormally thick as if to guard against breakage (column 6) others being unfinished at the edges (column 4) as if they had been cut from a larger piece of glass without subsequent smoothing of the edges. The character of these abnormalities in shape suggests that perhaps these glasses did not originate from the Lovibond establishment but had been prepared elsewhere to serve as working standards. If this were true it would probably be safe to assume that the grading, being a grading of working standards only, would be less reliable than that performed at the Lovibond establishment. The suspicion that these glasses might not have come from the Lovibond establishment is further strengthened when it is noted that a number of these same glasses do not bear the engraved word "Lovibond." To test whether there exists a significant connection between the engraved marks and abnormalities in shape, the glasses were divided into three

TABLE 6

Connection Between the Engraved Marks and the Abnormalities in the Shape of the Glasses

Group	Criterion for Grouping	Total Number of Glasses	Number of Glasses of Abnormal Shape: Rough-Edged No.	%	Thicker Than 3 mm. No.	%	Total Number of Glasses of Abnormal Shape No.	%
1	Those having "Lovibond" engraved on them	92	3	3	5	6	8	11
2	Those have "Reg'd No. 410631" engraved on them	13	0	0	0	0	0	0
3	Those which do not belong to either of the first two groups	24	13	54	7	29	18	75
	Totals	129	16		12		26	

groups according to their engraved marks: (1) those bearing the engraved mark "Lovibond," (2) those bearing the engraved mark "Reg'd No. 410631" but not "Lovibond," and (3) those bearing neither of these marks.

Table 6 shows that there *is* a connection between the engraved marks and the abnormalities in shape; 75 per cent (18 out of 24) of the glasses in group 3 are of abnormal shape, and 69 per cent (18 out of 26) of the glasses of abnormal shape are also glasses of group 3. It is concluded, therefore, that the glasses in group 3 are probably different in origin from those of groups 1 and 2. Perhaps they are working standards rather than authentic Lovibond glasses. If this is the case, it is possible that the engraved numerals of the glasses of group 3 are less reliable as an index of their color than those of the glasses of groups 1 and 2. Table 7 serves to investigate this possibility by evaluating the average deviation of the regrade numerals from the engraved numerals.

It is shown in table 7 that the mean deviations of the regrade numerals from the engraved numerals are, in three cases out of five, greater for group 3 than for groups 1 and 2, being particularly greater for glasses having engraved numerals 7.1 among which glasses many (11 out of 21) of the glasses of group 3 occur. It is safe to conclude that the glasses of group 3, tentatively regarded as working standards, are somewhat less accurately graded by their engraved numerals than are glasses of groups 1 and 2. The average mean deviation for group 3 is 0.258 as compared to 0.192 for groups 1 and 2.

TABLE 7

Relative Reliability of the Engraved Numerals of Group 3 and the Engraved Numerals of Groups 1 and 2

Lovibond Numeral Engraved on Glass	Number of Glasses (n)			Average Deviation From Lovibond Numerals (D)		
	All Glasses	Groups 1 and 2	Group 3	All Glasses	Groups 1 and 2	Group 3
7.0	18	15	3	0.22	0.23	0.20
7.1	25	14	11	0.20	0.14	0.27
7.6	52	48	4	0.20	0.19	0.25
7.8	11	9	2	0.24	0.21	0.35
8.0	16	15	1	0.19	0.20	0.15
Totals.....	122	101	21	Mean 0.205	0.192	0.258

Group 3, then, is made up of glasses which are less copiously engraved, less carefully finished and less carefully graded. It is consistent to regard group 3 as made up of working standards rather than primary standards. The primary standards themselves (groups 1 and 2), however, are not strikingly superior to the working standards since they are characterized by an average deviation only about 30 per cent smaller (compare 0.192 with 0.258). The separation of group 3 has served to account, then, for only a minor portion of the errors discovered in the engraved numerals as indices of color. The numerals engraved on Lovibond red glasses between 7.0 and 8.0 must, therefore, be regarded as only an approximate index of their color.