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REPORT NO. 880

INFORMATION ON THE INSTITUTE'S LIMNOPHOTOMETER

by

John Greenbank

Part I: CALIBRATION AND TEMPERATURE CORRECTION

Foreword

Presumably it was the famous second-century Greek philosopher, Pantosteus, who originated the saying, "The blind man has at last come through the forest, but lo his hands are torn and bleeding!"

The scientific experimenter, seeking by an untried and uncertain method to obtain information, may find that before the desired result is to be had many obstacles must be overcome, many seemingly unexcusable mistakes will be made, and an unbelievable amount of time will be consumed.

So it was in the experiment described below. Inexperience, trial-and-error procedure, and improvised apparatus, all combined to cause delay and inconvenience. Matters which seem absurdly trivial, such as the turn of a bulb in its socket or the color of a man's shirt, suddenly assumed great importance. Many blind leads were followed, and many mistakes were made. Yet finally there emerged the needed and usable information. The blind man had managed to stumble through the forest!

Introduction

In the course of an extended study of winter-time lake conditions[1] a considerable number of measurements were made of the relative penetration of light through various kinds and amounts of ice and snow. For this purpose a limnophotometer with special adaptations was used. A brief description of the instrument is given in the next section.

The heart of the photometer is a factory-built Weston photometric unit, which originally was, per se, calibrated to read in light-intensity units, i.e., in foot-candles. However, in the construction of the limnophotometer, the physical and electrical characteristics of the Weston unit were so modified that the resulting instrument is not direct-reading in photometric units. Rather, it may be read directly only in scale-units.

In order to evaluate these readings in terms of absolute photometric units, it was necessary to obtain some sort of factor, equation, or curve, of conversion. It is true enough that rough comparative, or relative,[2] figures may be obtained simply by dividing one scale reading by another. But such calculation rests upon the assumption that the conversion factor, from scale-units to photometric units, is a constant, which assumption has proved to be not strictly true.

1/ I. F. R. Report 853: Limnological Conditions in Ice-Covered Lakes, Especially as Related to Winter-Kill of Fish. John Greenbank.

2/ Specifically, what usually is desired is the percentage penetration of light through a given layer of ice, snow, or water; i.e., the per cent of the light incident upon the upper surface of that layer which emerges from the bottom surface.

Furthermore, for some purposes (especially for comparison with the data of other workers), it is desirable to express the readings in terms of absolute units. Therefore it became the purpose of the experiments herein described to establish a means of conversion.

A secondary purpose was the discovery of the relationship of temperature and scale-readings; since the instrument has been, and may be, used at various temperatures. As may be inferred from the discussion below, this temperature relationship, although a simple thing mathematically, proved to be somewhat involved and tedious in its development.

Much more than merely perfunctory acknowledgement is due to W. F. Carbine, of the Institute staff, for his willing and patient assistance throughout the tedious, repetitious, and at times seemingly almost futile, work of the experiments, a considerable portion of which work was done outside of regular working hours.

Also greatly appreciated are the help and advice generously given by Professor H. H. Higbie, of the University of Michigan College of Engineering, and the use of laboratory facilities of the Electrical Engineering Department. Thanks are extended to D. S. Shetter and Louis A. Krumholz, of the Institute, for assistance in the experiments; to C. M. Flaten, for drafting; and to W. C. Beckman, for photography.

Description of Instrument

The photometer was designed, in 1941, by the writer and Grant J. Lindenschmidt, who was then craftsman for the University Museums, and it was constructed by Mr. Lindenschmidt in the Museums' shop. It follows, in general, the usual design of submerged photometers, but has certain modifications for use under the ice. A complete description of the instrument, as well as references to the literature on photometric measurement in water, given in the Institute for Fisheries Research Report No. 853 referred to above.

Two Weston "Photronic" cells are mounted, in tandem, in a water-tight brass case. The case is rectangular in shape; and it has, in its upper wall (or lid), twin windows of plate glass, directly above the two cells. Above these windows is a space in which may be inserted, as occasion demands, a color filter or other filtering unit. This space usually is water-filled, but may be air-filled if necessary. Above this space is a second window, of opal flashed glass. This window is removable, for the insertion of color filters, but is always used, since its function is the diffusion, or dispersion, of light rays, which diffusion prevents the loss of certain low-angle light.[3] The upper surface of this diffusion window constitutes, specifically, the "target" which is referred to in discussions below.

Color filter glasses are provided, covering certain specified ranges in the red, blue-green, and blue-violet regions of the spectrum. In addition two interchangeable neutral gray filters, made of exposed and developed photographic film, were used, in the winter work mentioned above, to reduce the light intensity on bright days.

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[3] For a discussion of the function of this diffusion glass, as well as other theoretical aspects of limnophotometry, see: Atkins, W. R. G., et al; Measurement of Submarine Daylight; Journal du Conseil International pour L'exploration de la Mer; Vol. XIII, No. 1, 1938.

The present photometer, incidentally, conforms in all essential respects with the standard specifications set forth in this paper.

The "Photronic" cells are connected by a water-proof electrical cable to an extremely sensitive microammeter. This meter has six ranges, and a range-selector switch.

The cell-containing case may be suspended in the water by its electrical cable; or, by means of a detachable pipe handle, it may be thrust through a hole in the ice, and held under the ice at a distance of a foot or more away from the hole.

The operation of the instrument is, very briefly, as follows. A meter reading is made with the target just under the selected layer of snow, ice, or water. Then, immediately, a reading is made with the target just above that layer; i.e., generally, in the air. (In practice, several alternate readings usually are made.) During the time consumed by this process the conditions of sky, and therefore of light, must remain unchanged. The two readings, after appropriate conversion to photometric units, are used to make a percentage calculation.

Calibration Procedure

1. Standardization with Known Light Source.

It was essential to find, first, the mathematical relationship between the meter reading and the actual amount of light incident upon the target of the photometer (as explained above, the instrument has been modified so that it no longer reads directly in foot-candles, as it did when it came from the Weston factory). For this determination, a horizontal bar and slider arrangement, in the photometric laboratory of the Engineering College, was used. By means of this device the distance between the light source and the target of the photometer could accurately be measured, to the nearest millimeter.

The light source consisted of a Wabash B2 type, 500-watt, daylight blue, photoflood incandescent bulb. This type bulb was chosen because of its relatively high light production at an approximate "point-source," and because the spectral quality of its light is fairly close to that of diffuse daylight.

The B2 bulb was standardized by photometric comparison with a "primary" standard, i.e., a U. S. Bureau of Standards Certified bulb. By means of a Lummer-Brodhun[4] visual comparison photometer, the ratio of the light intensities of the two bulbs was obtained, and hence the light-power of the B2 bulb could be computed.

Then the bulb was placed at various measured distances from the target of the limnophotometer, and for each distance the meter reading was recorded. With the light distance and the light intensity known, the foot-candles incident upon the target could be calculated.

This calibration experiment was performed on June 1, 1942, by Professor Higbie and the writer. The temperature of the cells during the experiment was, through oversight, not measured. By back-calculation made later (see the following sections), it was determined to have been approximately 35° C.

Next in logical, although not in chronological, sequence was the second performance of this calibration, at another (and this time a recorded) temperature. This was done on August 6, 1942, by

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[4] Cf. any standard physics text-book.

W. F. Carbine and the writer. The temperature of the cells was approximately 27° C.

2. Determination of Temperature Effect

It was necessary to know, secondly, the quantitative effect of temperature upon the meter reading. It is true that temperature correction coefficients accompanied the original factory-built unit; but it was presumed (and correctly so) that these would no longer obtain after the modification in construction. Furthermore it is probable that these coefficients were only approximations; since they depended upon the assumption that the current evolved by the cells, and hence the meter reading, is in "straight-line" proportion to the temperature—an assumption which apparently is not valid (see mathematical discussion below).

In the calibration procedure described above, the temperature of the cells was dependent upon that of the air in the laboratory; it was not possible to vary this temperature readily, nor through any very large range. Therefore an apparatus was constructed, by means of which the temperature of the cells could be held at any desired temperature from 0° C. to 40° C., while light-measurements were made. This equipment was set up in a room (in the University Museums Annex) which could be made reasonably light-tight.

The apparatus (Figures 1 and 2) consisted, essentially, of a vertical bar and a slider which could be set at any desired height and which carried a light bulb. Two bulbs were used, one at a time. Very strong light (for the higher scales of the meter) was obtained from a Wabash B2 type bulb (not calibrated); and for light of a lower intensity a 50-watt daylight blue bulb was used.

Directly beneath the light bulb, the target of the photometer was placed in a metal tub, where by submersion in water it could be kept at a given temperature. Temperature stabilization was brought about by the addition, from time to time, of small amounts of either hot water or ice, as needed. The inside of the tub was painted black, to minimize stray light rays. A small electric fan was used to prevent local warming effects ffom the heat of the light bulb.

The usual performance of a "run" was as follows. The tub was partially filled with water, covering the upper face of the target. As indicated above, the temperature was maintained at a constant value. The slider was set at several successive points oh the bar, and at each setting a meter reading was made. Each of the points on the bar was marked with crayon. Then the temperature of the water was changed, and with the slider set at the same points a new series of meter readings was obtained. This procedure was repeated for each of several temperatures.

Thus, for each slider setting, comparative readings at two or more temperatures, but with the same light-power and light-distance, and hence with the same light-intensity, were obtained. It must be emphasized, however, that the absolute values of these light-intensities were not known. Neither had the light bulb been standardized, nor was it feasible with such comparatively crude apparatus to measure accurately the light-distance.

The originally intended use of the data obtained, as well as their final disposition, will be discussed below.

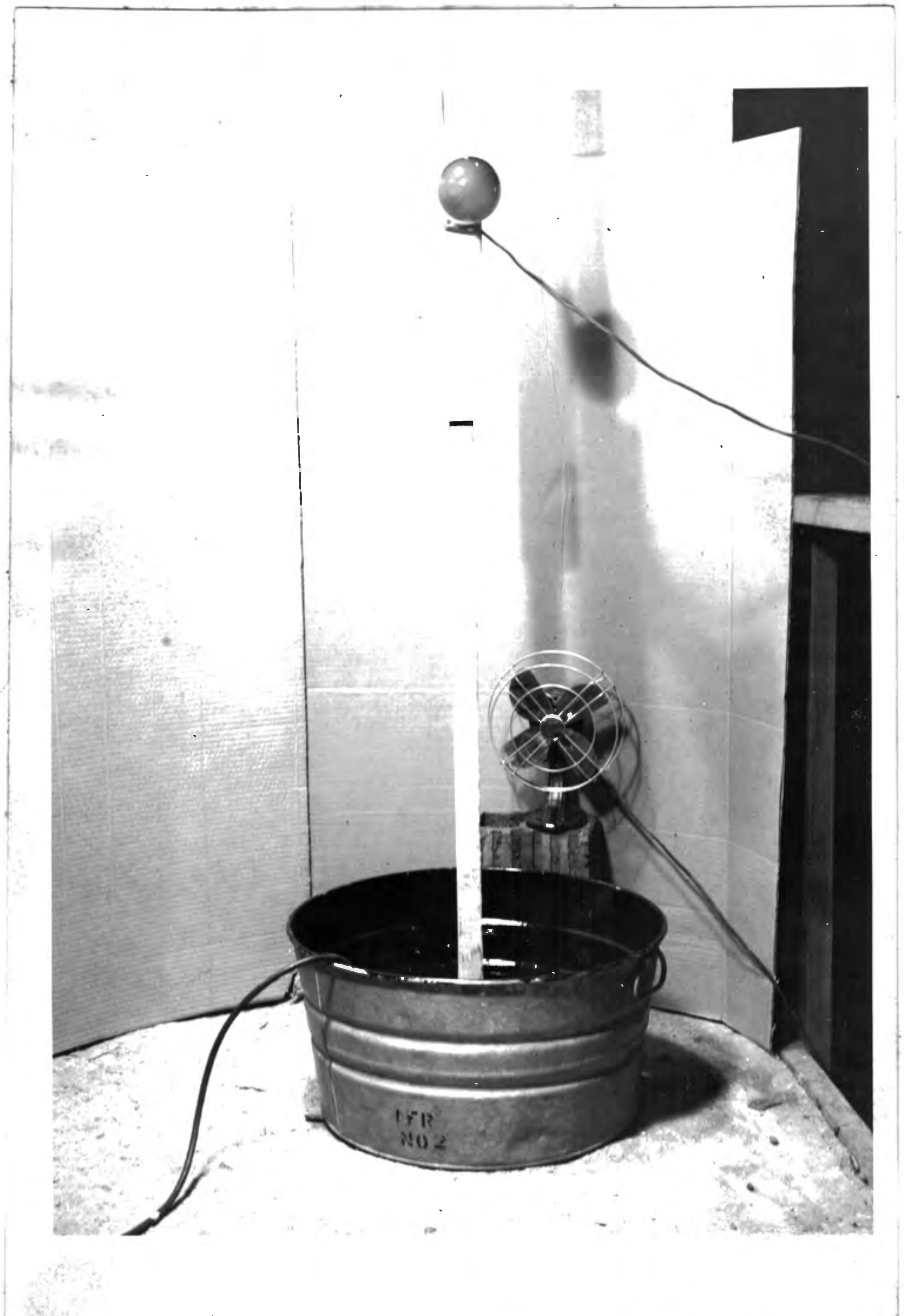


Fig. 1. Apparatus for obtaining temperature correction data for limnophotometer.

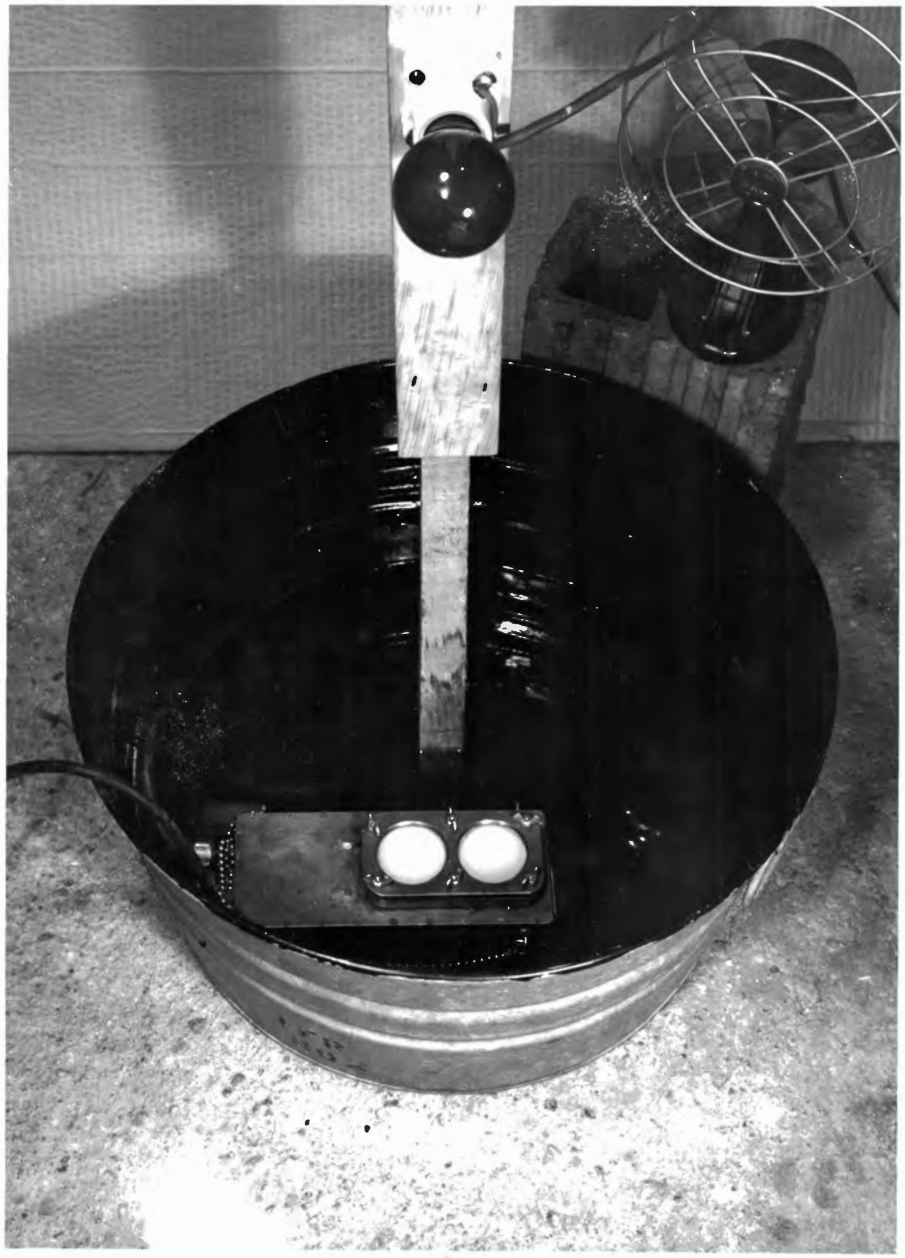


Fig. 2. Close-up view of apparatus of Fig. 1.
The "receiver" of the limnophotometer
is shown in the tub.

In all, this experiment was performed seven times, various modifications of the apparatus and technique being adopted from time to time. These changes can best be shown by a resumé of the seven runs.

(1) June 19, 1942. In this initial run, a clamp-on reflector, rather than the later-used slider, was used to hold the light bulb. The clamp-on socket proved to be much too unstable; the identical setting of distance and angle of light could not be duplicated; and the data obtained were worthless.

(2) June 22. The slider arrangement was adopted, giving stability and duplicatibility to the bulb setting. However, following this performance it was found that light-colored clothing worn by the operator was responsible for a significantly large amount of stray light reflection. Hence in subsequent work the operator stood well back from the apparatus during each reading.

(3) July 1. Still not all of the "kinks" had been removed. After this run there was discovered what proved to be a very large source of error. During each series of readings (i.e., the readings at each separate temperature), one of the two bulbs used was taken from the socket on the slider, and the other bulb was inserted in its place. In this exchange, it often occurred that a bulb would be farther rotated in the socket during a series of readings at one temperature than during that at another. Since the filament in the bulb was unsymmetrical in the particular plane in question, a small part of a turn meant a considerable change in light-power. The error likely to have arisen from this source was sufficient to

render all of the data of the first three runs useless.

(4) July 3. To obviate the error mentioned just above, a duplicate slider was used. Thus each bulb remained in position in its socket throughout a run, the sliders being interchanged. Temperatures used in this run were: 0°, 10°, 25°, and 40° C.

(5) July 5. No change in the apparatus was made. Temperatures from 0° C. to 40° C., in small steps, were used; but relatively few readings were made at each temperature.

(6) July 24. In order to prevent error from stray line-voltage fluctuations, a voltmeter and a rheostat were introduced into the light circuit. This refinement, although desirable, probably was not strictly necessary; for the line-voltage was found not to fluctuate greatly. Hence in the mathematical treatment of the data (see below), the results of the run of July 3 are held to be sufficiently accurate to be usable.

In this sixth run, temperatures at which readings were taken were: 0°, 10°, 25°, and 40° C.

(7) August 2. The apparatus and technique were the same as in the preceding run, except that the voltmeter was not used. A few readings were made at each of these temperatures: 15°, 20°, 25°, 30°, 35°, and 40° C.

Mathematical Analysis of Data

The mathematical treatment of the data, and the conclusions and curves derived therefrom, can best be presented in a series of steps, as follows.

a. The data obtained in the experiment of June 1 (see above) were transformed into foot-candles and corresponding meter readings, and drawn up into Table 1. Since the instrument was too sensitive to yield readings on the lower (that is, the 3 and $1\frac{1}{2}$) scales at the light distances obtainable with the apparatus, these figures (Table 1A) were obtained indirectly, by the use of a neutral filter. This filter was, itself, first calibrated, by making corresponding readings with and without it.

The figures in the last column in Table 1 and Table 1A are perhaps self-explanatory. Were these figures (for any given scale) a constant, it would mean that the meter-reading would be directly proportional to the light-intensity; in other words, a "straight-line" relationship would be indicated. However, these figures vary, in regular progression, showing that the curve which represents the relationship of meter-reading to light-intensity (examples of which curve are shown in the graphs of this paper) is not a straight line, but is the curve of a higher-degree equation of some sort.

b. The figures of Tables 1 and 1A were plotted on cross-section paper in a set of six curves (one for each scale of the meter), thus making a "working" graph. This graph is not included herein, since it was constructed only for the purpose of making further calculations. It was, however, similar to Graph 1, except that it had six curves, rather than three (the process of lumping these curves is described below).

TABLE I

Calibration of Limnophotometer, with a Light Source
of Known Intensity. June 1, 1942
For Detailed Information, see Footnotes and Text

Scale	Meter Reading	Distance from Light to Target, feet	Foot-candles Incident on Target	Foot-candles ÷ Reading √
300	300	0.758	1414	4.71
	250	0.873	1068	4.27
	200	1.012	794	3.97
	150	1.222	545	3.63
	100	1.555	336	3.36
	50	2.27	158	3.16
150	150	1.114	655	4.37
	125	1.265	508	4.06
	100	1.468	378	3.78
	75	1.760	262	3.50
	50	2.21	167	3.34
	25	3.27	76	3.04
30	30	2.62	119	3.97
	25	2.95	93	3.72
	20	3.38	71	3.55
	15	4.00	51	3.40
	10	5,15	31	3.10
	5	7.26	15.4	3.08
$7\frac{1}{2}$	30	5.34	29	3.87
	25	5.98	22.7	3.63
	20	6.86	17.3	3.46
	15	8.14	12.3	3.28
	10.5	9.88	8.3	3.17
3	30	8.57	11.1	3.70
	25	9.65	8.7	3.48
	24	9.88	8.3	3.46

Temperature = approximately 35° C.
Intensity of B2 bulb used as light source = 813.2 candle-power

√ For the $7\frac{1}{2}$-scale, use reading ÷ 4
For the 3-scale, use reading ÷ 10

Sample Calculation:
Distance = 0.758 ft.

$$\frac{813.2}{(0.758)^2} = \frac{813.2}{0.575} = 1414 \text{ Foot-candles}$$

$$1414 \div 300 = 4.71$$

TABLE IA

Calibration of Limnophotometer, Continued.
A Neutral Filter was Used. June 1, 1942
See Notes, and Text

Scale	Meter Reading	Foot-candles Incident On Filter	Foot-candles Reaching Target	Foot-candles ÷ Reading√
3	20	138	6.9	3.45
	15	97	4.85	3.23
	10	63	3.15	3.15
	5	30.4	1.52	3.04
1½	30	104	5.2	3.47
	25	85	4.25	3.40
	20	67	3.35	3.35
	15	47	2.35	3.13
	10	30.9	1.55	3.10
	5	14.9	0.75	3.00

√ For 3-scale, use reading ÷ 10
For 1½-scale, use reading ÷ 20

Temperature = approximately 35° C.
Intensity of B2 bulb = 813.2 candle-power
Factor for filter = 20.0

Sample Calculation:
Foot-candles reaching filter = 138
Foot-candles reaching target = 138 ÷ 20.0 = 6.9

6.9 ÷ (20 ÷ 10) = 3.45

The temperature at which these figures had been obtained was not, as yet, known. For working purposes, however, it was assumed, for the time being, to have been approximately 40° C.

c. Similarly, a graph was constructed from the data of Table 2, which data were obtained at a known temperature, namely 27° C. This graph, with certain adjustments and modifications (such as the lumping of six curves into three), eventually became Graph 2.

d. The next step was to establish more firmly the relationship of meter-readings at 25° (or 27°) with those at 40°, as well as those at other temperatures.

Originally it was presumed that the meter-reading, for any one scale, might be shown to be a first-degree function of the temperature, and hence that only a factor, rather than a curve, would be needed to make temperature corrections. However, it became evident upon inspection of the data that the case is otherwise. It is apparent not only that such relationship is of a higher degree (seemingly somewhat sigmoidal), but also that a separate temperature-correction curve would be required for each portion of each scale.

Thus, to ascertain the foot-candles equivalent to a given meter reading at a given temperature, use would have to be made, successively, of an instrument-calibration curve and a temperature-correction curve. Why not, then, combine these curves, and thus produce a series of different instrument-calibration curves, for different temperatures. Thus only one curve would need to be used for any one reading. In the following paragraphs the process of effecting that combination is described.

By the use of the data obtained in the experiments of July 3, July 24, and August 2 (see above), there could be obtained, for a

TABLE 2

Calibration of Limnophotometer. August 6, 1942
For Explanations, See Tables 1 and 1A, and Text
Temperature, 27° C.

Scale	Meter Reading	Foot-Candles
300	278	1100
	194	684
	130	428
	91	288
150	135	520
	107.5	387
	76.5	256
	57	183
30	28.9	107
	24.0	85.2
	20.1	69.5
	17.0	56.9
	14.2	46.1
	11.0	34.9
	8.8	26.4
7½	28.5	26.4
	24.3	21.9
	19.0	16.1
	15.0	12.6
	10.4	8.3
3	29.0	10.2
	24.4	8.3

TABLE 3

Temperature Correction Data. July 3, 1942

For Treatment, See Text

Scale	Meter Reading At 0° C.	10° C.	25° C.	40° C.
300	248	239	223	200
	222	214	199	180
	190	179	168	155
	170	162	157	142
	136	132	126	115
	89	85	83	76
150	131	127	119	109
	104	102	96	88
	80	76	74	68
	69	67.5	65	60
	55	54	52	48
	42.5	42	40	37.5
30	26.2	26.0	24.6	23.3
	22.5	22.3	21.2	20.0
	18.3	18.0	17.4	16.5
	15.5	15.0	14.5	13.7
	13.1	12.8	12.2	11.7
	9.9	9.7	9.3	8.9
7½	28.0	26.7	25.9	23.6
	25.8	24.6	23.6	21.5
	20.2	19.2	18.4	17.0
	16.3	15.5	15.0	13.9
	13.8	13.0	12.5	11.5
	10.4	10.0	9.6	8.9
3	26.8	25.5	23.9	21.5
	23.5	22.5	21.1	18.9
	20.0	19.0	17.9	16.0
	16.7	16.2	15.2	13.6
	14.0	13.4	12.6	11.2
	10.0	9.8	9.2	8.3
1½	28.0	26.2	25.2	22.4
	23.6	22.3	21.0	18.7
	20.8	19.9	18.8	16.8
	18.2	17.3	16.4	14.6
	15.0	14.4	13.3	12.0
	8.7	8.3	7.6	7.0

TABLE 4

Temperature Correction Data. July 24, 1942

For Treatment, See Text

Scale	Meter Reading At			
	0° C.	10° C.	25° C.	40° C.
300	166	163	155	135
	137	136	131	113
	124	125	117	105
	100	99	95	83
	65	65	65	53
150	97.5	97.5	93	81
	78	77.5	75	66
	59	59	56	51
	50	50	48	43
	41	40	37.5	34
30	26.2	25.5	24.5	22.5
	20.0	19.7	19.0	17.6
	17.0	16.8	16.2	15.2
	13.7	13.7	13.3	12.3
	11.2	11.2	11.0	10.3
	9.6	9.5	9.0	8.7
7½	23.1	22.8	22.0	20.5
	21.5	21.2	20.6	18.7
	16.8	16.5	16.0	14.5
	13.5	13.2	13.0	11.5
	11.3	11.0	10.8	9.3
	8.4	8.2	8.1	7.2
3	21.9	21.4	20.6	18.0
	18.9	18.7	18.0	15.6
	16.5	15.7	15.0	13.1
	14.0	13.5	12.9	11.2
	11.4	11.0	10.6	9.4
	8.4	8.1	7.7	6.5
1½	22.7	22.1	21.3	18.8
	19.5	18.9	18.1	15.7
	17.2	16.4	16.0	13.5
	15.0	14.5	14.0	12.0
	12.1	11.6	11.1	9.7
	7.1	6.9	6.6	5.5

TABLE 5

Temperature Correction Data. August 2, 1942

For Treatment, See Text

Scale	Meter Reading At					
	15° C.	20° C.	25° C.	30° C.	35° C.	40° C.
300	205 158	200 155	193 147	182 140	170 133	165 128
150	122.5 73	120 72	115 70	110 67	106 65	102.5 63
30	24.8 16.8	24.0 16.6	23.7 16.0	22.5 15.5	21.7 15.0	21.4 14.8
$7\frac{1}{2}$	26.1 18.3	25.5 18.3	24.5 17.2	23.7 16.3	23,1 16.0	22.6 15.8
3	23.9 18.0	23.2 17.3	22.0 16.1	21.0 15.5	20.3 14.7	19.9 14.4
$1\frac{1}{2}$	20.8 16.5	20.8 16.0	19.0 14.7	18.5 14.2	17.6 13.7	17.0 13.2

given meter-reading at 25°, the corresponding reading at 40°, or vice versa (Tables 3, 4, and 5).

The readings obtained at 25° were translated, by means of the working graph (see c., above), into foot-candles. Then, from these values in foot-candles, and the meter-readings at 40°, a new working graph (for 40°) was constructed.

Similarly, from the original working graph for 40°, and the data of Tables 3, 4, and 5, a second working graph for 25° was made.

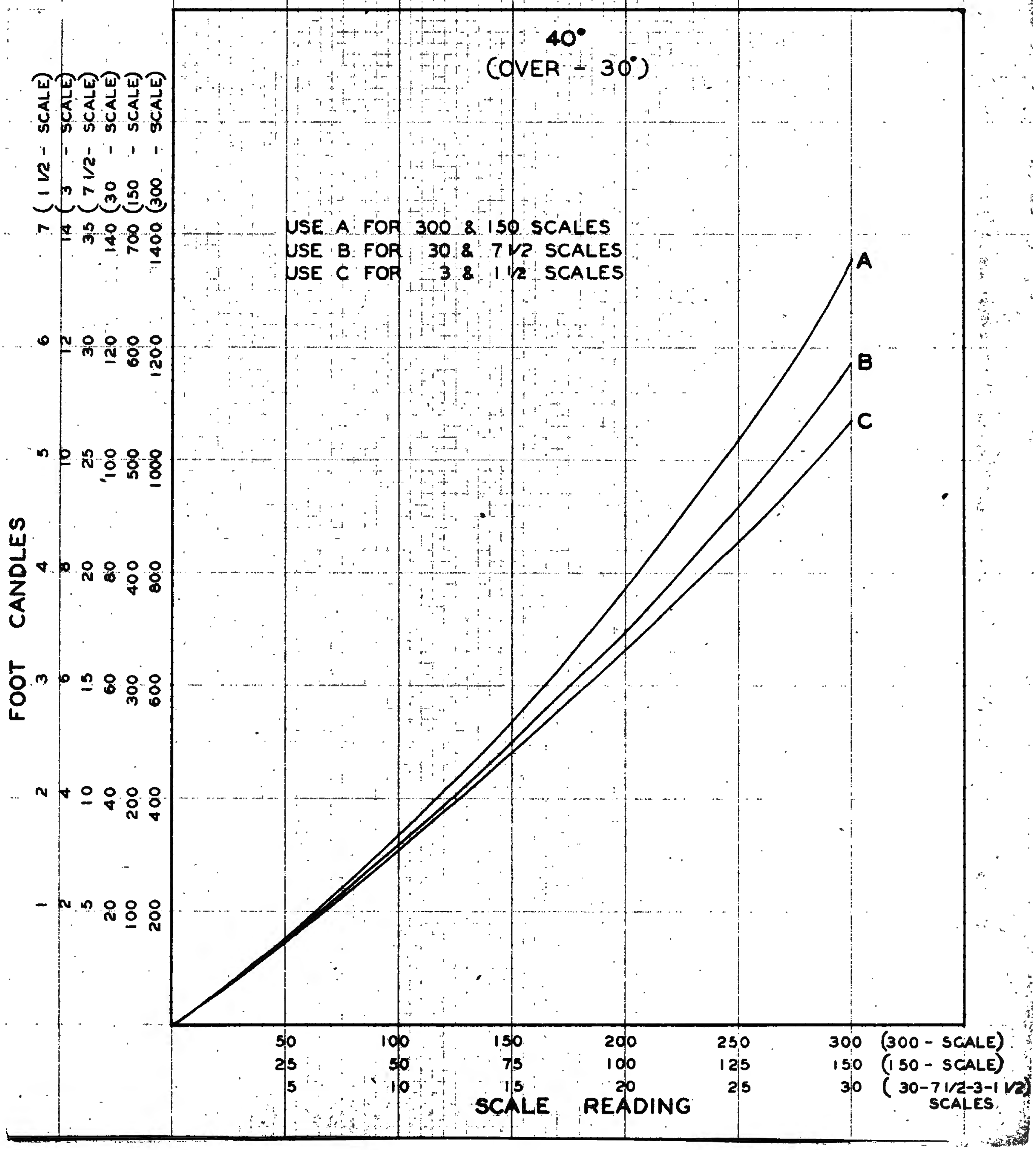
e. There were now at hand four trial graphs: one labelled "25°", and based on data obtained at 27° (see c.); one called "40°", and based on data obtained at approximately 35° (see b.); and one each, "40°" and "25°", constructed by use of the first two, respectively, and Tables 3, 4, and 5 (see d.).

It may be seen that the two of each pair of these graphs were not strictly identical, since they were based upon somewhat different temperatures. However, the difference between 25° and 27° is relatively slight; and that between 35° and 40° is, in effect, rather small, since in that part of the temperature range the effect of temperature is not so great.

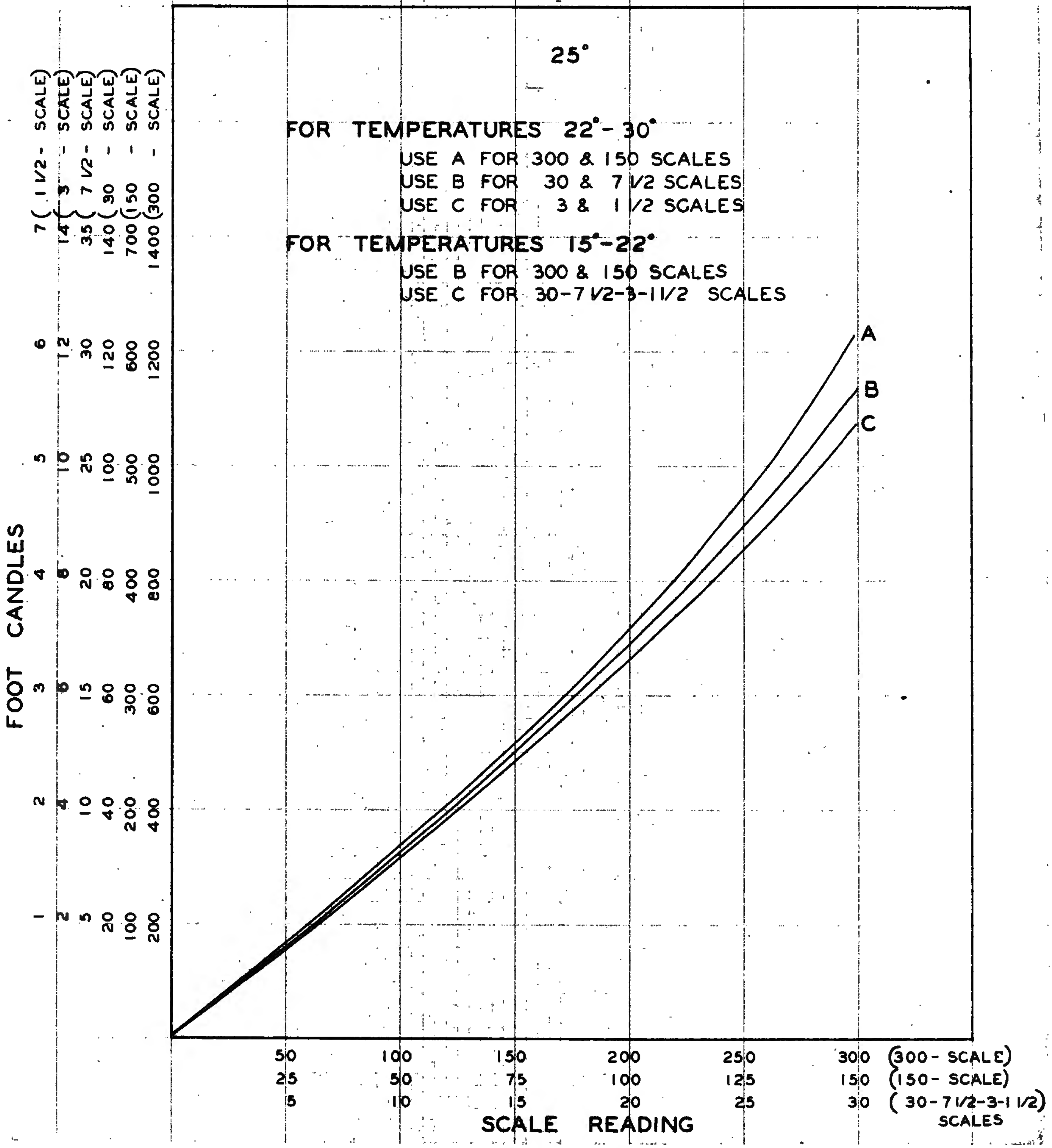
Hence, for practical purposes, the graphs of each pair were nearly enough alike so that, by minor inter- or extrapolation, reasonably true graphs for the desired temperatures (Graphs 1 and 2) could be obtained.

f. Next, a procedure similar to that of d. was used to construct a graph for 0°, by using the graphs for 25° and 40° and the data of Tables 3, 4, and 5. This graph (with modifications) is presented as Graph 3.

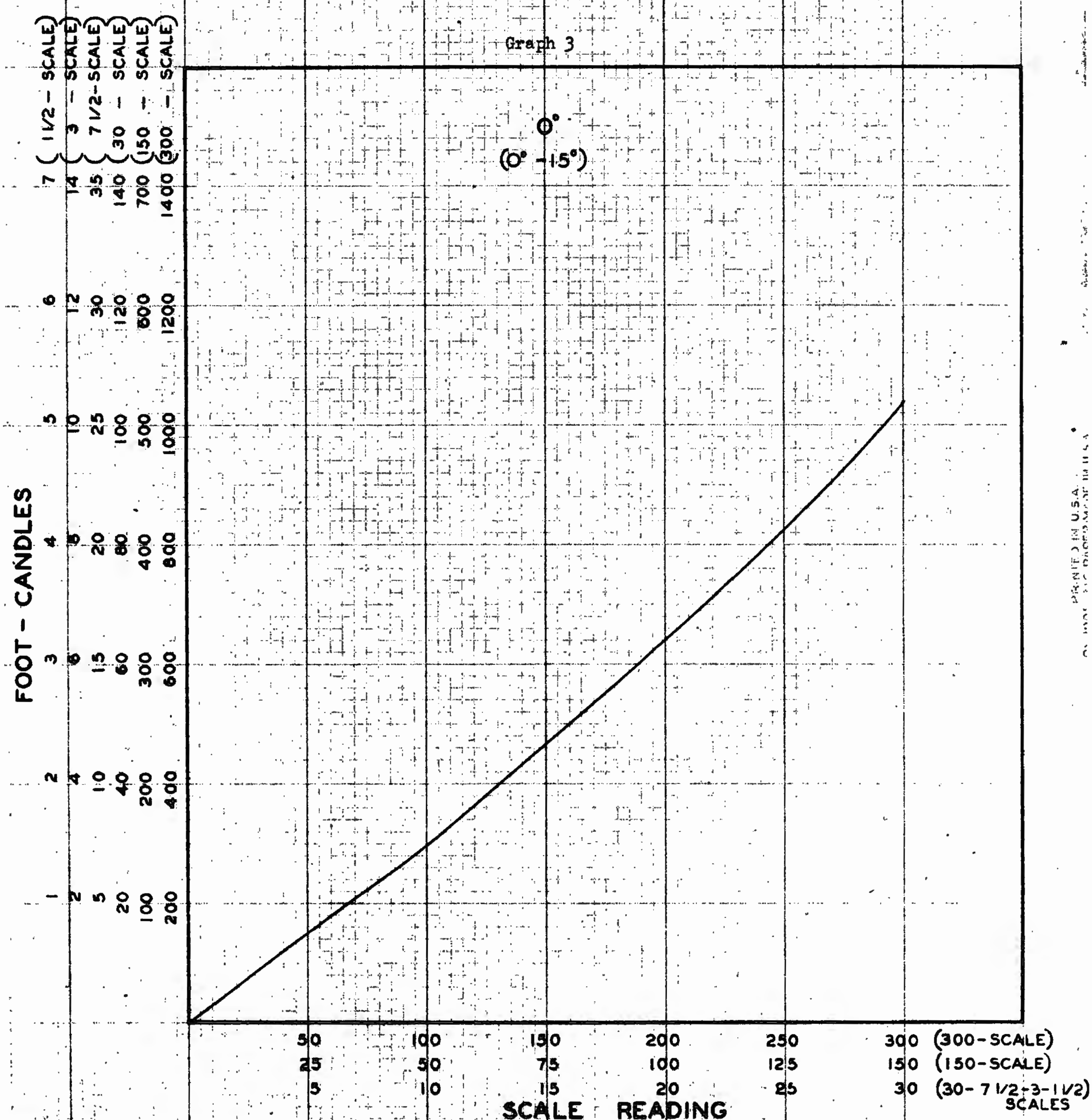
Graph 1


40°
(OVER - 30°)
USE A FOR 300 & 150 SCALES
USE B FOR 30 & 7 1/2 SCALES
USE C FOR 3 & 1 1/2 SCALES
A
B
C
FOOT CANDLES
7 (1 1/2 - SCALE)
14 (3 - SCALE)
35 (7 1/2 - SCALE)
140 (30 - SCALE)
700 (150 - SCALE)
1400 (300 - SCALE)
6 12 30 120 600 1200
5 10 25 100 500 1000
4 8 20 80 400 800
3 6 15 60 300 600
2 4 10 40 200 400
1 2 5 20 100 200
50 100 150 200 250 300 (300 - SCALE)
25 50 75 100 125 150 (150 - SCALE)
5 10 15 20 25 30 (30-7 1/2-3-1 1/2) SCALES
SCALE READING

Graph 2


25°
FOR TEMPERATURES 22°- 30°
USE A FOR 300 & 150 SCALES
USE B FOR 30 & 7 1/2 SCALES
USE C FOR 3 & 1 1/2 SCALES
FOR TEMPERATURES 15°-22°
USE B FOR 300 & 150 SCALES
USE C FOR 30-7 1/2-3-1 1/2 SCALES
A
B
C
FOOT CANDLES
1 2 3 4 5 6 7 (1 1/2 - SCALE)
2 4 6 8 10 12 14 (3 - SCALE)
5 10 15 20 25 30 35 (7 1/2 - SCALE)
20 40 60 80 100 120 140 (30 - SCALE)
100 200 300 400 500 600 700 (150 - SCALE)
200 400 600 800 1000 1200 1400 (300 - SCALE)
50 100 150 200 250 300 (300 - SCALE)
25 50 75 100 125 150 (150 - SCALE)
5 10 15 20 25 30 (30-7 1/2-3-1 1/2) SCALES
SCALE READING

Graph 3


0°
(0° - 15°)
FOOT - CANDLES
7 (1 1/2 - SCALE)
14 (3 - SCALE)
35 (7 1/2 - SCALE)
140 (30 - SCALE)
700 (150 - SCALE)
1400 (300 - SCALE)
SCALE READING
50 100 150 200 250 300 (300-SCALE)
25 50 75 100 125 150 (150-SCALE)
5 10 15 20 25 30 (30-7 1/2-3-1 1/2) SCALES

Additionally, a trial graph for 10° was made in the same manner; but it was so nearly identical with that for 0° that it is not here presented (as a matter of actual fact, Graph 3 is somewhat of a compromise between the trial graph for 0° and that for 10°).

g. As originally constructed, each trial graph had six curves, one for each meter scale. However, the six lay so close together as to be almost confusing; hence, a great deal of convenience was to be gained, and little accuracy lost, by grouping certain curves together.

Thus in Graph 1, curve A represents an interpolation between the curves for the 300 and the 150 scales, and so forth. In Graph 2 an even greater lumping is utilized, for here two temperature ranges are, in effect, covered by the same three curves.

In Graph 3, all six curves have been lumped into one, since in that temperature region all of the curves are relatively close to each other.

h. As is by this time obvious, what really exists is an infinite series of curves for each scale; that is, a separate curve for each temperature. To avoid hopeless confusion, only a few of these curves can be drawn up and used. The curves of Graphs 1, 2, and 3 have been selected on the following bases:

Graph 1, although labelled "40°", is, to be exact, more nearly correct for about 35° - 37° C. In usual field work, temperatures above 35° are seldom encountered; but the graph may be fairly accurately used up to 40°.

Graph 2 covers the temperature range most commonly used in field work, and, as it happens, the range in which the temperature effect is relatively large. Therefore this range has been broken down into two sub-ranges, with appropriate instructions for the choice of curve.

Graph 3, as indicated, may be used with relatively little error for any scale, and within its specified range of 0° to 15°. Specifically, it is most nearly accurate in the portion of that range which is between 0° and 5°; it was drawn up primarily for use in interpreting the data of under-ice measurements.

Remarks

The calibration curves, as finally presented, are far less crude than one might at first be led, by the above account, to suppose. Much more than a sufficient amount of data was obtained to establish quite well the general shape of the curve. Thus the only arbitrary decisions to be made were those in regard to the selection of curves to cover various temperature ranges. Here refinement gave way to convenience, to a certain extent, but, even so, with a minimal sacrifice of accuracy. For it may be noticed that the curves for various temperatures are, after all, not greatly (even though significantly) divergent from each other. There is, in fact, some overlap among the curves used.

It is probable that these curves, if used with the proper care and judgment, will give results never more than 2 to 4 per cent in error. Such an error is not at all out of line with other probable errors connected with the use of the instrument or with under-water photometry in general.

Finally, it may be remarked in passing that of the numerous papers on limnophotometry examined in the course of the study of winter conditions (mentioned above), the large majority made no mention of any temperature correction of readings whatsoever (the presumption being, in some instances at least, that temperature effect was not taken into consideration, and hence that a significant source of error may have been overlooked); furthermore, some of these papers were so vague concerning the method of evaluating readings in terms of absolute photometric units that one is left with some slight doubt that a reliable instrumeht calibration had been made!

Afterword

It is not altogether improbable that at some future time the instrument in question may be reconstructed, modified, or otherwise disturbed to the extent that it will have to be recalibrated. In order that such calibration may be performed more expeditiously, and with the avoidance of certain time-consuming trial-and-error practices described above, the following suggestions are set down:

An apparatus such as that described above, and pictured in Figures 1 and 2, could be used. It could, feasibly, be refined to the extent of making possible the accurate measurement of the distance from the light bulb to the target. Then by using a bulb previously calibrated elsewhere, together with a means of maintaining a very constant line-voltage (i.e., voltmeter and rheostat), it would be feasible to compute actual foot-candles of incident light. Thus the calibration curves could be drawn up directly, for the several temperatures, rather than by the roundabout process described above.

With the same, or an even simpler, set-up a neutral filter (one which, it is assumed, does not change the quality of the light passing through it, but only reduces the quantity) may be calibrated, simply by making corresponding readings with and without the filter, with the same light-power and at the same temperature, and calculating the ratio thereof.

PART II: INSTRUCTIONS FOR CARE AND USE

(For a description of the construction of the instrument, as well as details of calibration, see Part I of this report.)

1. The Meter

The meter of this limnophotometer is an extra-sensitive microammeter, reading (now) in arbitrary scale-units. It is a precision meter, extremely delicately made. Its cost was over one hundred dollars, net. Therefore it should be given as careful treatment as one would give a fine watch. It should never be subjected to jar (hence the sponge-rubber mounting), nor to dampness or excess heat. The ordinary heat or cold of field operations will not harm it. Its bearings are jewelled, and need no attention (for heaven's sake, do not try to oil them!).

2. The Range-Selector Switch

This switch should be left on the "Off" position at all times except when a reading is being made. Then it should be turned from that position (i.e., toward the lower, or more sensitive, ranges) <u>only as far</u> as is necessary to obtain a reading on the proper scale. It should not be turned to a more sensitive scale than that which can thus be used, for doing so throws the needle more or less violently off the scale. To do that, momentarily, is a mistake that can easily be made, and one which probably does no permanent harm to the meter; but it does, nevertheless, reflect careless operation.

3. The Cable

No attention need be given the rubber-covered cable, except to see that it does not become kinked or otherwise damaged.

The cable was made only a certain length because the brass case of the receiver will withstand only a certain hydrostatic pressure. Therefore measurements at greater depths cannot be made with this instrument.

The function of the plug and socket is obvious. It is rather immaterial whether these are left connected or unconnected between uses.

4. The Receiver

By "receiver" is meant the brass case with all its contents and appurtenances.

a. The inside of (the main part of) the case must be kept dry, at all times and at all costs. It is so constructed that it should remain so. But in the event of a failure of a gasket, or submersion to too great a depth, or for some other reason, a leak may occur. At any time that leaking is suspected, it is imperative that the case be opened up (by removing the series of screws around the edge of the top plate) and thoroughly dried out (and not with heat!). This should be done as soon as possible, even in the field if necessary; although a short exposure to a few drops of water will not cause an irreparable damage to the Weston cells, for they themselves have a covering.

In reassembling the case, extreme care must be taken to replace each part in precisely the position it had; otherwise, the calibrations will no longer hold. Ordinary rubber cement is satisfactory for the gasket of the plate.

b. The plate-glass windows in the plate must be maintained in leak-proof condition. If the glass becomes loose, or if the cement leaks, the glass must be recemented in, using aquarium cement or some similar water-proof cement. Again, extreme care must be used in replacing parts exactly in their previous positions.

c. The space in which filters are placed (i.e., the space under the opal-glass and above the plate-glass) need not be kept water-tight. In fact, according to theory, it should be water-filled, in operation; although in practice it probably makes little difference either way, just so a semblance of consistency is observed.

5. Filters

The color filters are placed, when desired, in the space under the opal glass.

The instrument is provided with color filters in three spectral ranges, red, blue-green (green), and blue-violet (blue). The spectral qualities of these filters (more fully described in Institute for Fisheries Research Report No. 853) conform quite well to those designated as standard by the International Conseil.

In the work mentioned above, two "neutral gray" filters, "Nos. 1 and 2", were used. These, however, being of celluloid film, proved to be mechanically unstable (not able to withstand scratching, etc.), and should, if possible, be replaced by glass or some other sturdy substance.

6. Operation Under The Ice

A gas-pipe handle is provided, which may be attached to the receiver when it is desired to thrust it under the ice.

7. Making a Measurement

a. An unchanging sky is essential. Usually a cloudless sky is suitable, although it is not an infallible indication of unchanging light intensity. Good results have been obtained, at least in the winter-time, with a very heavily (but continuously) overcast sky.

b. With the receiver in the air, but with its face parallel to the surface of the water, make a preliminary observation, recording the scale used, and the reading.

Note - Each reading should be made with the needle having come to rest after moving from left to right. That is, let the needle move to the left by setting the switch on the "Off" position, or else to the scale just less sensitive than the one in use; then turn the switch to the position of the scale in use. The needle will move to the right and will stop with little swinging. This technique conforms to that used in calibration.

c. Immerse the receiver to the desired depth and make a reading. A series of depths may be used in succession.

d. Again make a measurement in the air. Repeat the process until check readings are obtained.

e. Obviously shadows, such as that of a boat, must be avoided.

8. Conversion of Readings

a. Using the curve, on the conversion graphs, which most closely fits the scale and temperature in question, convert meter reading to foot-candles. In some instances a certain amount of judicious graphical interpolation is possible.

b. It may not be known, sometimes, just exactly what the temperature of the cells was during a certain measurement. Suppose, for instance, the receiver to have been in the comparatively warm air, in the summer, and then to be submerged to below the thermocline, there to be held an insufficient time for the cells (inside the brass case) to become the same temperature as the surrounding medium.

In such cases obviously the only possible thing to do is to estimate the cell temperature as nearly as possible.

Incidentally, it is the temperature of the cells to far the greatest extent, that of the cable only slightly, and that of the meter scarcely at all, that affects the meter reading.

c. Sample calculations --

(1) No filter

In air:

Scale = 300
Reading = 215
Temp. = 28° C.
Using the "A" curve of Graph 2,
Foot-candles = 780

At 15 feet depth:

Scale = $7\frac{1}{2}$
Reading = 26.3
Temp. = (approximately) 20°
Using "C" curve of Graph 2
Foot-candles = 22.7

% illumination at 15 feet, or
% penetration to 15 feet =

$$\frac{22.7}{780} = \underline{2.91\%}$$

(2) Using neutral gray filter "No. 2"

In air:

Scale = 150
Reading = 115
Temp. = 3° C.
Factor for filter = 20
Read from Graph 3,
(Foot-candles) = (375)
Foot-candles = 375 x 20 = 7500

Under 15 inches of ice, plus 6 inches of snow:

Scale = $1\frac{1}{2}$
Reading = 12.0
Temp. = 0.5°
Read from Graph 3,
(Foot-candles) = (1.80)
Foot-candles = 1.80 x 20 = 36.0

$$\% \text{ Penetration} = \frac{36.0}{7500} = \underline{0.48\%}$$

d. When filters have been used, a new element enters into the calculations.

If a neutral filter was used, the readings obtained from the graph must be multiplied by the factor for that filter, in order to obtain true foot-candle values, as illustrated in Example (2) above. The constants for the two neutral filters originally made for the instrument (the celluloid filters) were: 10.0 for "No. 1", and 20.0 for "No. 2". If other filters are used, their factors must be ascertained (as indicated in Part I of this report).

If color filters are used, the absolute values in foot-candles cannot be obtained, nor would they carry any meaning. Suppose, for instance, that a red filter is used. The light which is recorded by the instrument is that portion of the total available light (i.e., at face of the target) which passes the red filter and which actuates the Weston cell. The quantitative relation of this light to either the total light available or the "red" light available is not known.

Relative, or percentage, values can, however, be obtained. Values obtained from the graphs may be divided one by the other, as above; but these values have no absolute meaning; in other words, they cannot properly be called "foot-candles" (of any kind of light). If written into tables, such figures should be parenthesized, or otherwise distinctly designated.

Example (using green filter)

In air:

Scale = 300
Reading = 275
Temp. = 35°
Using "A" curve of Graph 1,
(Foot-candles) = (1180)

At 20 feet:

Scale = 30
Reading = 15.8
Temp. = (approximately) 24°
Using "B" curve of Graph 2,
(Foot-candles) = (53)

% penetration, of green rays, to 20 feet =

$$\frac{(53)}{(1180)} = \underline{4.49\%}$$

N.B. Neither the (1180) nor the (53) has any absolute value.

e. In many instances, it is possible to make a reading on one of two or more scales. It does no harm, of course, to make a reading on the second scale, for check purposes. But in case only one reading seems necessary (or in case it is necessary to decide upon the relative dependability of readings on two scales), certain points should be borne in mind in choosing the proper scale to use.

A reading near the upper end of any scale is subject to proportionately larger error in conversion, since the calibration curves are spread farthest apart at this end.

On the other hand, a reading too near the lower end of a scale ought not to be used if it can be avoided. It is more difficult to make an exact reading at that end of the scale, because each scale-division means more in terms of relative amount (it may easily be seen that an error of 0.1 in a reading of 5.0 is much more significant than an error of 0.1 in a reading of 20.0).

Therefore it is desirable, whenever possible, to use a scale such that the reading will fall somewhere in the middle (or slightly above the middle) portion of the scale.

INSTITUTE FOR FISHERIES RESEARCH

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