DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

George K. Burgess, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, No. 325

[Part of Vol. 20]

RECENT DEVELOPMENTS IN LAMP LIFE-TESTING EQUIPMENT AND METHODS

BY

J. F. SKOGLAND, Associate Physicist

R. P. TEELE, Jr., Senior Aid

Bureau of Standards

September 11, 1926

PRICE 15 CENTS

$1.25 PER VOLUME ON SUBSCRIPTION

Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON

GOVERNMENT PRINTING OFFICE

1926

RECENT DEVELOPMENTS IN LAMP LIFE-TESTING EQUIPMENT AND METHODS

By J. F. Skogland and R. P. Teele, jr.

ABSTRACT

The candlepower scale of a horizontal photometer, with test and comparison lamps at a fixed distance apart, is a slide-rule scale, to within the limits of photometric observational error. In conjunction with such a candlepower scale other scales have been arranged to compute required values of lumens per watt, percentage light output, and percentage efficiency.

Vacuum tungsten lamps have, for each size, a constant ratio of total light output, measured in lumens, to the value of mean horizontal candlepower. To adapt the horizontal photometer to measure lumens per watt directly as required by the revised specifications for incandescent lamps issued in 1923, it was, therefore, necessary to add to the equipment scales computed on the basis of the known reduction factors for each size of lamp.

Other life-test requirements are that mean light output and mean efficiency during life can be readily determined. Scales from which these values are read directly, on the photometer, in percentage of the initial values have also been added to the equipment.

By the use of cams the slide-rule relation of computing scales has been adapted to the integrating sphere photometers, used to measure spherical candles or lumens directly.

Simplified methods of integrating the light output and efficiency curves of lamps derived as a result of the photometric measurements during life have been devised. The method does not require the actual construction of percentage efficiency and percentage output curves and reduces the computation to simple addition.

CONTENTS

I. INTRODUCTION

1. PURPOSE OF THE PAPER

Special methods and corresponding auxiliary equipment have been gradually developed as a result of continuous study of the problems of life-testing incandescent electric lamps at the Bureau of Standards. In these developments are incorporated methods which, without sacrifice of accuracy, reduce the work to an extremely simple system of procedure, preventing lost motion and avoiding repetition of work. These life tests, which are practically continuous, determine the compliance with specifications of the lamps of all brands supplied under contract to departments of the Government during each fiscal year. The measurements and computations usually involved total well into the thousands. There is, therefore, a field for simplification of methods applicable not only to the work of the bureau, but also, it is hoped, at other laboratories where life tests of large numbers of lamps are made.

It is the purpose of this paper to describe briefly the test methods and the construction and use of the computing scales and other accessory equipment used in connection with bar and sphere photometers, employed for making photometric measurements on incandescent lamps while under test.

2. EFFECT OF THE REVISED SPECIFICATIONS

Lamps supplied to the Government are purchased under master specifications.[1] At the time the present specifications were introduced it was found that the required determination of mean light output and mean efficiency during life imposed a noticeable extra burden in comparison with the previous method of obtaining only the life in hours to a specified light-output level. The advantages of the revised specifications were, however, so marked that there was no thought of return to former methods, and consequently the new problems introduced had to be solved. These problems have become less and less onerous as means for their easy solution have been devised until it can be said at present that the records and their evaluation are at least as easily obtained as were those under the former specifications.[2]

Before describing the essential features of the apparatus the general requirements of life-test procedure will be outlined.

II. TEST PROCEDURE

1. INITIAL RATING TEST

Although the manufacturer specifies an initial rating for each size of lamps supplied, not only does his specified rating vary from time to time, but, because of unavoidable inherent variations peculiar to the lamps themselves, individual lamps and groups of lamps are necessarily allowed considerable deviations from the nominal specified rating. Consequently, for tests based upon exact ratings the actual rating of each lamp must be determined. This, the first step in the test procedure, is done by measuring the lamps on a photometer, where the usual method is to derive the efficiency rating in lumens per watt from the observed values of lumens and watts (or amperes) at a chosen voltage.

2. TEST-RACK VOLTAGES

Years of experience in lamp testing through all of the developments from carbon lamps to present-day gas-filled lamps of from six to eight times the efficiency of that original type have not changed

[1] Bureau of Standards Circular No. 13, 10th ed., Feb. 7, 1923; United States Government Specifications for Large Tungsten Filament Incandescent Electric Lamps, Federal Specifications Board Standard Specification No. 23.

[2] As is well known, incandescent lamps generally show a decrease in light output and efficiency during the period of operation to burn out on test or in service. The present specifications take into account the different paths followed by the light output and efficiency curves of the individual lamps by requiring that the average values of these quantities during life shall not fall below a specified percentage of the initial values. All determinations are based upon the flux of light in all directions and not on the intensity in any one zone or direction. Under the former specifications no account was taken of the performance after an arbitrary light-output line had been passed, nor of the shape of the curves here or above this line. The performance curves were not considered as a measure of light output or efficiency area from which actual mean values of these quantities could be determined. The advantages of the revised procedure are thus immediately apparent, since account is taken of the amount of light supplied and of the average efficiency of operation during life.

the method of basing the life tests on some chosen efficiency. The efficiency of the test lamps must, therefore, be measured. Either by successive trial or by reference to average curves showing the changes in efficiency for changes of voltage, voltages must be determined at which the lamps must be burned in order to start the test sufficiently near the rated efficiency or at some derived value having a known relation to the rated efficiency.[3]

Because of the great saving of time and money effected by testing at efficiencies higher than the rated values, thus shortening the life at the expense of a relatively small increase in the power required, tests at rated efficiency are seldom run except in connection with investigations of life-efficiency relations which furnish data for reduction of test-life values to the values they would have at other efficiencies. Consequently, the testing laboratory is mainly concerned with rating lamps at chosen test efficiencies considerably higher than the manufacturer's nominal service rating. Fortunately the changes in light output and efficiency for changes in voltage are sufficiently consistent among lamps of a given type to permit computation of the test values from those obtained in the initial measurements. This eliminates the slow and tedious method of successive trial.

3. READINGS DURING LIFE

The lamps are burned on test at the determined test voltages, maintained constant within narrow limits. Regulated alternating current is most convenient for this work, as transformers suitably designed and interconnected give the required flexibility in voltage selection and regulation for changes of load on the individual test racks.[4]

After each predetermined period of burning, based on the anticipated test life, the lamps are removed from the test racks and read on the photometer to determine the values of electrical input and light output, from which the average efficiency during life may be obtained. The time of burn out, or other means of total failure, is also noted and the corresponding test life in hours is assigned to each lamp.

Figure 1 shows the light-output performance curves during life for 10 lamps of one size, with measurements made between test periods each 35 per cent of the estimated mean test life. The latter is assumed in advance for determining the length of the test periods

[3] The manufacturers' assignment of an initial rating is referred to above. It is assumed here that the test lamps conform to the rating within the specified limits and that such lamps as have not conformed to the rating are not represented by life-test lamps because they would be rejected as a result of initial tests of larger lots from which the selections for life test would be made only if the lots were acceptable, as provided in the specifications. (See footnote 1, p. 683.)

[4] For a detailed description of the transformer and rack connections of the bureau installation see B. S. Sci. Paper No. 265, Life Testing of Incandescent Lamps at the Bureau of Standards, by Middlekauff, Mulligan, and Skogland, Mar. 16, 1916.

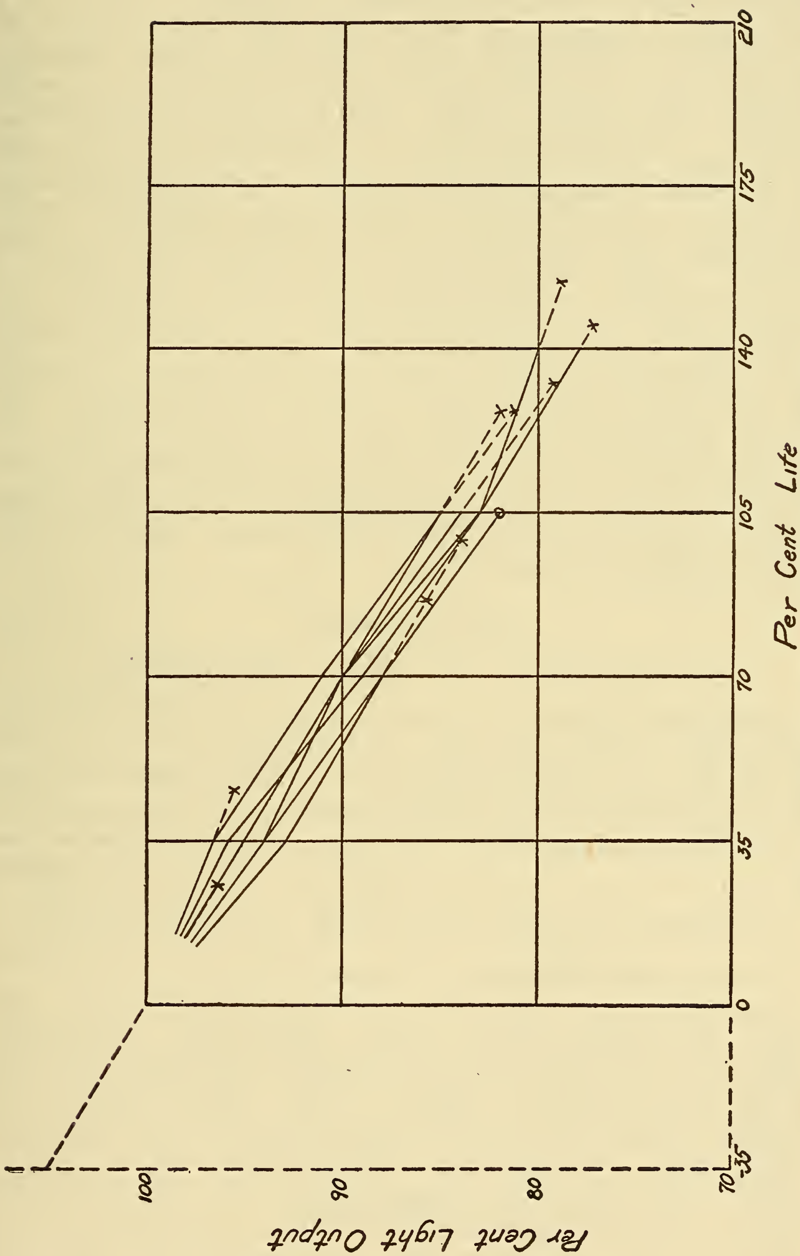


FIG. 1.—*Light-output performance curves of 10 lamps*

during which the lamps are burned on the life-test racks. Curves of efficiency performance are determined from the same measurements in connection with the electrical readings of wattage or current at a given voltage. Efficiency curves, not shown here, therefore, have the same abscissas as the light-output curves, but different ordinates. The dashed line extensions of the last segment of the curves extrapolate the lines to the point of burn out. All but one of the curves are thus extrapolated. This lamp failed at the conclusion of a test period. The backward extension from the initial reading for one lamp shows the method of extrapolation into the first test interval of a lamp which failed within that interval and for which only the initial value could be measured. This extrapolation is made as if the lamp performed on the mean curve of the group to the point of burn out, the extrapolated segment being that shown by the dashed line extending backward and as far above the 100 per cent ordinate as the mean of the group was below that ordinate at the first interval reading. This method of treating first-period failures was chosen because it fits consistently into the system of extrapolating by producing the curves to the right. These curves are shown merely for the purpose of illustration, and the method to be described does not require graphical representation of the observations.

III. APPARATUS

1. HORIZONTAL AND SPHERE PHOTOMETERS

Although all lamps are now rated and tested on the basis of total light output in lumens and efficiency in lumens per watt, such sizes of vacuum tungsten lamps as are known to conform initially and during life to standard values of spherical reduction factor are measured on a horizontal photometer bar. This photometer has a fixed distance between the test and comparison lamps and the photometer head is moved to points of photometric balance. The average values of mean horizontal candlepower read on the photometer are multiplied by the spherical reduction factor to obtain the corresponding spherical values, which are proportional to the light output in lumens. Other lamps (for example, mill-type lamps, carbon lamps, and gas-filled lamps of 50, 75, and 100 watts) are measured in an integrating sphere 30 inches (0.76 meter) in diameter. Some 100-watt lamps and all gas-filled lamps above 100 watts are measured in an 88-inch (2.24 meter) sphere. The test lamp occupies a fixed position within the sphere. The photometer is stationary and the comparison lamp is moved to the point of photometric balance. In this case the illumination of the photometer screen on the comparison lamp side is inversely proportional to the square of the distance between the comparison lamp and the photometer screen.

2. AUXILIARY EQUIPMENT

These three photometers have special auxiliary devices by which the necessary computations are made in a semiautomatic manner at the time the observations are taken. The arrangement and operation of some of these devices have been described in a publication of the Bureau of Standards,[5] but so many additions and modifications have since been made that only the general principles of design and operation remain. These principles are briefly those of the ordinary slide rule in connection with linear relations in lamp rating and are, therefore, original only in the manner of their application. If, instead of the usual scales of equal parts, the scale divisions are the logarithms of the corresponding numbers designated by the figures representing the numbers themselves, there results a relation of scale values referred to in what follows as logarithmic. This relation is essential in a computing device in which the scales are free to move relatively to each other. The desired logarithmic relation among the scales employed in the auxiliary devices is closely approximated on the horizontal photometer and exactly realized on the integrating spheres. The transformation of inverse square to logarithmic relations by a special motion employing a cam and scale carriage has been developed by Willis.[6] This adaptation, which applies to integrating spheres with fixed photometer and movable comparison lamp, is in part in use on the 88-inch (2.24 meter) sphere. The computations previously performed by the rack voltage computer of the Willis device have recently been transferred to another device, as will be explained later. The cam motion of the Willis scales has been applied to the comparison lamp on the 30-inch (0.76 meter) sphere, thus eliminating the scale carriage of his device and making the scale arrangement practically the same as that designed for horizontal photometers.

IV. DESIGN AND OPERATION OF THE SCALES

1. ON THE HORIZONTAL PHOTOMETER

(*a*) Basis of the Design.—On any horizontal photometer with a fixed distance between test and comparison lamps, like the bureau photometer mentioned above, the scale of mean horizontal candlepower extending from one-half to twice the central value closely corresponds throughout to a logarithmic scale with similar divisions constructed on a base[7] equal to 0.285 times the fixed distance. The maximum error of the logarithmic scale thus constructed as a

[5] See footnote 4, p. 684.

[6] A Direct Reading Computing Attachment for Sphere Photometers, Trans. Ill. Engng. Soc., 18, p. 62; 1923, Ben S. Willis.

[7] The base referred to is the distance from 1 to 10 on the scale of equal parts designating the logarithms opposite which the scale division is placed.

103131°—26——2

closely approximate indicator of horizontal candlepower is ± 0.26 per cent, being + for candlepowers above the central one and − for those below. The mean error is approximately ± 0.16 per cent, which is considerably less than the probable error of the observations and consequently negligible. These differences between the scales apply only when they are so placed that their central points coincide. The differences throughout any relatively short section of the scale may be made practically zero by choosing the point of coincidence near the middle of the section. At the present time, however, errors not exceeding 0.25 per cent for work of this kind are generally considered negligible.

(*b*) Fixed and Movable Scales.—The scale of mean horizontal candlepower, now considered as transferred to a logarithmic scale, is employed as a fixed slide-rule scale which, when placed in the proper relation to similarly constructed scales of wattage or current, can be arranged to read watts per candle on a third scale. Ampere scales, arranged as shown in Figure 2, are most convenient. Scales covering the desired range of current are placed on a cylinder which can be turned to use any chosen scale and may be moved in a direction along its axis.

(*c*) Setting the Scales.—The proper current scale must be chosen and set to a certain point for each voltage, thus making it in effect a scale of watts for that setting. It is possible to use a fixed voltage scale for this purpose.

As a matter of convenience in lighting the scales and presenting them in a postition for easy reading it is desirable to have as few fixed scales as possible. For this reason the following procedure is employed. A simple problem is set up to obtain a quick calibration without a separate voltage scale. Suppose 40-watt lamps are to be measured. Then, if the 0.4 division of the ampere scale is chosen and the photometer is set at 40 mean horizontal candles the watts per mean horizontal candle corresponding to any voltage E should be $\frac{0.4E}{40} = 0.01E$. For the 0.5 ampere division the 50 cp. point would yield the same result. Consequently for any similar choice of candlepower and current, reference need be made in the scale set-up only to the voltage, the chosen ampere division being set adjacent to the voltage number on the scale of watts per mean horizontal candle (wpmhc.) which may also be moved to a position for easy reading. For example, with the photometer at 40 mean horizontal candles, set 0.4 amp. to 1.12 wpmhc. for lamps run on the photometer at 112 volts. (See fig. 2, scales marked "amperes," "volts," and "watts per mhcp.," in connection with index A, under which the 112-volt line now just at the right of the tag marked "volts," was originally placed for the setting.)

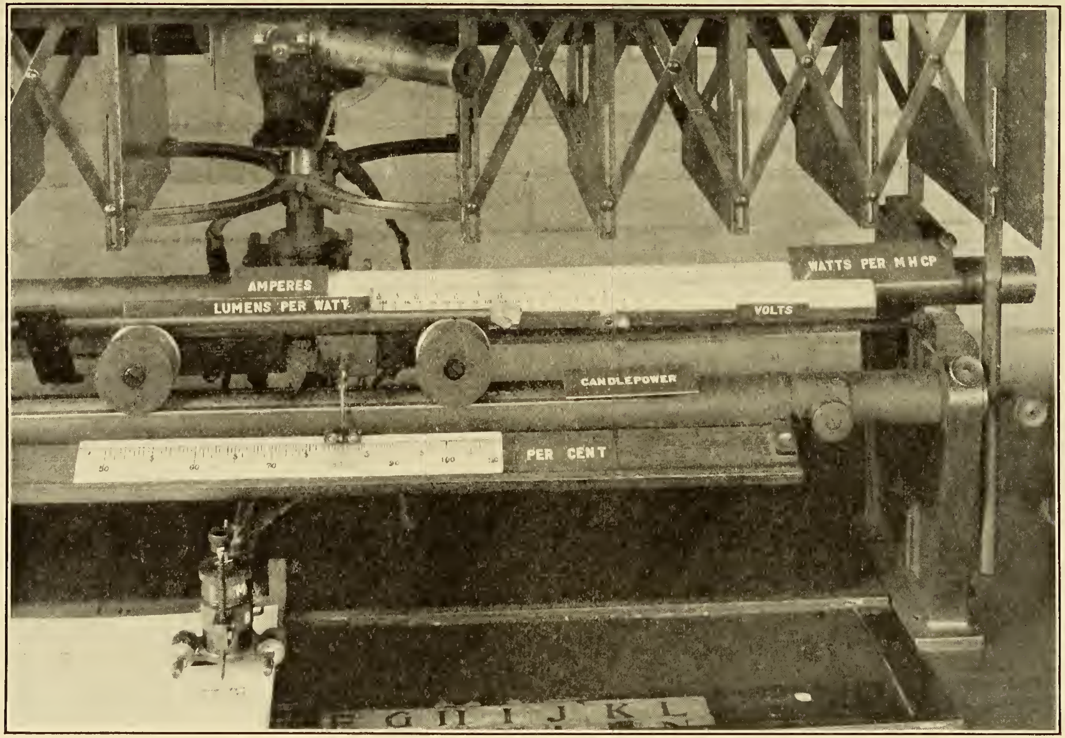


Fig. 2.—*Computing and recording devices on horizontal photometer bench*

(*d*) How the Computing is Done.—The scale of wpmhc. moves with the photometer to the point of photometric balance, thereby passing values of current proportional to the change in candlepower, since the scales are logarithmic. This applies to all of the scale divisions. When the photometer motion is toward higher scale values of candlepower, relatively smaller scale values of wpmhc. appear adjacent to any given value on the current scale. By construction the scales are in the proper relation to indicate the value of wpmhc. for that voltage, candlepower, and current, with values similarly indicated for all other values on the current scale. For motion in the opposite direction the relative changes are toward larger scale values of wpmhc., etc. The device functions, therefore, as a slide rule so placed and operated by the photometer motion as to solve the problem of initial rating directly at the photometer without transfer of the record to a separate computer.

(*e*) Equivalent Scales of Lumens Per Watt.—The convenient set-up of scales for any photometer voltage has been carried along on the horizontal photometer in connection with the calibration of the scale of efficiency in lumens per watt. For this purpose there are scales of lumens per watt, separately constructed for each spherical reduction factor (see Sec. III, par. 1), at the right of which are such of the wpmhc. divisions as correspond to the voltages used for the test lamps on the photometer, as explained on page 688. One of these double scales is shown in Figure 2 adjacent to the scale of amperes. By reference to movable index, *A*, which may be fixed in relation to the photometer for a given scale set-up, the scales are set to the proper points to give wpmhc. readings, as described above in paragraph (*c*) of this section, and then a transfer is made to the corresponding lumens per watt by sliding the scale along under the index. Although it is possible to use a single line under the lpw. scale as the point corresponding to the one at the index in the wpmhc. set-up, it is convenient to carry a full voltage scale repeated in each section, as shown, so that a check on the voltage employed may be obtained by a glance at the index line. In the figure the 112-volt setting has been made. The original wpmhc. setting was made with the photometer set at 40 candles. The photometer is now at about 41 candles. The length and mode of division of the voltage scales is of no consequence provided the two are of the same length, similarly divided, and properly placed with reference to the wpmhc. and lpw. scales. For a transfer of readings to lpw. the scale is moved only once, at the beginning of the set-up at one voltage. Because of the inverse relation between lpw. and wpmhc., the corresponding scales have increasing values in opposite directions.

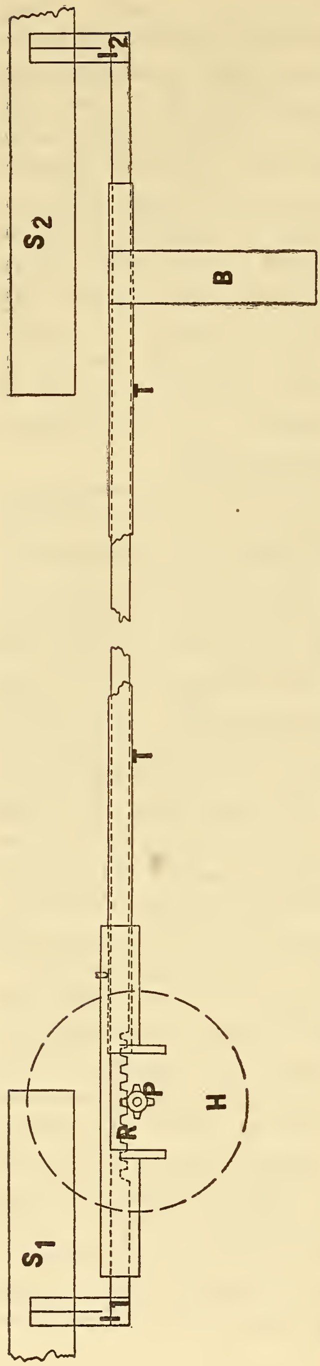


FIG. 3.—*Ampere pointer*

2. ON THE SPHERE PHOTOMETERS

The general relation and operation of the current and efficiency scales are the same on all three of the photometers. In connection with the logarithmic light-output scales they yield all of the data required for rating lamps at "photometer" voltage; that is, the efficiency and the light output or values proportional to the light output. In the sphere measurements, however, no reference is made to a scale of watts per candle, as the ratings are assigned only in lumens per watt in a manner described later in this paper.

V. ADDITIONAL EQUIPMENT

1. THE AMPERE POINTER

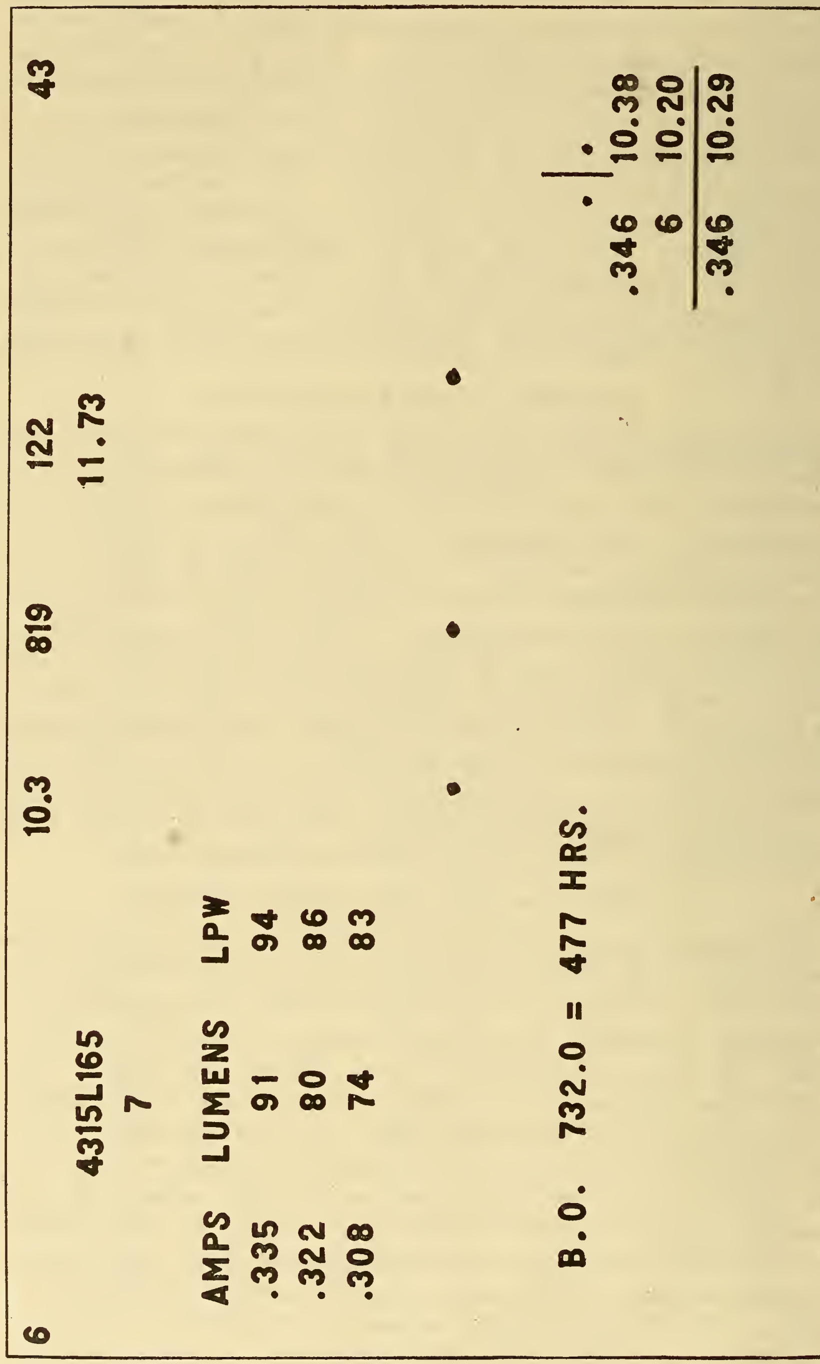
A special device has recently been added to the equipment of the horizontal photomoter. As shown in Figure 3, this consists of a rod carrying indices, I_1 and I_2, and moved by handwheel, H, within easy reach of the electrical operator, through pinion, P, which engages rack, R, integral with the rod. The tube, T, within which the rod is moved by wheel, H, is attached to the photometer by band, B, so that the entire device moves as a unit with the photometer when an observation of candlepower is taken. Before starting the observations the ampere scale, S_1, at the left is set by sliding it along the ledge which supports it until index, I_1, is exactly over the same value of current as that set under index, I_2, on the duplicate ampere scale, S_2, near the operator at the photometer. This index, I_2, appears in Figure 2 near the right-hand wheel of the photometer carriage. The scale is then clamped in this position throughout the run. During the observations, just after the photometer is balanced, handwheel, *H*, is turned by the electrical operator until index, I_1, stands over the observed current on the ampere scale. Index I_2, rigidly connected to I_1 by the rack and rod, also moves in view of the observer at the photometer to a position over the scale division indicating observed current, in line with which is the corresponding efficiency in lumens per watt awaiting transfer to the record. This observer, therefore, looks only for the line of index, I_2, which has just been set to the observed current, verified by audible announcement. Motions of wheel, *H*, are small once the first lamp of a given size has been run, so that a mere twist of the wheel through a fraction of a revolution suffices to make the settings of current, in line with which the efficiency is read.

2. RECORD CARDS AND HOLDER

On the horizontal photometer, data corresponding to the observed values of candlepower are stamped on the record cards which, by an arrangement carried along from the original design, are placed in a fixed relation to the candlepower scale. This is accomplished by setting the small car of Figure 2, carrying the cards as shown, at one of the points designated by letters adjacent to the track laid on the bench parallel to the photometer axis. This car has a projecting leaf spring which carries in tension a pin, *N*, along the top surface of the track. Corresponding to the lettered positions on the bench and, for the lamp cards, to similarly lettered "guide" cards inserted among them to designate each change of position, are holes in the track surface. The spring carried by the car forces the pin into the hole corresponding to the desired position, locking the car in place until the pin is pulled up for a change of position along the track.

3. STAMPING MAGNET AND INITIAL RECORD

The stamping magnet (*M* of fig. 2), carried by a rod normal to the bench, moves with the photometer and is actuated by current which flows in the circuit, by pressing a button within easy reach from the photometer handwheel (not shown) employed to move the photometer. As shown on the record card of Figure 4, the records of the initial values stamped by the armature point of the magnet appear as two dots near the lower right-hand corner of the card; that is, near the end of the card toward the higher candlepower and near the margin adjacent to the observer at the photometer. Each of these points is the record of one observer's value. In case of differences between these two observations greater than the allowable tolerance established by laboratory practice, another observer records a point. The three points may be retained or two of them chosen by crossing the inconsistent value from the record. In recording these points the observer merely moves the photometer along the bar to



6 10.3 819 122 43

4315L165 11.73

7

AMPS	LUMENS	LPW
.335	91	94
.322	80	86
.308	74	83

B.O. 732.0 = 477 HRS.

.346	10.38
6	10.20
.346	10.29

Fig. 4.—*Test record card*

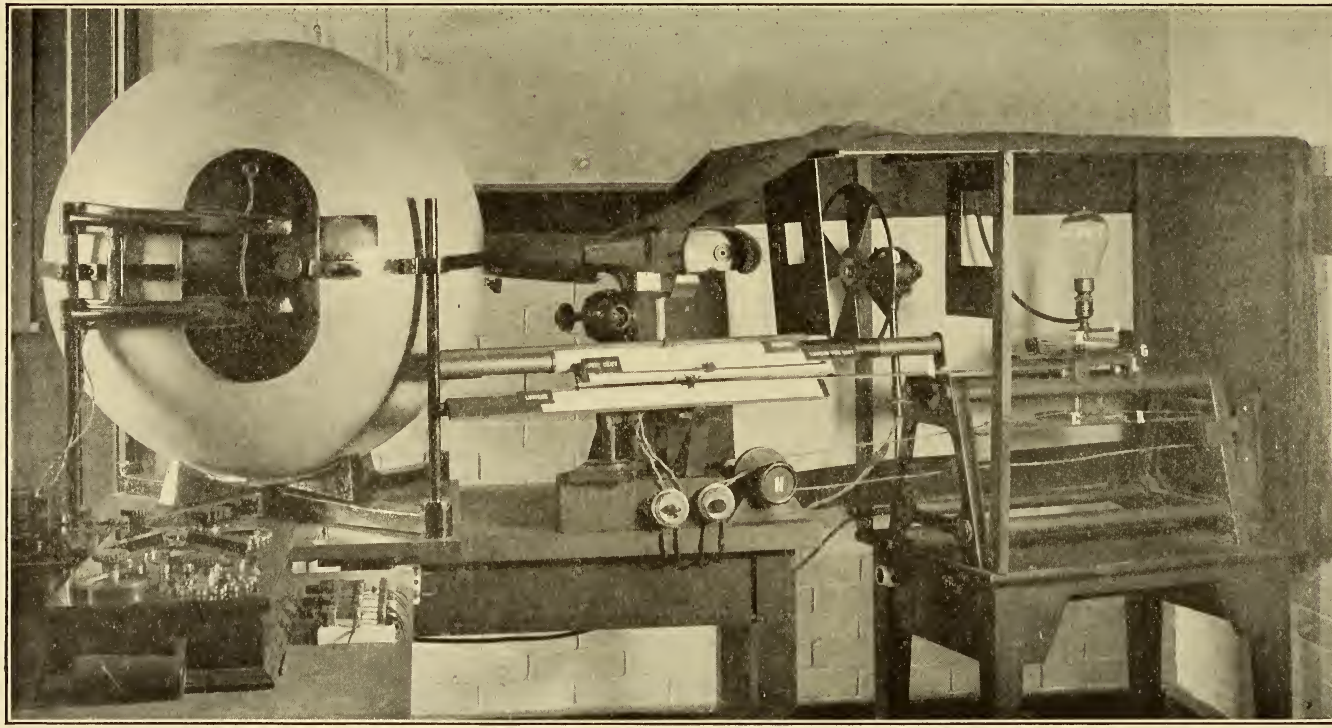


FIG. 5.—*30-inch sphere with special scales and auxiliaries*

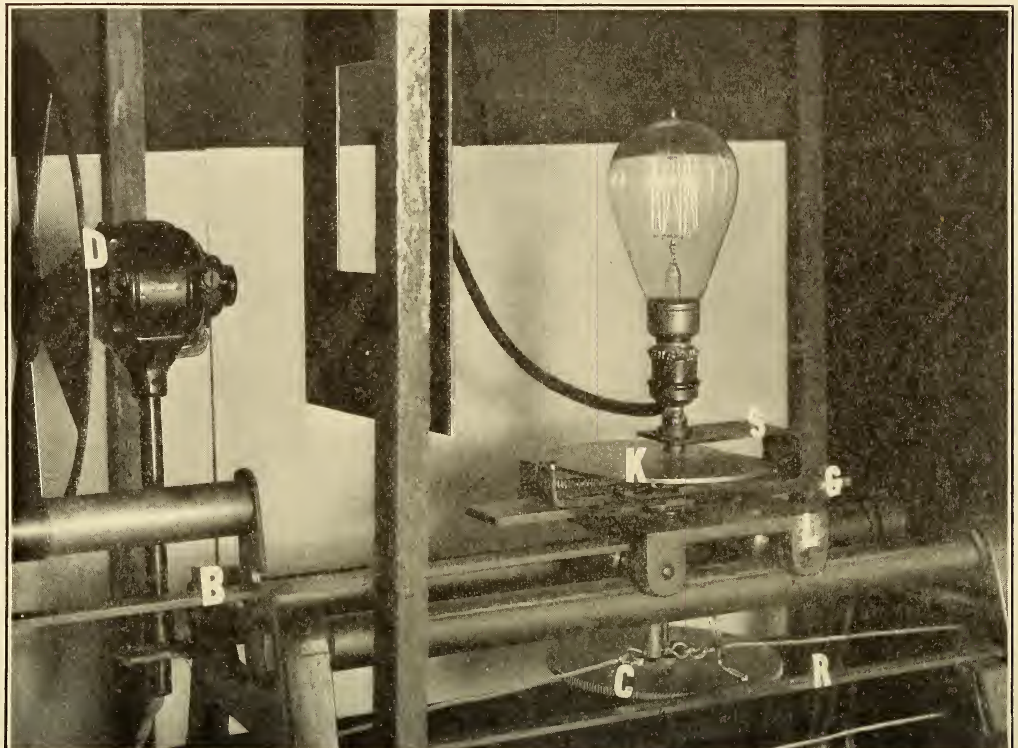


FIG. 6.—*Comparison lamp arrangement on 30-inch sphere bench*

the point of balance and presses the button in the circuit of the magnet. Adjacent to the points are written, as shown, the observed current and the corresponding value of efficiency read from the scale.

4. SECTORED DISKS

On the sphere photometers the numerical value of the scale lumens is written on the card record for each lamp. These scale values may be the actual lumens of the lamps under observation or derived values proportional to them, depending on the transmission factors of the rotating sectored disks (one of which appears at *D*

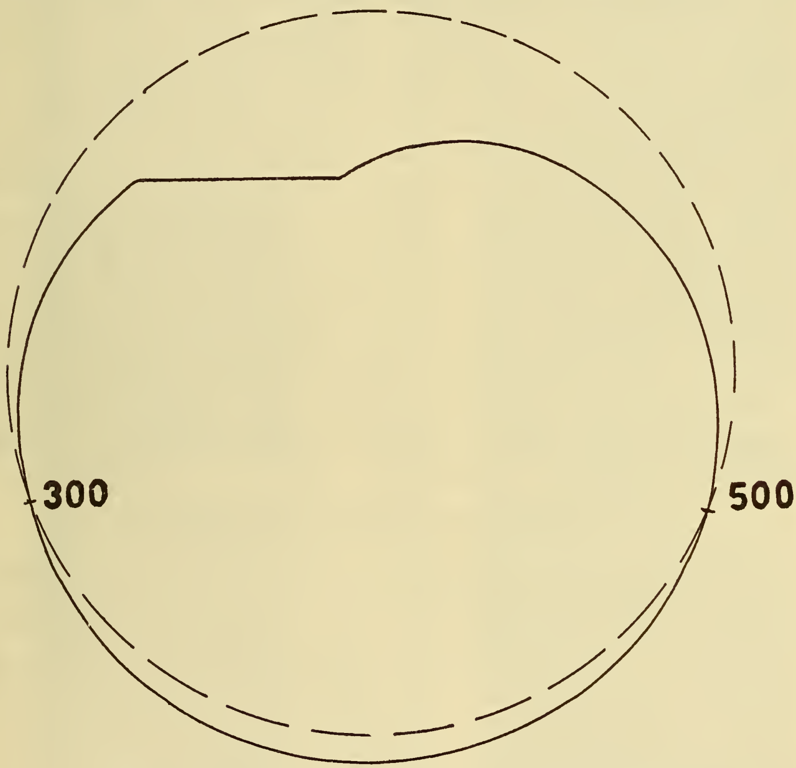


FIG. 7.—*Top view of cam used on 30-inch sphere bench*

in figs. 5 and 6) used to adjust the brightness of the photometer screen so that the readings will fall within the limits of travel of the comparison lamp. It would be possible to use a number of scales, each one based upon a single disk factor, choosing the one from which the actual lumens could always be read for a given disk combination.

5. CAM MOTION ON THE SPHERE PHOTOMETERS

The arrangement of the special cam, *K*, on the photometer bar of the 30-inch (0.76 meter) sphere is clearly shown at the right of Figure 6. A top view of the cam appears in Figure 7. The distance along any radius vector from the cam circle to the periphery of the curve is just sufficient to move the slide carrying the comparison lamp in guides on the plate, *G*, attached to the lamp carriage, *L*, a distance which gives the lamp a photometric position in the axis equivalent to the value indicated on the logarithmic (slide rule) lumen scale of Figure 8. The arrangement of stationary rack, *R*, and rolling gear circle, *C*, keyed to the vertical cam shaft makes the distances moved along the photometer axis by carriage, *L* (carrying the comparison lamp reciprocator, *S*, held against cam, *K*, by a spiral spring), the same as those measured on the gear and cam circles, which are equal. Bar *B* carrying the lumen index is rigidly attached to carriage *L* and moves with it. The dimensions of the cam required for a particular installation depend on the limits of travel of the comparison lamp. The arrangement of the cam is such that the comparison lamp and stand move easily and smoothly. The scale motion, or that of an index over the scale, may be geared down to make the readings convenient for long comparison lamp travel. The curve of the cam shown in Figures 6 and 7 intersects the cam circle at two points, corresponding to 300 and 500 lumens, respectively, and adjusts all values between 260 and 740 lumens for a set-up not involving sectored disks, and proportional values when disks are used. A 50 per cent disk (180° opening) on the test side, for example, makes the scale range from 520 to 1,480 lumens. A detailed description of the use of this scale and of the others of the group is given below in Section VI.

6. SCALES FOR COMPUTING RACK VOLTAGES

On the cylinder which carries the ampere scales of the horizontal photometer there is a logarithmic volt scale (fig. 9). Based on the characteristic curves by which, as a result of extensive investigations, efficiencies may be computed at any voltage within the range covered, there have been constructed, in proper relation to the volt scale, efficiency scales, one for each characteristic employed. The scale of lumens per watt (lpw.) for vacuum tungsten lamps is shown in place on the ledge of the holder in the lower part of the figure. There are two indices, one, I_2 of the previous reference, movable over the volt scale, and the other, over the lpw. scale on the ledge, as shown. The cards from the initial run are referred to and the upper index I_2 is set to the photometer voltage used. The lpw. scale is then moved along the ledge until the mean observed value is under the index. Using this arrangement merely as a large, easily read, and flexible computing device for this work, the photometer carriage to which the indices are attached is now moved until the lower index stands over the scale value corresponding to the desired test efficiency. The voltage nearest the upper index I_2 is chosen as the rack value at

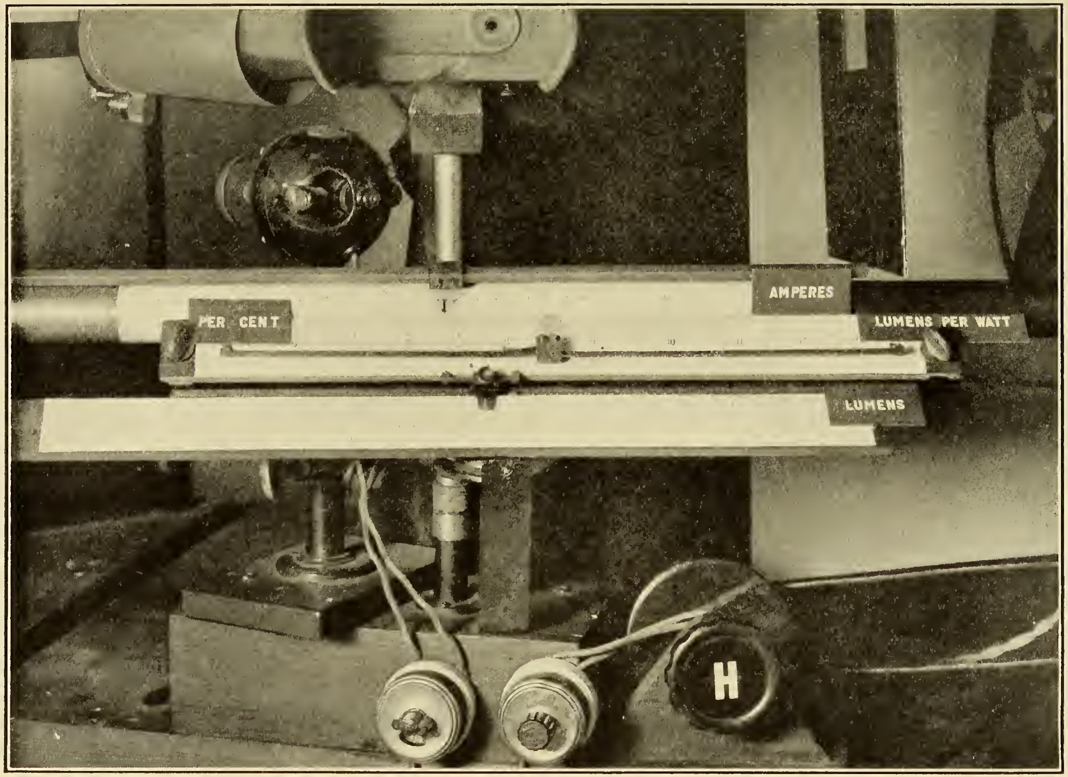


Fig. 8.—*Computing scales on 30-inch sphere bench*

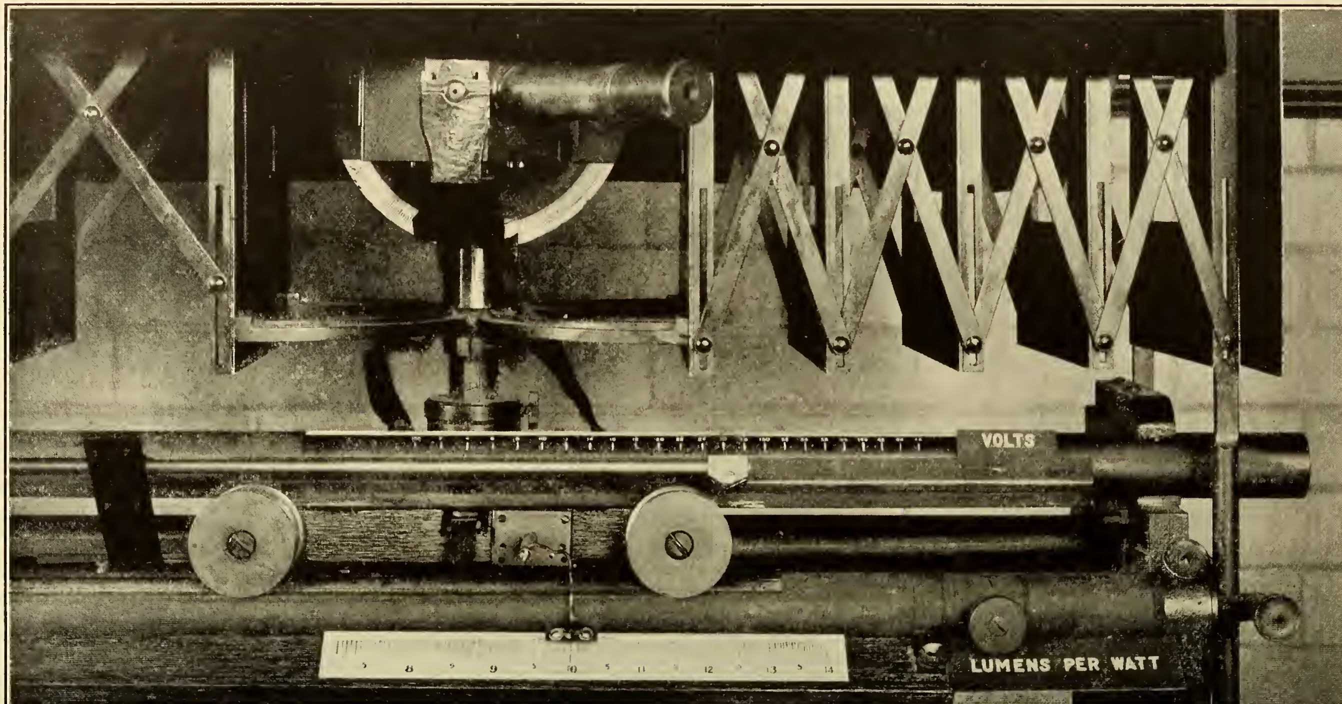


Fig. 9.—*Rack voltage computer*

which the lamp is to be operated on test. Index I_2 may then be moved in the same manner to the chosen rack voltage value and the corresponding efficiency recorded, or, for any considerable number of lamps in a test group, it may be safely taken for granted that, even for a choice such as is made from the 2-volt steps of the scale here shown, the desired mean efficiency for the group will be realized sufficiently closely without exact computation. As a matter of record the cards for our test lamps show the actual efficiency at rack voltage. All of this is much quicker in operation than in description.

Rack voltages for both vacuum tungsten and gas-filled lamps are determined on this computer, employing the same voltage scale but different efficiency scales, depending on the characteristic curve which applies, as stated above. The two indices and the ease with which the lpw. scales may be substituted and moved to a setting under the lower index are features of special convenience and rapid operation. The scales are clearly legible from the ordinary reading distance without eye strain.[8]

VI. READINGS DURING LIFE

1. THE SCALE OF PERCENTAGES

The scale at the bottom of Figure 2 has not yet been described. This is a logarithmic percentage scale constructed on the same base as the other scales of this auxiliary. Clamped to the stamping magnet (fig. 2) by a band *B* is the "finder" pin *F*, normally held up by a spring as shown. The magnet and its attachments are moved back in the normal to the photometer axis, by pushing the supporting rods through their bearings, until finder *F* is in line with the dots on the card record stamped as data on the initial run. (See Sec. V, par. 3). Then for readings between periods of burning on the life-test racks, with the lamp cards carried by the car at the position along the track indicated for the initial measurement, the photometer carrying the magnet and finder is moved until the point of the finder, pressed down against the spring, stands over the mean of the dots recorded as initial values. This is the 100 per cent value. Consequently the 100 division of the percentage scale is now set under the lower index by sliding the scale along its supporting ledge. A record on the card (fig. 4) is made of the percentage value which appears under the lower index when the photometer is balanced, and this

[8] There were in use for several years volt scales drawn on the same strip as the efficiency scales and so arranged that for any given photometer voltage the actual test efficiency could be read in line with the current observed at photometer voltage when the voltage scale and the efficiency scale moving with it were shifted until the rack voltage stood under the index. This method, although yielding direct readings of rack efficiency with sufficient accuracy, was found to be rather slow and tiresome on the first initial run because of the movements of the volt scale which had to be made to find the proper values of rack voltage, especially in the case of lamps not closely rated. In some cases, too, the rating assigned by the first observer had to be modified after the check reading was made. For these reasons the change to the present system was made, despite the fact that the previous method was novel and interesting.

point is stamped on the card as a check. These points stamped during life are in a line farther back from the card margin nearest the observer than are the initial points, since the magnet has been moved back to utilize the finder and can not be confused with the initial points.

2. RECORD OF PERCENTAGE EFFICIENCY

An interesting relation is involved in the next computation. Evidently if the current of a lamp, and consequently its watts at constant voltage, were to remain unchanged during life the efficiency would change in direct ratio to the change from the initial value of the light output. It would be indicated as a percentage of the initial value by the observed light output percentage. For a change in current, or in watts, the change in efficiency is a similar but inverse percentage. There is thus presented an excellent opportunity to avoid lost motion in reading percentage efficiency, because after setting the photometer at the light output percentage it is necessary merely to move over the scale with index I_2 (fig. 2) from observed to initial current to reach the efficiency percentage with the lower index, thus introducing the inverse percentage just mentioned. The use of the setting of the ampere pointer to observed current by the handwheel on the horizontal photometer is now plain. (See Sec. V, par. 1.) While the observer at the photometer is recording the percentage candlepower, read as described above, the electrical operator sets the ampere pointer by a turn of the handwheel bringing index I_2 to the observed current on the scale. The observer at the photometer then moves the photometer until index I_2 connected to it stands at the initial current, plainly shown in figures on the card record before him, and reads the percentage efficiency at the lower index from the same scale which has just indicated percentage candlepower.

3. ADVANTAGES OF PERCENTAGE READINGS

The procedure described above places all lamps on a percentage basis in the records both of light output and efficiency. Hence, it is necessary to set the current and efficiency scales for only the initial run. The mind of the observer is relieved of keeping track of dissimilar sets of figures for the record. For example, the current at constant voltage on practically all lamps drops during life. The typical form of record, therefore, is that of percentage light output values and percentage efficiency values between the light output percentage and 100. In all of this, too, the description is much longer than the action described and a half hour's experience with the apparatus itself would equal many pages of details of construction and use.

4. PROCEDURE ON SMALL SPHERE PHOTOMETER

The scales used on the 30-inch (0.76 meter) sphere are shown in Figures 5 and 8. As previously shown, the cam used with the comparison lamp at the right of Figures 5 and 6 results in the proper slide-rule relations among these scales. The central scale, rigidly connected to the comparison lamp carriage and moving with it during the measurements on the photometer, is used for the initial efficiency readings and also for the percentage light output and percentage efficiency readings during life. This part also carries the lumen index.

The procedure here is as follows: On the initial run, move the comparison lamp carriage by turning handwheel *H* until the lumen index of Figure 8 is set to any convenient value, say 500 (marked "5" on the scale). On the ampere scale set "lumens/1,000"; that is, 0.5 ampere (marked "5") to the efficiency in lumens per watt corresponding to 1,000 times the reciprocal of the photometer voltage. To illustrate: The 124-volt setting would show the lumen index at 5, and the "5" ampere line above, 1,000/124 = 8.06, which is the value of lumens per watt corresponding to 124 volts, 0.5 ampere, 500 lumens. The scale has this setting in Figures 5 and 8, with the photometer set at 420 lumens. The reciprocals are carried in a table specifying photometer volts and ampere scale settings in adjacent columns for reference in the set-up for any photometer voltage. On subsequent runs during life handwheel *H* is turned until the lumen index stands at the recorded initial value, and the downward pointing top index, which is free to slide along the heavy rod over the ampere scale, is set to 10 on the central scale (equivalent to 100 per cent). After this setting, any value of lumens observed during life appears on the central scale as a percentage value, and is so recorded. The upward pointing index is next moved along the rod, to which it is lightly held by the spring at its left, to the observed current. Handwheel *H* is now turned until this index is opposite the initial current shown on the record, and the percentage efficiency is recorded from the reading on the central scale under the top index.

5. COMPARISON WITH LARGE SPHERE AUXILIARIES

On the 88-inch sphere an equivalent method is followed, but the scale settings are not as direct because the sectored disk combinations used were not specially designed for this work. The scale set-up, however, is specified in a schedule, so that no time is lost in the calibration. On the 30-inch (0.76-meter) sphere a sectored disk of 50 per cent transmission (shown at *D* in figs. 5 and 6), in connection with an adjustable iris on the sphere window (not shown) and small adjustments of the lumen index along the short rod (shown in figs. 5 and 8) to the exact mean of the standards used, suffices for all of the calibrations and measurements. The motion of the lumen index along the rod is limited to a range not affecting the relative eccentricity of the cam, so that no significant errors are present in the scale indications.

6. POSSIBLE DIFFERENT PROCEDURE

It is practicable and easy to read actual rather than percentage efficiency on any or all of the test measurements, provided the ampere scale be set properly for each photometer voltage. The double index ampere pointer may also be applied to the sphere scales. We find, however, that there is ample time for the observer at the photometer to set and move the index and record the readings while the lamps in the sphere socket are being replaced and set to the proper voltage. The pointer is of greater advantage on the horizontal photometer because placing the lamps is quicker and there is more inertia to be overcome in moving the photometer than in moving the comparison lamp along the bar of the sphere photometers. Consequently, time is saved by having the electrical operator set the pointer to the observed current.

VII. SUMMARIES OF TEST RESULTS

1. EQUAL TEST PERIODS

A choice of equal periods (see Sec. II, 3, above) for burning the lamps on the test racks gives equal weight to all of the areas. Each may be considered as a right trapezoid below a section of the broken line assumed as drawn through the percentage values of the record, with the equal time intervals as abscissas and the percentage light output or percentage efficiency, as ordinates. Consequently, with a weight of unity assigned to each of these equal time intervals, integration of the curves for the full periods is reduced to simple addition. For this reason equal test periods have been adopted. The period chosen after extensive investigation as most satisfactory equals 35 per cent of the life criterion employed; for example, 140 hours for tests based on a 400-hour criterion.

2. EVALUATION OF FAILURES ON TEST

The failures on the test racks, which may occur at any time, must also be included. It has been found that a mass or combined extrapolation of a group of curves through a half period of the "dead-end" values that appear between the time of the last photometer reading and that of failure, regardless of the period within which the failures take place, results in an accurate mean value of percentage light output and percentage efficiency. Although the area thus found may vary considerably from the true combined areas of the curves, the actual life is also different from that assumed in making the extrapolations by an amount sufficient to yield as a quotient almost exactly the true mean ordinate of light output and efficiency. Lamps which fail at the conclusion of a full-test interval but before a photometer reading can be taken, or very near the time when replaced on test after measurement on the photometer, are evaluated for the full-test interval only. In the former case the values are extrapolated through the full period by an amount equal (except for lamps of notably abnormal performance) to the average change of the corresponding lamps of the test which were measured at the conclusion of the period; that is, these failures are considered as average lamps.

Reference to Figure 1 will make these points plain. The "dead-end" values of the individual lamps are shown by the dashed-line extrapolations terminating at the points marked by the crosses. Bearing in mind that the equal scale divisions of percentage life correspond to the chosen test periods (35, 70, 105, etc., per cent), it is seen that the individual lamps failed at points beyond the last test reading of from approximately one-sixth to five-sixths of the full period within which the failure occurred. One lamp failed at the even 105 per cent life after the percentage light output had been determined. The latter lamp has no dead-end value, and is not to be extrapolated.

If, now, instead of these end values we substitute dashed lines terminating at 17.5, 52.5, 87.5, 122.5, and 157.5 per cent life, extending or shortening the nine dashed lines to terminate at these half periods, the illustration would show the group as it is actually considered in the evaluations. If the lamp which failed at 105 per cent life had failed before a reading of light output could be made, the average change in percentage light output found for the lamps measured here would have been assigned, unless its record had shown a marked abnormal past performance. In the latter case it would be assigned a value based on its individual past values.

Remembering that the test periods are equal, we see that the sums of all of the last values of the percentage light output on the record, in connection with the corresponding sums of the values next to the last, may be used to extrapolate the entire group. This is in lieu of considering the individual lamps separately and it gives the "mass" extrapolation mentioned above. As an illustrative example, consider the following five lamps.

Lamp number	Per cent light output		Extrapolation to following mid period
	Last	Next to last	
1	81	87	78.0
2	77	86	72.5
3	88	93	85.5
4	70	80	65.0
5	54	67	47.5
Sums	370	413	348.5
Means	74	82.6	69.7

It is seen that the sum changed 43 for the full period, or 21.5 for the half period, giving $370 - 21.5 = 348.5$ as the extrapolated midperiod value, which is the same as the sum of the individual extrapolated values.

If instead of the terminal value we had desired the mean ordinate of the extrapolated half-period aggregate area, a value used in integrating the curves as referred to later, the change in the sum would evidently be halved, and the required value would be $370-10.8=359.2$, the result of a quarter-period extrapolation, made as follows:

$$\frac{413-370}{4}=10.8, \text{ as just found}$$

This is the extrapolation of one-fourth referred to in Section VII, 4.

3. FORM OF SUMMARY

Items of a summary as carried on a card for a lot of 40 lamps are shown in Table 1. Entries for the failures are preferably made after the measurements at the conclusion of each test period. This keeps the work up to date and minimizes errors in summarizing because a uniform number of items appear after a given test interval. These items give the measurements on the cards for the individual lamps. The table is divided into two parts, both horizontally and vertically. The two vertical divisions refer to the lumen maintenance and the efficiency in lumens per watt, respectively. Values immediately above the double horizontal lines are used in extrapolating. Values below the double lines are full-period values that need no extrapolation. They are values for lamps that fail at a test period after or during measurement and which do not go back on the racks. Values given in parentheses are used for extrapolation only.

TABLE 1.—*Form of summary of test data*

Test period	Size 25 watt	Lot No. 1011	Rated lpw. 9.5	Mean initial lpw. for test 11.05		Number of lamps, 40	Number of lamps and hours to failure	
	Number of values and sums of per centage lumens			Number of values and sums of per centage lumens per watt				
	Last	Next to last	Intermediates	Last	Next to last	Intermediates	Total	Mean
1	(2–200)	(2–212)	None.	(2–200)	(2–208)	None.	2–224	--------
2	5–470	(5–500)	None.	5–485	(5–500)	None.	5–980	--------
3	12–1, 044	12–1, 128	1–94	12–1, 095	12–1, 157	1–95	12–4, 452	--------
4	14–1, 116	14–1, 193	14–1, 390	14–1, 173	14–1, 246	14–1, 333	14–6, 799	--------
5	4–300	4–318	8–722	4–330	4–351	8–736	4–2, 440	--------
6	1–62	1–69	3–252	1–68	1–74	3–262	1–720	--------
Total	36–2, 992	31–2, 708	----------	36–3, 151	31–2, 828	----------	----------	--------
	(2–200)	(7–712)		(2–200)	(7–708)			
	[1](38–3, 192)	(38–3, 420)		(38–3, 351)	(38–3, 536)			
2	1–90	1–95	None.	1–94	1–97	None.	1–280	--------
4	1–70	1–78	2–180	1–75	1–82	2–185	1–560	--------
Total	2–160	2–173	----------	2–169	2–179	----------	----------	411
Total	[2] 38–3, 152 (=2, 992 +160)	33–2, 881 (=2, 708 +173)	28–2, 558	38–3, 320 (=3, 151 +169)	38–3, 007 (=2, 828 +179)	28–2, 611	40–16, 455	--------

[1] The sums in this line are used only for extrapolation.
[2] The values in this line are used in preparing Table 2.

The column headings "last," "next to last," and "intermediate" need explanation. Under each such column headings are given two figures, as (2–200), 5–470, 12–1,044, etc. The first figures are the number of readings that appear on the individual record cards for the corresponding test periods. The second figures give the sums of percentage lumen values, or percentage lumens per watt. Under the column "last" is entered for each test period the number of lamps and the sum of percentage lumens corresponding thereto for the lamps whose "last" or final reading was taken at the end of the particular test period; (2–200) in this column shows that two lamps failed during the first test period. Their initial reading was, therefore, the "last" for these lamps. The percentage lumens is therefore 100 for each of these lamps, or 200 for the sum. Likewise 5–470 indicates that five lamps failed during the second test interval, the sum of the percentage lumens being 470, and so on down the column. During the sixth test interval one lamp failed at 62 per cent lumens. The value 1–90 below the double horizontal lines, indicates that at the conclusion of a test period one lamp failed at the second test period with 90 per cent lumen maintenance. All the lamps of the lot necessarily appear in the "last" column, for all lamps have a "last" reading.

"Next to last" explains itself, but for the two lamps that failed during the first test interval, the value (2–212) is an extrapolated value based on the mean of the values for the lamps of the lot which were measured at the end of the first-test interval. These were placed as much above 100 per cent as the mean of the remaining 38 lamps was below 100 per cent. In this connection see Figure 1 and the explanation accompanying that figure. In the column headed "intermediates" are entered numbers of lamps and "sums of percentage lumens" and in the second part of the table "percentage lumens per watt," determined at the ends of test intervals intermediate between the initial readings and the next to last readings.

4. COMPUTATION OF MEAN VALUES

In Table 2 are shown the items of the summary of Table 1 grouped for integration and computation of the mean ordinates. The "next to last" and "intermediate" values are doubled in Table 2 because they are boundary lines common to adjacent trapezoids composing the area under the performance curve. Initial values, always 100 per cent, and "last" values occur but once in the areas which they bound. The following considerations will make the method plain: Consider any broken line with successive ordinates equally spaced along the scale of abscissas: A, the initial; B and C, the intermediates; and D, the last of the ordinates. Then the area between the line and the X axis equals $\frac{A+B}{2}+\frac{B+C}{2}+\frac{C+D}{2}=\frac{A}{2}+B+C+\frac{D}{2}$, and the mean ordinate $=\frac{A+2B+2C+D}{2}\div 3$. Evidently, by taking the first and last and twice the intermediate values, the items for Table 2 would be 1, A; 2, $2B$; 2, $2C$; 1, D, and the corresponding sum 6, $A+2B+2C+D$, giving the correct mean $=\frac{A+2B+2C+D}{6}$. Note here that the denominator equals the sum of the coefficients of the numerator. An extrapolation of one-fourth, as shown at the right of Table 2, determines the median of the aggregate trapezoid made up of the "dead ends" of the individual curves from the last photometer reading to failure at the assumed half period. Although two values are involved in obtaining this median, the coefficient is unity, because only a half area is involved. The final mean is, therefore, $\frac{A+2B+2C+D+\text{extrapolated median}}{7}$ for the broken line assumed above.

TABLE 2.—*Computation of mean ordinates*

	Percentage lumens		Percentage lumens per watt		Extrapolations	
	Number of readings	Sum	Number of readings	Sum	Percentage lumens	Percentage lpw.
Initial	40	4,000	40	4,000	3,420	3,536
Last	38	3,152	38	3,320	−3,192	−3,351
Next to last	66	5,762	66	6,014		
Intermediate	56	5,116	56	5,222	228	185
Extrapolated	38	3,135	38	3,305	228÷4=57	185÷4=46
Total	238	21,165	238	21,861		
	Per cent		*Per cent*			
Mean	88.9		91.85		3,192	3,351
(Rated)	(87)		(91)		−57	−46
					3,135	3,305

VIII. CONCLUSION

This complete system of life-test photometry, by employing computing auxiliaries, greatly simplifies all operations in a direct, rapid, and practical manner. The choice of equal test periods and the simple method adopted of extrapolating performance curves result in a system of obtaining mean values of percentage light output and percentage efficiency during life without introducing complicated or tedious mathematical operations. All of the devices are simple and easily understood by anyone capable of making the photometric and electrical observations. An added advantage is that the scales employed may be easily and quickly read without eyestrain. The fact that all results are read from the scales on a percentage basis gives the user freedom from reading and recording dissimilar or uncertainly related values. This makes the observer more efficient and less liable to error.

The assistance of A. T. Ruppert in connection with the special work herein described is gratefully acknowledged.

WASHINGTON, April 29, 1926.