A Preliminary Comparison of the Neon Lamp and Potentiometer Methods of Submarine Photo-Electric Photometry.

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With 2 Figures in the Text.

Our previous experience of submarine photometry (1925, 1926, 1928, 1929) indicated the desirability of obtaining additional information in certain directions and of speeding up the observations without sacrifice of accuracy; our aim was indeed to increase the accuracy, at the greater depths especially and in sub-surface observations. Further data upon the horizontal illumination, viz. that received by a vertical surface, were also wanted.

The above *desiderata* were sought as follows:

(*a*) To increase accuracy a more sensitive vacuum cell was obtained—a sodium cell of the Burt type, with "end-on" illumination. This had a sensitivity of 5·30 m.c. per 10^{-9} amp. as against 31·6 m.c. for the potassium vacuum cell previously used, photometer L. It was hoped that it would have been possible to use this down to bottom at Station E1, thus avoiding having recourse to a gas-filled cell; the latter has to be calibrated before and after use and the voltage change-over ratios have also to be determined, so that both on the score of accuracy and speed of operation a vacuum cell is to be preferred when possible. For several reasons, however, the Burt cell could not be used for the deeper water; firstly, owing to its smaller aperture the "end-on" is not as sensitive as the side window type, secondly, though mounted so that the aperture in the cell was close to a larger window in the new type of photometer case (described later), yet the mounting undoubtedly reduced the sensitivity somewhat, and thirdly, the plate glass, 12·5 mm. thick, reduces the middle of the solar ultra-violet somewhat, yet it is just here—at 360 mμ—that the sodium cell has its greatest sensitivity. In any case the diffusing opal glass must reduce the intensity in this region. Hence the sensitivity of this photometer, as given above, proved to be considerably less than was expected. Furthermore, it is possible that the absorption coefficient for the light to which the sodium cell responds is greater than that for the potassium cell, the latter being of greater wave-length. This, however, remains to be tested by the measurements. A greater accuracy throughout, especially in the deeper water, was attained, however, by using photometer J, already described (1929), but maintained in its condition of maximum sensitivity by a method communicated to us by the staff of the Research Laboratories of the General Electric Co. The gas-filled potassium cell, mounted as photometer J, has its sensitivity increased by the passage of a relatively large current caused by exposure to bright light. The subsequent gradual loss of sensitivity when subjected to low illumination, implies that in deep water the cell is not as sensitive as one would expect from the voltage change-over ratio, determined at a lesser depth. For all measurements to be comparable, the sensitivity should be the same. This we formerly sought to maintain by avoiding the passage of a really large current at any time by reducing the applied voltage for bright light, the safe limit being determined by trial. A correction was also introduced, assuming the change of sensitivity to be a linear function of the time. The method, now adopted, is the reverse. The cell is momentarily connected with a voltage just sufficient to produce a glow discharge in absence of light. This leaves it in a highly sensitive state ; immediately after the glow the measurement is made at the voltage appropriate to the illumination. This is the best one can do with a gas-filled cell. A special series of tests was carried out to ascertain the accuracy thus obtainable. These are described elsewhere. (Atkins, 1931.) If the glow were allowed to continue the cell would be ruined. The method gives results which seem to be more constant than those obtained formerly, but not as constant as with a vacuum cell. With light of low illumination, however, the far greater sensitivity of the gas-filled cell outweighs this defect and the readings become more accurate, being much larger.

To sum up, for accuracy and speed of work down to moderate depths the Burt cell (photometer M) or the potassium vacuum cell (photometer L) may be used, but for the greater depths the potassium gas-filled cell (photometer J) must be used. What these depths actually are depends upon the clearness of the water at the time.

(*b*) Observations immediately above and below the water surface are obviously desirable because owing to the shadow of the ship the light just above the water is always less than that as measured on the deck-house roof. Measurements in the latter position serve, however, to detect any change in general illumination. The shadow error is not a constant. The stern of the ship is always kept pointing towards the sun, so that with a bright sun—say $\beta=3$—the shadow is relatively unimportant, since only a percentage of the diffuse light is cut off. With overcast sky, $\beta=1$, this loss becomes the same percentage of the total light.

As the photometer is lowered through the water the shadow error increases at first and then decreases. It is obvious, however, that it is soon rendered insignificant by the absorption of the water, so though it may affect the percentage values of the illumination at the lesser depths it will have but little effect on the absorption coefficients calculated from them.

The difference between the measurements just above and just below the water surface denotes the loss due to irregular surface reflections, the submarine photometer—even when in air—having a few millimetres of water over its opal disc. Formerly we allowed 15 per cent to cover these shadow and reflection losses and took it that the sub-surface light was 85 per cent of that on the deck-house roof, on an average.

Under calm weather conditions with diffuse light and opal disc over photometer it is quite possible to obtain tolerably good measurements just above and just below the water, using the potentiometer method of measuring the photo-electric current. (See Series 48.) As a rule, however, the conditions render such measurements impossible, because the photometer swings too much, the wave motion is too great at the surface, and the sunlight just below the surface is naturally very variable.

For such measurements the neon lamp method described by J. H. J. Poole (1928) has many advantages, since it gives a measure of an integrated current over any convenient period of time. The measurements made with it in Lower Lough Bray have already been described (J. H. J. and H. H. Poole, 1930). Photometer M was used for this work. The neon lamp outfit taken to sea was the same one that had been at Lough Bray. Since its serviceableness on ships and small boats is great, while its cost and weight are low, an outline of the principle upon which it works is given further on. The fact that the method integrates the current makes it immaterial whether the latter varies irregularly, provided that over the period of the measurements the mean current remains constant. In other words the general illumination must not change—or if it does a series of integration measurements must be performed and an average taken, just as in the potentiometer method. By the help of the neon lamp method measurements were obtained just above and just below the water surface and at depths down to 5 m.; concordant measurements are not easily obtained at depths less than 5 m., using the potentiometer method.

(*c*) Series relating to the horizontal light intensity and the intensity of light travelling upwards have already been given (1928, 1929). These refer to light received on a photometer window placed vertically, or inverted. Williams (1929) has since made similar measurements with a projecting tube to ensure that only light at 90° to the vertical should enter. Further measurements appeared desirable and as a new case to contain the Burt cell had to be made, it was so designed as to be better adapted for being slung with window vertical. This could most

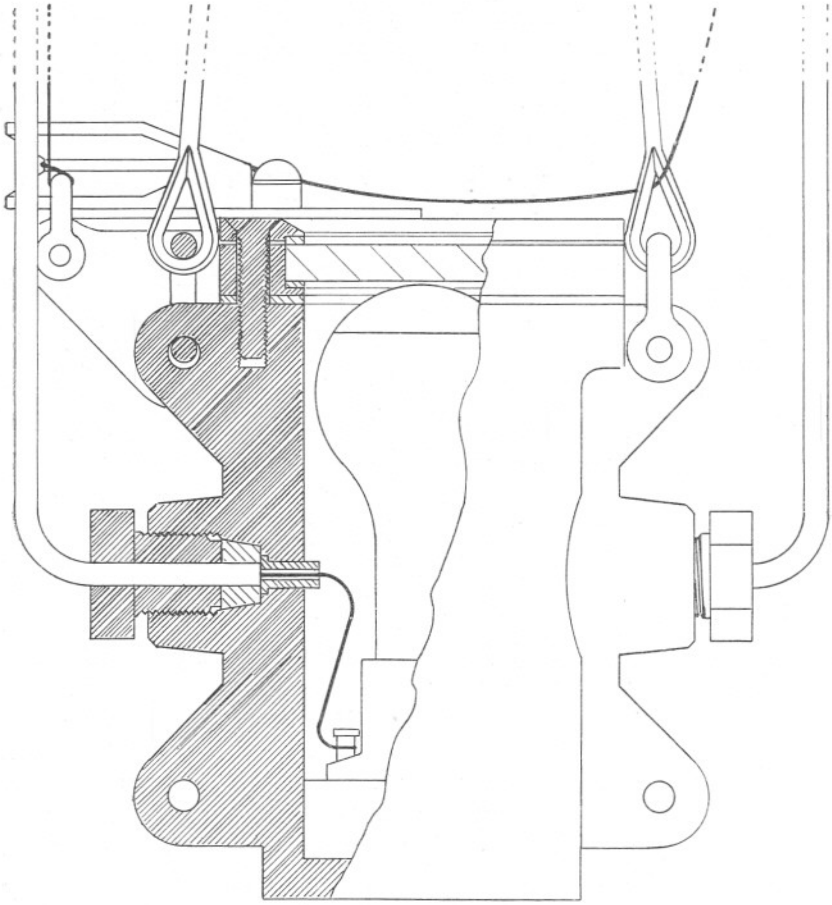

Fig. 1.—Above is shown, in part section, the new type of submarine photometer case with photo-electric cell, the height of the latter, with standard U.S.A. radio valve base, being 16 cm. Immediately over the window of the cell comes the plate glass window, 12·5 mm. thick, which is fixed as described in the lid, one screw of which is shown. The cable leads enter at the sides. Note the lower bolt-holes for lateral or inverted suspension. The photometer is shown with window cover swung clear by applying tension to the twine (full black line) on left-top corner. The twine works in the groove of the wooden projecting piece, which is a cut-away sector of a disc. It is necessary to have the twine passing through a shackle mounted on a metal flange to secure adequate leverage. The insertion of the cables has been described for the earlier type. The opal disc, attached by wax above the plate glass window, is not shown.

conveniently be done by having a cylindrical case (see figure, where the case is shown in part section) and using an " end-on " rather than a side exposure cell. This design was slung by two diametrically opposed steel wires, instead of by four—one from each corner of a box. Moreover, additional bolt-holes were placed, as indicated, near the bottom of the case so that by merely changing one suspending wire and passing its bolt through one of the side lower bolt holes one could sling the photometer with window vertical, instead of horizontal. By using both the lower bolt holes the photometer may be slung in an inverted position. In former measurements the alteration in position had to be made by lashing, with consequent delay and some uncertainty as to a precise setting of the photometer. Figure 1 shows the new type of case. It was lighter and rather easier to handle than the old one. Its greater length, however, made it more apt to tilt in the water were the ship to drift rapidly. This must have been without practical importance in the work here described.

MEASUREMENT OF THE PHOTO-ELECTRIC CURRENT.

(a) The Potentiometer Method.

This has been used as previously described. Occasionally with large currents the drop in potential was measured across a 40,000 ohm resistance instead of the usual 100,000 ohm.

In spite of the additional precautions described in our later work (1929) surface leakage continued to be a trouble in very damp weather. The surface of the potentiometer was coated with paraffin wax, with some effect. Nevertheless on October 15, 1929, at Station E 1, with an east wind blowing into the deck-house the leakage was so bad that operations were about to be suspended for the day. As a last resort the insulated metal box containing the H.T. batteries and connected to the negative pole, as shown in the figure facing page 301 (1929), was earthed to a nut on the iron tube carrying the steering chain on the port side of the deck. All troubles ceased immediately. A " dark current " was, however, found again on October 21, but this was traced to photometer M, which on opening was found to have leaked around the window. The internal fittings and cell were washed in distilled water and thoroughly dried ; the calcium chloride was renewed ; finally a good seal was effected by heating the upper portion and the window holder in an air oven and pouring " SIRA " (Scientific Instrument Research Association) wax between the two pieces. These were then screwed together and the wax which extruded was pared away. The photometer has not recently been used at sea, but has been, since December, 1929, upon the roof of the Laboratory attached to a Cambridge Inst. Co. " thread recorder " (1930, 1). No leakage into the cell has occurred.

(*b*) THE NEON LAMP METHOD.

This has been described by J. H. J. Poole (1928), who first devised it, and is figured by J. H. J. and H. H. Poole (1930).

We are indebted to Dr. J. H. J. Poole and to the Physical and Optical Societies for permission to reproduce the figure (Fig. 2). The wooden box containing the condensers, neon tube and safety resistance R (about 20,000 ohms) is indicated in section. Its shape has been modified to

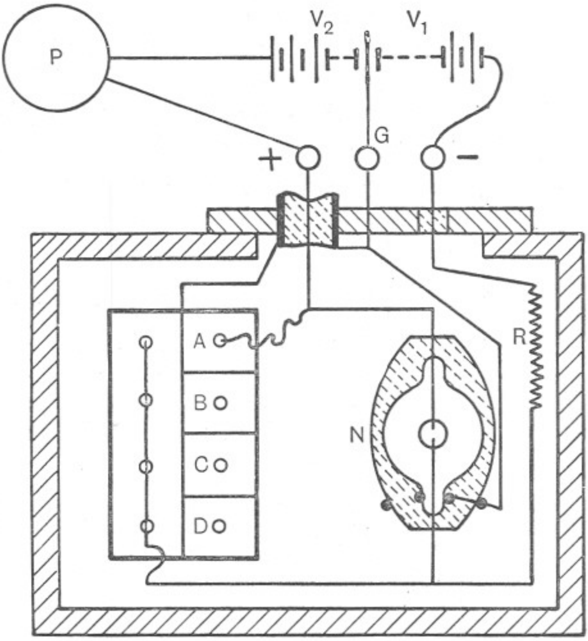

FIG 2.

show the electrical connexions more clearly. For a detailed description the original paper should be consulted.

The ordinary photo-electric circuit is used to charge a condenser, or, in practice, one of a set of four, of capacities as shown, A $=0{\cdot}5\ \mu$F, B $=0{\cdot}05\mu$F, C $=0{\cdot}005\mu$F and D $=0{\cdot}0005\mu$F, any one of which can be used by making connexion with a wander plug. A neon lamp, N, is connected in parallel with the condenser. Provided the voltage across the terminals of the lamp exceeds about 130 a flash will appear from time to time in it, the condenser being partially discharged thereby. It has been shown that the rate of flashing is proportional to the charging current, namely to the mean value of the illumination over the period. The voltage must be high enough not only to ensure flashing but also so that the effective potential across the photo-electric cell, P, is always in a region in which small changes are without great effect upon the sensitivity, if absolute measurements of illumination are to be made. A sufficient potential, V_1, should be connected to a guard ring, G, attached to the neon lamp, to overcome the effect of small leaks, otherwise a current due to a certain number of metre candles would be required merely to balance the leakage. If the guard-ring potential be too high, flashing will occur in the dark. With a small rate of " dark " flashing, for which allowance can be made, the apparatus is in its most sensitive condition. Usually the total potential, V_1+V_2, should be 230–240 volts, and that across the guard-ring 170 volts.

In the measurements here described the ideal conditions were not satisfied, for though flashing began at about 132 volts, with photometer M, it was not possible to go much above 150 volts without obtaining " dark current " flashes, though at 60 volts M had previously showed no signs of leakage, internal or external. It had accordingly been fitted up without connecting its own guard-ring. For uniformity therefore a nominal, and closely an actual, voltage of 150 was selected and was employed with the deck photometer H (potassium vacuum) and the submarine photometers M (sodium vacuum), L (potassium vacuum) and J (potassium gas-filled).

These preliminary measurements with the neon lamp method were obviously unsuited for the accurate measurement of illumination, especially for low intensities, since the absence of a guard-ring potential introduced the error mentioned above, namely, that a certain minimum illumination was required to overcome the effects of leakage in the neon lamp and condensers. On the other hand, an error of the opposite sign was introduced by the leakage in photometer M. This error was much the larger of the two, and to keep the net dark-current down to a reasonable magnitude, which could be corrected for, the potential was reduced, as above. Hence the anode potential across the photo-electric cell was small, and its variation during the cycle of charge and partial discharge of the condenser must have considerably affected the sensitivity of the cell.

The interest lies rather in determinations of a comparative nature near the surface or at a small number of metres below it. These were, where possible, checked against determinations made by the potentiometer,

It must be pointed out that the effective capacity may differ considerably from the nominal capacity in parallel with the neon lamp, for the leads themselves have a certain capacity which may be quite considerable in the case of the submarine cable. This lessens the sensitivity of the method for work in the sea, but does not impair its usefulness for the lesser depths. This compounded capacity may be denoted thus : A M, capacity A ($0{\cdot}5\mu F$) with that of photometer M, including its leads. In practice the time taken for a convenient number of complete flashes is measured; from this we can at once find either the time (t) of a single flash, which is inversely proportional to the current, or the number of flashes per minute (n) which is directly proportional to the current.

Inspection of Table I will make the method of standardization clear. This work took one hour under conditions of steady illumination and would have taken longer with variable light or at sea.

TABLE I.

September 29th, 1929. Standardization of neon lamp apparatus on roof of Laboratory, Plymouth, with photometers H and M side by side on parapet. H was used with potentiometer to determine V, shown in thousands of metre candles, k.m.c. When H was attached to the neon lamp apparatus, M, previously standardized against H, was used with the potentiometer. Number of flashes per minute=n. The window of M was wet as used at sea. Voltage was 150 on neon lamp apparatus, usual 60 v. with potentiometer. The series given are the means of five, four, five, and six highly concordant determinations respectively.

G.M.T.	V., k.m.c.		V., k.m.c., per flash. per min.	Ratios of sensitivities.
		nAM		$\frac{AM}{AH}$
3.10–3.24	40·58	17·6	2·31	11·0
		nAH		$\frac{BH}{AH}$
3.25–3.46	35·18	1·38	25·50	12·4
		nBH		$\frac{BM}{BH}$
3.47–3.59	32·20	15·7	2·06	8·2
		nBM		$\frac{BM}{AM}$
4.0–4.10	27·35	108·9	0·251	9·2

Next day, September 30th, the apparatus was taken to sea on the *Salpa*, but the weather was so bad that preliminary trials only could be carried out, inside the Breakwater. It was necessary to ascertain whether the capacity of the cables attached to M was altered by immersion. The coil had never been in salt water before. The wind was from S.W., strong and freshening, waves breaking, uniformly grey sky.

The ratio of the rates of flashing were determined with photometers side by side: (a) coil in air, (b) half in water, (c) almost all in water; results were obtained respectively for this ratio:—BM/BH, (a) 7·53, (b) 5·75, (c) 7·09, and 7·47. Under the adverse weather conditions these may be taken to indicate no change. A small alteration would not seriously affect comparative results. Taking the mean of the ratios, omitting the second, we see that BM/BH=7·35, as against 8·22 on the roof the previous day, using the same method and voltage. Comparing M and H, each with 60 volts anode potential, by means of the potentiometer, the ratio M/H=8·89 was obtained as against 8·75 under good weather conditions on the Laboratory roof on September 27th. This ratio 8·89 gives 4·75 metre candles per 10^{-9} amp. for M, for diffuse light, the corresponding value for H being taken as 42·3 m.c. It may be pointed out that the MH ratios determined by the potentiometer and neon lamp methods are not comparable, both on account of the different voltages—the effective voltage in the latter being low—and of the capacity effect.

TABLE II.

V_a and V denote the illuminations, in k.m.c., as shown by the air and submarine photometers ; ss denotes photometers side by side on deckhouse roof, a denotes submarine photometer swinging just clear of the water and b just below the water surface. The percentages p and p' refer to the roof and sub-surface positions respectively, p_n and $p_{n'}$ being the corresponding values found with the neon lamp apparatus. The values for the vertical absorption coefficients μ_v‡ and μ_{vn} (the latter with the lamp), are entered opposite the lower depth of the range taken, viz. 5 m. value is 4 to 5 m.

Time of flash, with 0·05μF condenser=2·70 sec., for photometer H and 0·394 sec., for photometer M, ratio M/H=7·71, at 2·11 G.M.T.

Date, Remarks, etc.	G.M.T.	V_a k.m.c.	d m.	V k.m.c.	p	p'	μ_v	p_n	p_n'	μ_{vn}
SERIES 47 and SERIES N2	2.4	40·2	ss	40·2	100	121	—	100	138	—
2.10.'29. Off Pier Cellars, Caw-	2·34	40·4	b	33·3	82·5	100	—	72·7 71·8	100	—
sand Bay, depth 8 m.	2.42	35·8	1	13·0	36·3	44·1	0·821	—	—	—
Wind strong N.W., waves	2.51	60·4	1	21·1	35·0	42·5	0·858	—	—	—
breaking at times, long	2.58	56·9	2	10·6	18·6	22·6	0·630	19·0	26·3	0·867†
swell. Sun weak through	3.25	19·5	3	1·62	8·29	10·1	0·809	10·7	14·8	0·568
broken clouds, some blue	3.46	25·9	4	1·04	4·01	4·87	0·725	4·74	6·56	0·821
sky.	3.50	20·2	5	0·385	1·91	2·32	0·744*	1·79	2·48	0·969
	4.4	18·7	6	0·236	1·26	1·52	0·420	0·49	0·68	1·31

* Mean 0–5 m., 0·746 for μ_v and 0·818 for μ_{vn}.

† 0 – 2 m.

‡ In previous papers we used μ for the absorption coefficient calculated on the supposed mean length of the path of the beam reaching the photometer and λ for the vertical absorption coefficient. μ_v is now used for the vertical absorption coefficient as when dealing with the colour of the light we require the usual symbol λ to denote wave-length.

Date, Remarks, etc.	G.M.T.	$\alpha°$	Light.	β	d m.	V_a k.m.c.	V k.m.c.	p %	p' %	μ_v
SERIES 48. 14.10.'29.	1.25		Sun clear, sky	2·32	—	52·0	52·0	100	134	—
M Photometer. At E1.	1.36		clear blue, few		a	51·1	45·2	88·5	116	—
Wind S.W., very light,	1.45		clouds low on		b	51·9	38·8	74·8	100	—
water smooth, almost	1·50	31	horizon. Visi-		1	51·9	32·2	62·0	82·9	0·188
glassy, only slight swell.	1·56		bility good.		2	45·9	20·4	44·5	59·5	0·332
Depth 73 m.	2.0				5	45·7	9·91	21·6	28·9	0·238
	2.4	30			10	44·2	2·70	6·11	8·18	0·253
	2·7				15	44·0	1·02	2·32	3·10	0·194
	2.9				20	43·6	0·396	0·91	1·22	0·187
	2·12	29			25	43·6	0·163	0·375	0·502	0·177
	2·16				30	43·1	0·068	0·157	0·210	0·174
	2·19	28			35	43·1	0·029	0·066	0·088	0·172
	2·25	27			40	37·9	0·010	0·026	0·035	0·186
	2·39				35	38·4	0·017	0·045	0·060	0·168
	2·42 *	25			30	38·4	0·052	0·131	0·175	0·219
SERIES 49. 14.10.'29.	4.6	12		1·21	—	14·4	14·4	100	—	
M Photometer. At E1.	4·12	11			5	13·9	2·94	21·1	28·2‡	0·252‡
	4·16				10	13·5	0·878	6·50	8·7	0·236
	4·21	10			15	11·9	0·258	3·07	4·1	0·150
SERIES 50. 14.10.'29.	4·33	8	Sun clear, but		5	9·54	1·410	14·80	37·2	0·198
L Photometer. At E1.	4·36		low, sky clear,		10	8·90	0·444	4·99	12·5	0·217
Surface glassy, a flat	4.40	7	visibility good.		15	8·52	0·134	1·56	3·9	0·232
calm. Secchi disc 8½ m.	4·42			1·11	—	774	—	—	—	—
in sun on W., at 4.45 and	4·44	6		1 08	—	7·36	—	—	—	—
9 m. in shade on E.	4·57	4			b	5·17	2·055	39·8	100	—
	5·1	3			a	4·45	2·120	47·7	123	—

* The neon lamp method series N3 came in between.

‡ Calculated on the sub-surface value 74·8 per cent of Series 48, or allowing the usual 15 per cent loss only 0·278.

Date, Remarks, etc.	G.M.T.	$\alpha°$	Light.	d m.	V_a k.m.c.	V k.m.c.	p %		μ_v
SERIES 51. 15.10.'29.	12·6	31	Sun hazy but	5	43·1	8·56	19·8		0·291
M Photometer. Near	12.11		clearing, sky	10	44·3	2·36	5·32		0·263
El. Wind E., light.	12·19		blue with much	10	64·8	3·23	4·97		0·276
Secchi disc 10 m. in	12·29		haze.	15	58·1	1·02	1·77		0·207
shadow of ship to W.,	12·34			20	57·0	0·386	0·678		0·191
9 m. in sun on E. of ship.	12.39			25	56·2	0·161	0·286		0·172
	12·44			30	56·2	0·060	0·107		0·197
	12·48			35	57·9	0·025	0·043		0·181
	12·52			5	59·2	9·05	15·2		0·330*
	1·0	30		ss	56·2	56·2	100·0		—
						H k.m.c.	p_h‡ %	$\frac{p_h}{p_v}$	μ_h
SERIES 52. 15.10.'29.	1.21	29	Sun clear, visi-	5	51·4	2·700	5·26	0·266	—
M Photometer. Slung	1.25		bility good, no	10	51·7	0·995	1·93	0·375	0·201
horizontally. Near El.	1.28		clouds.	15	50·9	0·248	0·487	0·276	0·275
Moderate swell, waves	1·31	28		20	50·4	0·121	0·241	0·356	0·140
breaking, wind S.E., light	1.33			25	48·7	0·045	0·093	0·323	0·191
to moderate.	1.36			30	48·7	0·034	0·069	0·650	0·058
	1·40	27		5	48·5	1·770	3·66	0·184	— †

* 5–35 m., μ_v=0·195.
‡ Relative to the vertical light in air, p_v is p of Series 51.
† 5–30 m., μ_h=0·158.

Date, Remarks, etc.	G.M.T.	$\alpha°$	Light.	d m.	V_a k.m.c.	V k.m.c.	p %	μ_v
SERIES 53. 15.10.'29.	2.42	22	Sun clear, low	ss	38·4	38·4	100·0	—
Photometer J. Near	2.45		clouds only,	ss	36·7	36·7	100·0	—
El. Wind S.E., light to	2.57		visibility good.	5	32·2	6·57	20·4	0·285*
moderate, swell moderate	3.5	20	β=1·59.	10	31·2	2·02	6·50	0·228
and decreasing.	3.10	19		—	28·9	—	—	—
	3.15	18		15	26·7	0·644	2·41	0·198
	3.19			20	26·8	0·330	3·12	0·134
	3.22	17		25	26·3	0·187	0·712	0·110
	3.32	16		30	23·6	0·110	0·467	0·084
	3.35			35	23·6	0·073	0·310	0·082
	3·44	14		40	20·0	0·047	0·236	0·056
	3.55	13		35	15·1	0·048	0·317	0·078
	3.59			45	14·9	0·022	0·149	0·091
	4·5	12		50	14·3	0·011	0·075	0·073†
	4.12	11		55	10·8	0·008	0·072	0·114‡
	4.19	10		5	8·88	1·90	21·4	0·275*
	4.26	9		5	7·53	1·63	21·7	0·272*
	4.34	8		ss	6·51	6·51	100·0	—

* Assuming 15% loss at surface, including shading due to ship.
† For 45–55 m. ‡ For 5–55 m.

Date, Remarks, etc.	G.M.T.	$\alpha°$	Light.	β	d m.	V_a k.m.c.	V k.m.c.	p %	μ_v
SERIES 54. 21.10.'29.	12.10	29	Sun and blue	2·23	—	48·4			
Photometer J. About	1.12	28	sky with mov-			42·8			
one mile W. of Rame Hd.,	1.26		ing clouds.			21·4			
depth 33 m. Wind S.W.,	1·30					23·9			
light to fresh, some waves	1.42				ss	45·3			
breaking.	1.48				ss	47·6			
	1.54				ss	21·6			
	1.59	24			ss	18·9			
	2.7				ss	40·4			
	2.25	22		1·82	5	33·1	5·78	17·5	0·315
	2.33	21			10	33·6	1·46	4·35	0·278
	2·45	20			15‡	27·4	0·406	1·48	0·216
	2.57				15§	27·9	0·397	1·42	0·223
	2.59				15	25·5	0·376	1·48	0·216
	3.4	18			20	25·1	0·099	0·39	0·263
	3·8				25	24·6	0·036	0·15	0·199
	3.14				30	24·1	0·008	0·03	0·287*
	3·16	16		1·36	—	23·9	—	—	—
	3·30	14			5	18·9	2·89	15·3	0·342
	3.40	13			5†	15·1	2·16	14·3	0·356

‡ J at 12 volts up to this.
§ J at 60 volts. J_{60}/J_{12}=2·34.
† J at 12 volts again.

* 5–30 m., 0·244.
ss Photometers side by side for calibration.

Date, Remarks, etc.	G.M.T.	Light.	d	p	p'	μ_v
SERIES N1. 30.9.'29.	11.40	Sky overcast.	ss	100	168	—
Photometer M. Just		Thickening for rain,	a	70·5	118	—
inside Plymouth Break-		occasional drops in	b	59·5	100	—
water, depth 13 m. Wind		afternoon. At 12.30	b¹	55·5	93·5	—
S.W., strong and freshen-		V=18·6 k.m.c., and	1	39·6	66·6	0·404
ing, waves breaking.		at 2.45 V=6·1.	2	25·6	43·1	0·435
			3	16·0	26·9	0·495
			4	10·0	16·8	0·469
	1.40		5	6·67	11·2	0·401
	2.0		6*	5·12	8·61	0·266
			7	3·43	5·77	0·399
			0–7	—	—	0·410

* Changed over from condenser B (0·05μF) to C (0·005μF) for each photometer, viz. H on deck-house roof and M in water.

Date, Remarks, etc.	G.M.T.	Light.	d	p	p'	μ_v
SERIES N2. 2.10.'29.		Blue sky and broken	ss	100	138	
Photometer M. Off		clouds; sun weak	b	72·7	100	
Pier Cellars, Cawsand		through clouds.	b¹	71·8	98·7	
Bay, depth 8 m. Wind			2	19·0	26·1	0·867
strong, N.W., long swell,			2	19·1	26·2	—
waves breaking.			3	10·9	14·7	0·568
			3	10·5	14·3	—
			4	4·75	6·52	0·821
			4	4·74	6·51	—
			5	1·79	2·47	0·969
			6	0·49	0·67	1·31
			6	0·48	0·66	—
			0–6			0·831

Date, Remarks, etc.	G.M.T.	$\alpha°$	Light.	d	p	p'	μ_v
SERIES N3. 14.10.'29.	3.24	17	Sun clear, sky	5	33·7	36·4	0·216
Photometer M. At E1,	3.29		clear blue, few	4	41·8	45·2	0·144
depth 72 m. Wind S.W.,	3.33	16	clouds low on	3	48·3	52·2	0·304
very light, water almost	3.39	15	horizon. Visi-	2	65·5	70·8	0·138
glassy, only slight swell.	3.44	14	bility good.	1	75·2	81·3	0·207
	3.51	13		b	92·5	100	—
	3.57			a	100	108	—
				0–5	—	—	0·202
SERIES N4. 21.10.'29.	3.52	11	Sun and blue	5	14·3	18·7	0·407
Photometer J. About	3.58	10	sky with clouds,	4	21·5	28·4	0·228
one mile W. of Rame Hd.,	4.6		light fairly	3	27·1	35·7	0·356
depth 33 m. Wind light	4.10	9	steady.	2	38·7	51·0	0·179
to fresh, some waves	4.16	8		1	46·3	61·0	0·392
breaking.	4.21	7		b	68·5	90·3	—
	4·29	6		a	77·0	—	—
	4.39	5		a	76·0	100	—
	4.50	3		ss	100·0	132	—
				0–5			0·312

DISCUSSION OF RESULTS.

Table II records the results obtained in Series 47–54, in which measurements were made as usual by the potentiometer method, and in Series N1–N4, in which the neon lamp method was used.

The lettered sections which follow relate in general to those similarly lettered in the introduction.

(a) It was never found possible to use the new vacuum sodium photometer (M) down to the bottom, 70 m.; the greatest depth was 40 m. (Series 48), at which the illumination was 10 m.c. Photometer L had previously been used to 40 m. (Series 19), the illumination being 150 m.c. The inadequate cable length prevented its use at a greater depth. Were the aperture to be increased somewhat and the cable lengthened it appears that a potassium cell could be used to greater depths than a sodium cell. Thus at Station E1 on 14/10/'29 the sodium cell gave, for the vertical absorption coefficient, μ_v, between 5 and 35 metres, the value 0·193 (Series 48), whereas next day the gas-filled potassium cell J gave 0·139 over the same range (Series 53). Obviously the shorter mean wave-length registered by the sodium cell is more heavily absorbed than is the rather longer radiation to which the potassium cell is sensitive; for the wave-length sensitivity data see Figure 2, page 466, Vol. 15, this journal. Such a result is in keeping with the findings of Shelford (1928) for the upper 15 m. in the Puget Sound, below which the transmission of the light affecting the sodium cell was the greater. A comparison of photometers M (sodium) and L (potassium vacuum) on 14/10/'29 at E1 gave, from 0–15 m., μ 0·228 and 0·213 for M and 0·216 for L. This is close agreement, but it may be seen in the figure that this particular potassium cell showed greater response to shorter wave-lengths than did other potassium cells; in any case the gas-filled cells show a sensitivity shift towards longer wave-lengths. The three values of μ_v for 14/10/'29 were obtained at 2 P.M., 4.15 P.M. and 4.35 P.M., mean times, of each series, and serve to show that there was no appreciable alteration in absorption due to phototropic movements of zooplankton, as had been suspected previously on other occasions; at this season, however, no considerable amounts of zooplankton would be found.

As regards the state of the water from year to year it is of interest to consider the mean values of μ_v from 5–35 m., at E1. The determinations in 1925, 1927 and 1929 were made with potassium gas-filled cells K and J, that for 1928 with a vacuum cell, L; μ_v=0·146 (1/10/'25), 0·104 (3/10/'27), 0·124 (2/10/'28) and 0·139 (15/10/'29). At this time of year the vertical circulation, brought about by surface cooling, has just taken place, so that the water column is isothermal and homogeneous. There are, however, considerable differences in μ_v from year to year. These are probably to be sought in the amount of suspended matter, in which inshore water is richer than that further out to sea. Examples illustrating this may be found by comparing Series 47, Cawsand Bay, μ_v=0·78, Series N1, Breakwater, μ_v=0·41, Series 54, near Rame Head, μ_v=0·24, Series 51, near E1, but closer to shore, μ_v=0·19. These measurements were with the sodium photo-electric cell, save Series 54, in which a gas-filled potassium cell was used, giving a value rather lower than with a sodium cell. Since it was not possible, as shown in our 1929 paper, to correlate the changes in μ_v with seasonal changes it would appear desirable to study it on a line across the English Channel, or further out into the Atlantic, for it might give indications of the origin of the water similar to those given by salinity determinations, and perhaps more delicate, even though of lesser percentage accuracy.

(*b*) As previously pointed out the shadow error, due to taking the deck-house roof reading as being a measure of the illumination just above the water surface, is both large and variable. Thus in Series N1, with no sun, the shadow loss was 29·5 per cent of the total illumination as measured on the roof; in Series N4, with a clear sky and low sun it was 23·5 per cent; in Series 48, with a clear sun and sky and $\beta=2{\cdot}3$, the loss was only 11·5 per cent. In Series 50, with a clear sun and sky, but late in the afternoon with $\beta=1{\cdot}04$, the loss was 52·3 per cent; in this case the shading must have been abnormally great, the deck-house photometer perhaps sloped towards the sun with the ship's roll and the photometer above the sea was entirely shaded from the sun; but whatever the explanation such measurements were obtained.

In obtaining illuminations below the surface the readings must be multiplied by the factor 0·935, which is the ratio for the light in air to the light just below a smooth water surface for diffuse daylight (see p. 184, 1926 paper).

The submarine photometers were standardized in air, with opal glass in position and window wet, bubbles being excluded. The light in air was measured by the roof photometer, H, so that in the water over the window may be taken as 0·935 of this. Accordingly the "air" reading of the submarine photometer corresponds to an illumination in the layer of water just outside its window only 0·935 times what one assumes for the purpose of standardisation. The factor is an approximate one for an assumed uniformly bright sky. This correction has been made in obtaining the figures given in the table.

The light lost upon entering the water was measured directly in five series, being obtained from the illumination just above the surface "*a*" in the tables, and that just below the surface "*b*." Values for $a-b$ were as follows: Series N1, 15·5 per cent; N3, 7·5; N4, 10·5; 48, 15·5; 50, 16·5; mean, 13·1.

Formerly, in calculating μ_v, $0-5$ m., we took the deck-house roof illumination and deducted 15 per cent to obtain the sub-surface illumination, *b*. This would have been approximately correct for the surface loss, but is quite inadequate for the shadow loss.

It would therefore appear that it is essential to obtain *a* directly if *b* cannot be obtained on account of the roughness of the sea. If neither can be obtained values for the percentage submarine illumination may be got by assuming a surface loss of 15 per cent for choppy water or 8 per cent for calm water, and making an approximate allowance for the shading due to the ship according to the lighting conditions prevailing at the time.

It follows from this that the neon lamp method is of value, for only under really good weather conditions can *a* and *b* be obtained by the potentiometer method. The latter, however, has the advantage for work down to the greater depths.

(*c*) As regards measurement of the "horizontal light," namely, that falling on a vertical surface, only one series (No. 52) has been obtained in addition to those previously reported, Series 15 (12/9/'27), Series 25 (6/3/'28). The latter series, with an efficient opal diffusing disc, gave 0·61 – 0·47, mean 0·54 as the ratio of horizontal to vertical light from 0 – 25 m. Series 52, within the same limits, gives 0·37 – 0·22, mean 0·31, as determined with sodium photometer, instead of potassium in Series 25. Further measurements are desirable.

SUMMARY.

1. J. H. J. Poole's neon lamp method (1928) of integrating the photoelectric current is serviceable for work at sea down to moderate depths, which further experience may extend considerably. It is specially valuable for determining the light just above the water, and at such depths down to 5 m., at which the variability of the light renders the potentiometer method (1925) very difficult or quite impossible in rough water. For greater depths, down to 70 m. (bottom in the English Channel around our normal range) we have so far been able to use the latter only.

2. The loss due to the shadow of the ship, obtained by subtracting the illumination just above water from that on the deck-house roof, was found to vary from an extreme case of 52 per cent, and a normal loss of 30 per cent, with an overcast sky, down to 11 per cent with a clear sun at 31° altitude.

3. The loss of light due to its entering the water was found to vary from 7·5 to 16·5 per cent, mean 13·1 per cent.

4. It is desirable that the illumination just above and just below the water surface should be determined by the neon lamp method as a routine.

5. It was found that, under the isothermal and homogenous water conditions obtaining during the first half of October, the vertical absorption coefficient, μ_v varied at Station E1 (about twenty miles outside Plymouth Sound) from $\mu_v=0{\cdot}146$ in 1925 to $\mu_v=0{\cdot}104$ in 1927, 1928 and 1929 being intermediate with $\mu_v=0{\cdot}124$ and 0·139 respectively, over the range 5–35 m. These potassium cell values are less than similar determinations with a sodium cell, for which the value $\mu_v=0{\cdot}193$ corresponds to the 0·139 value for potassium.

6. A modified form of submarine photometer case has been described, so constructed that its opal receiving surface can be altered from the

horizontal to the vertical or inverted positions merely by altering one or two bolts and shackles. It has two shackles instead of four. The one series of measurements made with it and its sodium cell, gave a mean value 0·31 for the ratio of the horizontal to the vertical submarine illumination between 0 and 25 metres.

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