Underwater Light Sensors
SKUW Series

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Skye Instruments Ltd.

Skye Instruments is based in the UK and we are very proud to be celebrating being in business since 1983. Our products are designed and built in the UK. We have a very wide product base and our sensors & systems are used for plant & crop research; micro-climate, global climate change studies; environmental monitoring and controlled environment installations.

Products include light sensors & systems, weather monitoring sensors, automatic weather stations, plant research systems, soil and water research systems.

Feel free to contact us via our e-mail, or any of the methods below

Have a Smartphone? Scan this QR code to access our website for more information about your product:

Please be aware that the information in this manual was correct at time of issue, and should be 100% relevant to the accompanying product. We take great pride in our ever-evolving range of products, which means that sometimes the product may change slightly due to re-design.

If you have any queries, please do not hesitate to contact our technical team by any of the methods above.

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1. INTRODUCTION

Skye Instruments' family of specialist light sensors include sensors to measure different parts of the ultra violet, visible and infra-red spectrum for a wide range of applications.

Underwater sensors are rated IP68, suitable for permanent immersion for depths up to 4 m, or short term immersion for depths up to 20m.

All sensors use high quality photodiodes and optical filters, and are individually calibrated to National Standards. Each is supplied with a traceable Calibration Certificate.

The Underwater Light Sensor is available in amplified or unamplified versions. The amplified version includes a built in amplifier with a choice of outputs for compatibility with most dataloggers, data acquisition systems, controllers and PLCs. The outputs can be one of a range of voltages or alternatively a 4-20mA loop current – please see your Calibration Certificate for the exact model and output range of your sensor. 2-channel versions are also available but only without internal amplifiers.

These sensors are cosine corrected, which means that they accept incoming light according to Lambert's Cosine Law. Essentially this means that light is measured from the hemisphere directly above the sensor. 2-channel versions are also available as narrow angle sensors with a 25° field of view instead of a cosine correcting diffuser.

2. TYPES OF SENSORS & OPERATION

2.1 LIGHT SENSORS FOR UNDERWATER MEASUREMENTS

The family of Underwater Light Sensors are available with a choice of the same responses as our standard single channel light sensor, i.e. PAR Quantum, PAR 'Special', PAR Energy and Lux. They can also be supplied with custom wavelengths. 2-channel sensors are available.

These sensors have cosine corrected heads, each containing a photodiode and filter system responding to light according to the response curves in Appendix 1. Custom wavelength versions will be supplied an individual spectral response curve.

Underwater sensors are rated IP68, suitable for permanent immersion for depths up to 4 m, or short term immersion for depths up to 20m.

Each sensor has been calibrated against a reference lamp, whose own calibration has been carried out at the National Physical Laboratory (NPL). They are calibrated for use with any natural or artificial light source.

Linearity is excellent with a maximum of 1% deviation up to levels beyond 200,000 µmol m^{-2} s^{-1} (greater than normal solar irradiance).

N.B. The maximum output for some sensors will be limited by the amplifier gain and output voltage limits.

2.2 POSITIONING OF SENSORS

For accurate positioning of the sensor Skye recommend the use of the underwater levelling frame (SKM 228). The sensor can be secured using the M6 hole in the base and supplied bolt and washers. Great care should be given to the placing of the sensor, in order to achieve accurate and repeatable results.

2.3 COSINE CORRECTED SENSORS

Since the sensor is intended to measure light falling on a horizontal plane (i.e. the ground), it is designed to collect light from the whole hemisphere. This is why light sensors are cosine corrected. Light rays perpendicular to the sensor are fully measured, while those at 90° are not accepted (they pass parallel to the surface of the plane or the ground and never intercept it). Rays at intermediate angles are treated according to the cosine of their angle to the perpendicular. Imagine the sun overhead, you feel its rays strongest when directly overhead, and much weaker when the sun is near the horizon. The sensor measures light from the different angles in a similar way, stronger when overhead than at low angles.

The cosine response of the sensor is shown in Appendix 2.

2.4 NARROW ANGLE SENSORS

Sensors without a diffuser have narrow angle 25° field of view is normally mounted with the light collecting apertures facing downwards, for the measurement of reflected light. These sensors have the suffix ND after the part number.

Please see Appendix 3 for the narrow angle response and area of measurement for these sensors.

2.5 SENSOR MAINTENANCE

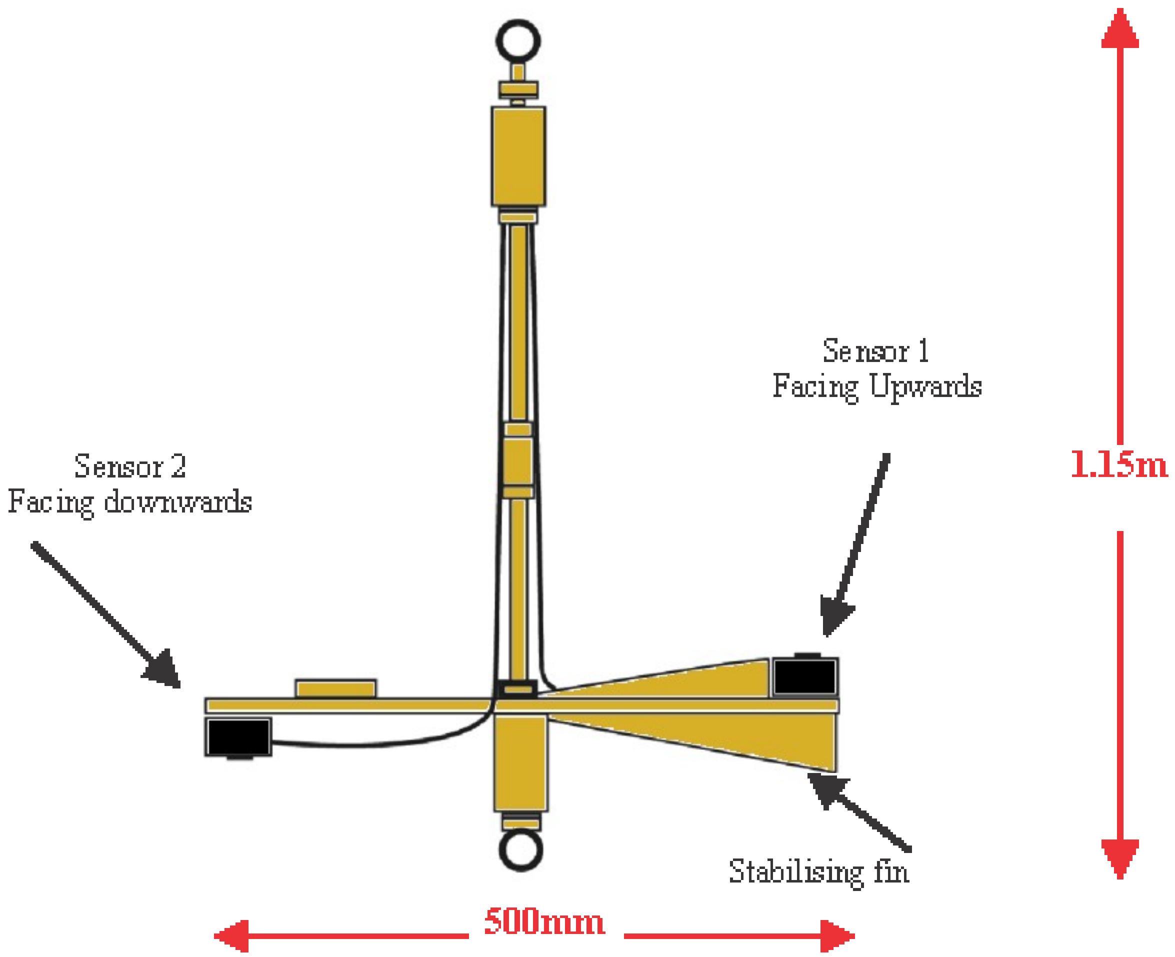
For temporary immersion applications all underwater light sensors should be cleaned after each use. The sensor body should be rinsed in clean water. The top light collecting surface (white diffusing disc) should be cleaned using a soft cloth dampened with de-ionised water. Take care not to scratch or damage this surface as this may affect the sensor calibration. The sensor cable should be secured to avoid movement damage or chafing in the water. Sensors should be dried before being stored away.

For long term immersion applications regular cleaning may be required. Environmental factors such as water mineral content, salinity and algae growth will determine how often cleaning should be carried out.

Skye Instruments light sensors and meters are recommended to be calibrated every 2 years. Please return to Skye where the sensor will be calibrated against the reference lamp and a new calibration certificate issued. The calibration change, if any, since last calibration will also be shown on the certificate.

3. UNDERWATER LOWERING FRAME

SKM 228 is an underwater lowering frame designed for the Skye Underwater Light Sensors



The lowering frame enables Skye light sensors to be mounted vertically (facing upwards and / or downwards) suitable for underwater measurements. Each Skye sensor is cosine corrected and accepts light from a hemisphere, so two sensors, facing one in each direction, allows both incident and diffused or reflected light to be measured. The stabilising fin keeps the structure vertical and stable, even in flowing waters. Made from a brass and stainless steel construction it is corrosion and maintenance free.

4. OUTPUTS

4.1 CURRENT OUTPUT

The output from these sensors is direct from the photodiode. A photodiode responds to the light level and the reading is directly obtainable in µA.

4.2 AMPLIFIED SENSORS (part numbers containing "/A "or "-420")

Voltage output sensors (/A) require a power supply between 5 and 15 volts DC, however the power supply voltage must be increased for sensors with a maximum output >2V (see table below). Current consumption is approximately 1mA, meaning that they can be powered from a logic high output of some computer cards and PLC's (check the specifications of the equipment first).

4-20mA loop current versions (-420) require a power supply of 12-36 volts DC.

Sensor Output:	**Power Supply Required:**
Up to 0-2 V	5-15 V DC
Up to 0-5 V	9-15 V DC
Up to 0-10 V	12-15 V DC
4-20 mA	12-36 V DC

The output voltage or loop current is linear with increasing light levels and will rise to a maximum value.

The precise scaling factor is given on the sensor's calibration certificate.

Voltage output sensor will have a small zero/dark offset voltage of ±0.2 mV. Even with a 2 V output sensor this represents an error of only 0.01% and can be reasonably ignored. With most systems it will be below the minimum resolution of measurement anyway and thus will not be resolved for measurement, it will appear as zero. If desired and possible, the offset can be measured and subtracted or added to all measurements, since it is a constant offset.

5. CONNECTIONS

Underwater sensors may be supplied wire ended for connection to the user's own equipment, or with a connector fitted for compatibility with Skye's own DataHog or MiniMet datalogger ranges, or SpectroSense2 meter range.

5.1 CURRENT OUTPUT SENSORS

Single Channel Sensors

Wire Colour:	Function:	Pin Number (/SC7):
Orange	Signal –ve	2
White/Orange	Signal +ve	4
Grey	Cable screen	6

2-Channel Sensors

Wire Colour:	Function:	Pin Number (/SC7):
Blue	Signal -ve (Channel 1)	2
Orange	Signal -ve (Channel 2)	3
Green	Signal ground	4
Grey	Cable screen	6

5.2 VOLTAGE OUTPUT AMPLIFIED SENSORS (part numbers containing "/A")

Wire Colour:	Function:	Pin Number (/SC7):
Orange	Sensor +ve output	1
White/Orange	Sensor -ve output	4
White/Brown	Power supply ground	5
Grey	Cable & Amplifier Screen	6
Brown	Power Supply +ve	7

5.3 4-20 mA AMPLIFIED SENSORS (part numbers containing "-420")

Wire Colour:	Function:
Brown	+ve in
White/Brown	-ve return
Grey	Cable screen

5.4 Extension Cable (Part number CAB-SKUW-SC7)

This is a one to one extension cable suitable for use with all SKUW…/SC7 sensors. At one end an inline Bulgin SC7 plug is fitted for connection to the light sensor. At the other is end an inline Bulgin SC7 socket is fitted for connection to a Skye SpectroSense2 or DataHog2.

Pin Number:	Wire Colour:
1	Blue
2	White/Orange
3	White/Blue
4	Orange
5	White/Brown
6	Cable Screen
7	Brown

6. SPECIFICATIONS

Working Range (1)	See calibration certificate
Housing	Delrin
Dimensions	86mm (h) x 49mm (d)
Weight	295g (with 3m cable)
Cable	4 x 2 x 26AWG, 100 Ω, Polyurethane Nominal overall diameter 6.25mm
Detector	Silicon photodiode
Sensitivity	See calibration certificate
Spectral Response	Standard Wavelengths: See appendix 1 Custom wavelengths: See individual spectral response curve
Linearity error over working range	<0.2%
Absolute calibration error (2)	Typically 3%, but <5%
Cosine error (3)	see appendix 2
Azimuth error (4)	<1%
Temperature Co-efficient	± 0.1%/°C
Long term stability (5)	± 2%
Response Time (6)	<10ms
Operating Range	-20°C to +70° C 0-100% RH
IP Rating	IP68 • 4m permanent immersion • 20m temporary immersion
Mounting	M6 x 7mm tapped hole in base. Sensor supplied with M6 x 16mm screw + 4 x 1.5mm washers to suit panel thicknesses of 3-10mm.
Power Supply Requirements	Voltage output sensors – max output +2V DC 4-20mA loop current sensors require 12-36V DC

NOTES ON SPECIFICATIONS

(1) All Skye sensors will work at levels of irradiance well above that found in terrestrial sunlight conditions, room or growth chamber lighting. These are default working ranges, check individual calibration certificate.

(2) Main source of this error is uncertainty of calibration of Reference Lamp. Skye calibration standards are directly traceable to NPL standard references.

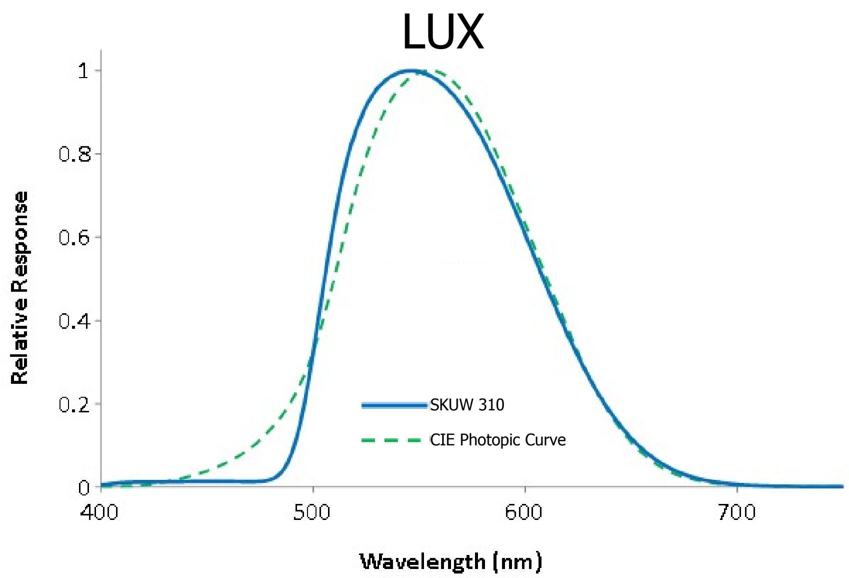
(3) Cosine error to 80º is typically 5% max. Figures shown are for normal use sources, e.g. sun plus sky, diffuse sun, growth chambers, etc.

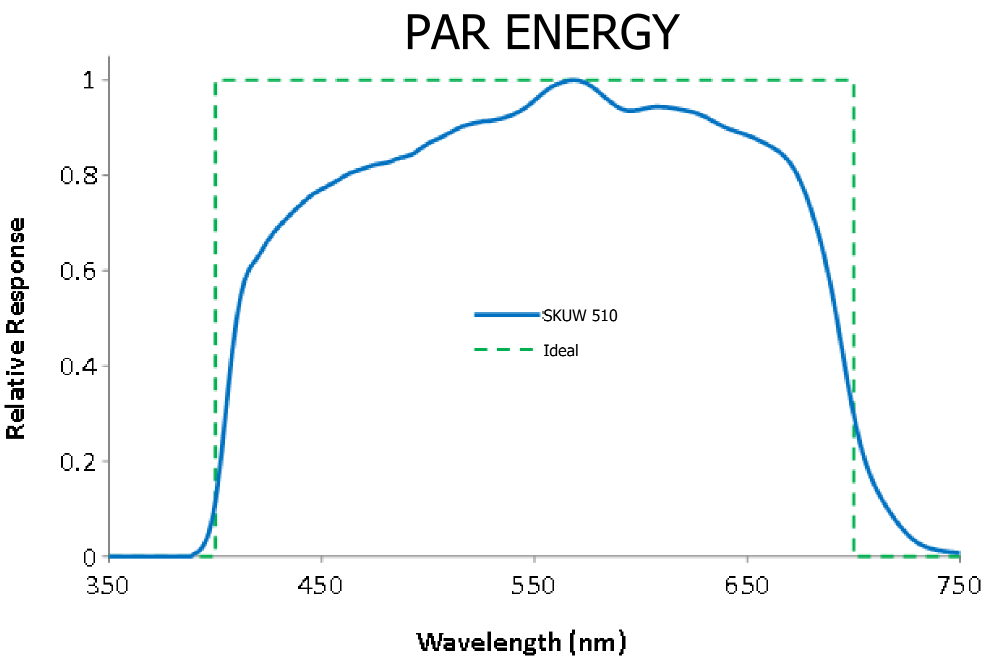
(4) Measured at 45º elevation over 360º.

(5) Maximum change in one year. Calibration check recommended at least every two years. Experience has shown that changes are typically much less than figures quoted.

(6) Times are generally less than the figure quoted, which is in milliseconds. They may be slightly increased if long leads are fitted, or those of a higher capacity cable.

APPENDIX 1 - SPECTRAL RESPONSE CURVES





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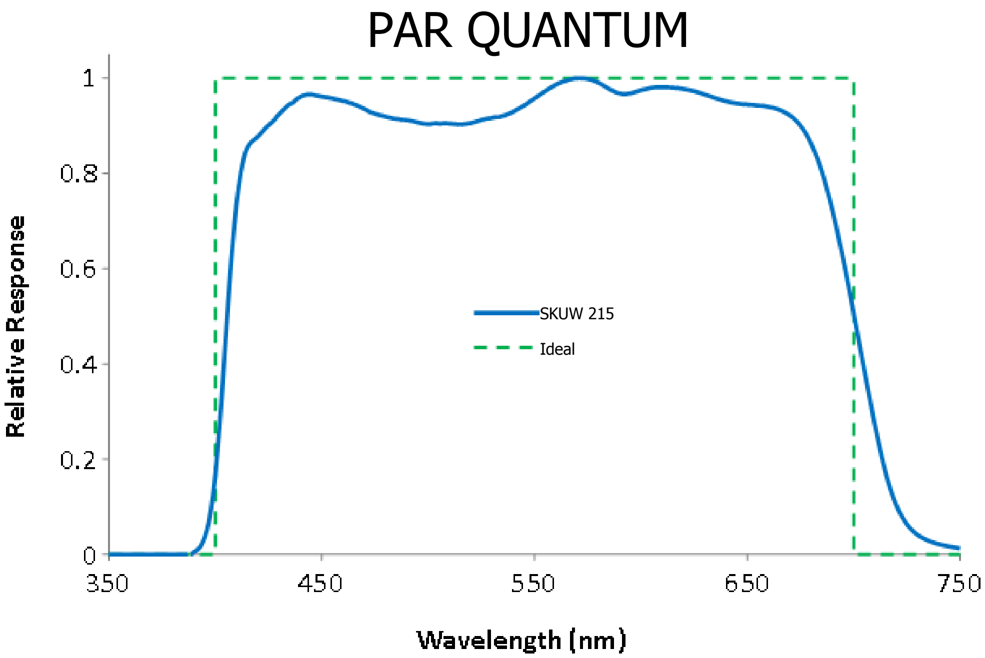
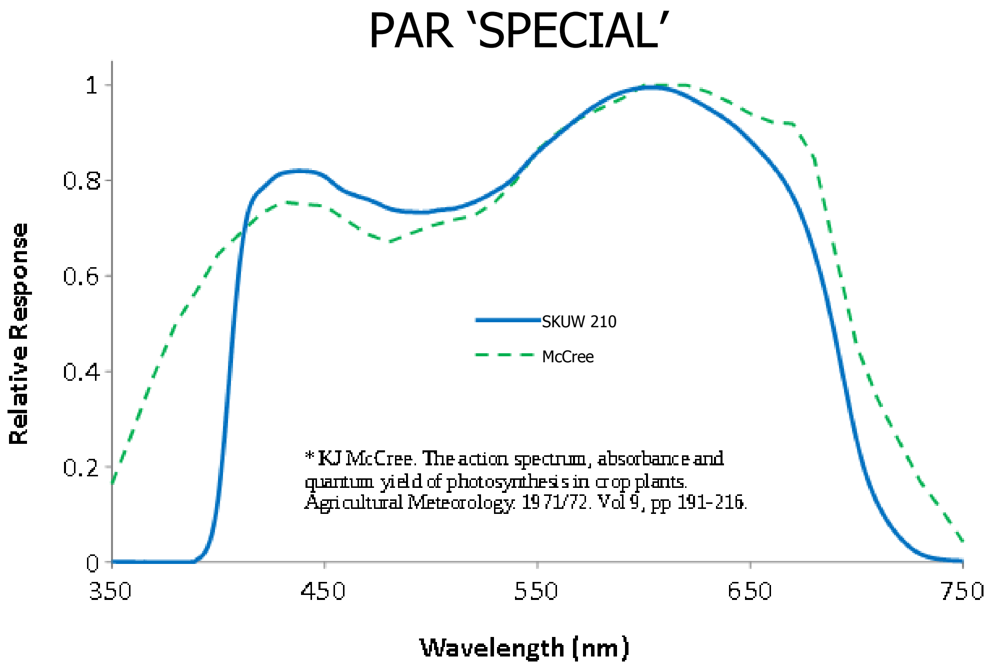
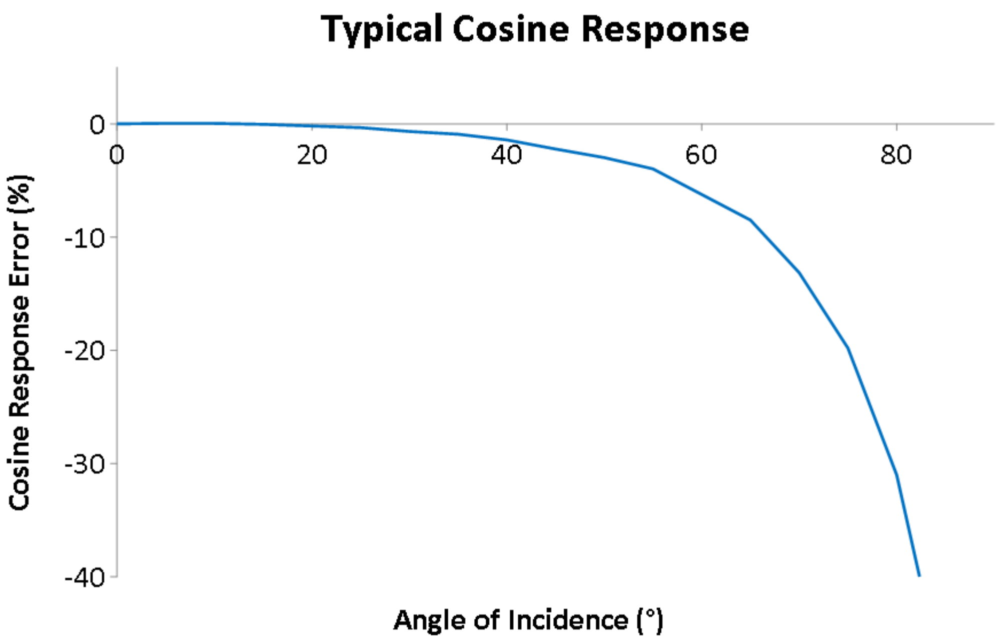




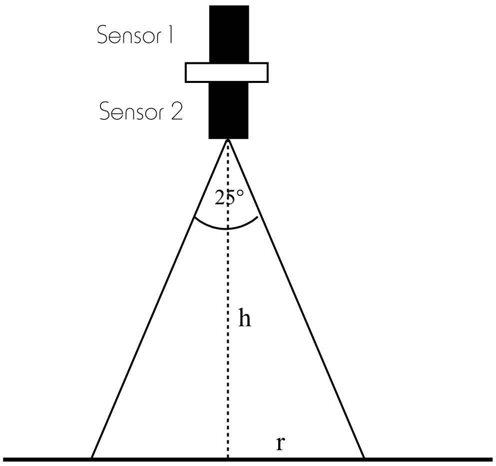
APPENDIX 2 – COSINE RESPONSE



APPENDIX 3 – NARROW ANGLE LIGHT ACCEPTANCE

For the measurement of reflected or up-welling light, the sensor has a smaller, defined field of view and can accurately measure from a defined ground area.

It has a 25° cone field of view (12.5° off perpendicular). The area of ground in view to the sensor is then defined by the height above the ground, as shown below:



Sensor 1 is cosine corrected and is measuring incident light.

Sensor 2 is narrow angle and is measuring reflected light.

Both incident and reflected light is measured simultaneously by two matching sensors, to eliminate fluctuations in solar radiation

EXAMPLES OF MEASUREMENT AREA

HEIGHT OF SENSOR, h (m)	**RADIUS OF CIRCLE, r** (m)	**AREA OF MEASUREMENT** (m^2)
0.50	0.11	0.04
0.75	0.17	0.09
1.00	0.22	0.15
1.25	0.28	0.24
1.50	0.33	0.35
1.75	0.39	0.47
1.80	0.40	0.50
2.00	0.44	0.62

APPENDIX 4 UNDERWATER LIGHT MEASUREMENT

Skye Instruments' light and radiation sensors are individually calibrated and the calibration is traceable to the UK National Physical Laboratory in London.

The SKM 228 Underwater Lowering Frame allows one or two light sensors to be attached and submerged. Its construction keeps the sensors vertical and steady in still or flowing waters. The sensors can be mounted facing upwards or downwards in any combination as preferred.

There are published papers available which describe light measurement under water, some references are below.

In summary, light sensors under read in depths greater than 10cm. On average under water measurements should be multiplied by 1.3 to compensate for this.

Also 'surface popple' effects (constantly changing reflections on the water surface) should be averaged out over a time period (such as with a DataHog datalogger) and single 'spot' measurements should be avoided.

REFERENCE

D.F.Westlake. Some problems in the measurement of radiation under water: A review. Photochemistry & Photobiology 1965 Vol 4 pp849-868

APPLICATION NOTES FOR UNDERWATER LIGHT

(BASED ON A REPORT BY THE UK FRESHWATER BIOLOGICAL ASSOCIATION)

Water is a medium with significant attenuance (which varies with depth and dissolved and suspended materials; e.g. transmission to 1m may be between 90 and <10-4 % of the surface irradiance) and a surface with a reflectance which varies with sun (and diffuse radiation) angle and distribution.

Incident and submerged irradiance varies enormously and rapidly; the attenuance is relatively constant. Given the % transmission T2 (100% submerged surface at depth z) and absolute values at the surface, absolute values submerged can be readily calculated. Hence a laboratory studying light underwater usually has equipment for recording insolation and a meter with surface and underwater sensors to measure % transmission. Underwater recording is so difficult, because of the problems of maintaining a clean sensor, that it is only attempted when absolutely essential.

Mathematical analyses and models of light underwater usually use the vertical attenuation coefficient , which is derived from transmission. If I_o is the irradiance immediately under the water surface and I_2 is the irradiance at depth z then

$$= \frac{[\ \ln (Io / I2)\ ]}{z}$$

z is the attenuance of a stratum of z m

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Diffusion by scattering is much more important underwater than in air and in many situations the upwelling flux may be significant. However, aquatic organisms are not standard shapes and a facing global (4) collector is no nearer a standard shape than a horizontal upward facing surface, and may be much less convenient. The horizontal surface is widely accepted as a convenient standard. Checks on the upwelling component can be made by inverting the horizontal surface. If horizontal surfaces are used they must have a cosine response which is particularly important early and late in the day and in turbid waters.

The immersion of a collector has optical consequences which mean that a submerged sensor exposed to x W m^{-2} does not give the same reading as an identical sensor in air exposed to x W m^{-2}. Within the first few centimetres (actually said to be when z <0.9 r, where r is the radius of the collector) there is an extra error due to multiple reflections between the water surface and the sensor. It is convenient therefore to avoid taking readings at less than 0.1m. The observed difference between a surface and a submerged sensor at 0.1 m is due to optical effects at the collector-water interface (the true immersion error), reflection at the water-air surface and the attenuance of 0.1m of water. In clean water the latter is small (of the order of a 1% decrease).

Various methods have been proposed to measure the true immersion effect. Berger (1961) used a blackened funnel with 0.9 r of water above the cell. Smith (1969) used a spectroradiometer under the collector, immersed to a series of depths, and illuminated by a collimated beam. Surface reflection was calculated from Fresnel's equation. He showed that the immersion error depended on wavelength (for his collector between 0.74 at 440nm to 0.80 at 700nm) so that ideally it is necessary to use a weighted factor for any particular spectral distribution. In practice a weighted factor for white light is used. Given this inaccuracy it is probably adequate to determine the weighted factor directly using the submerged sensor in a large tank of clean water (the Freshwater Biological Association used >3m diameter for readings down to 30 cm) exposed to daylight. A series of readings over depths greater than 0.1m are taken.

In the field, take readings in open water on a calm day over a range of depths greater than 10cm. If the surface reading is I_o and the submerged readings without any correction are V_z, then plot apparent transmission V_z / I_o on a logarithmic scale against depth on a linear scale. Log (V_z / I_o) should be a straight line which can be extrapolated to zero depth. This intercept is the apparent sub-surface value Vo. If reflection R is determined from the sun angle and sky conditions (Anderson 1952, see Table 1) then:

V_o, the apparent value above the surface = $V_o / (1-R)$

The true immersion error $E = V_o / I_o$

A complete system to measure light underwater needs equipment to hold the sensors horizontally in known positions. The surface sensor is most conveniently mounted on a float that can be anchored to a bank or boat. Except in rough water this automatically keeps it horizontal. For oceanographic or rough weather on lakes it may be necessary to support the surface sensor on deck in gimbals, but these are not normally supplied as part of a system.

An underwater mount should hold the sensor at right angles to a vertical pole with a plumb line. A graduated line is helpful for measuring depth. A vane is also advantageous in moving waters. In deep, moving water is may be necessary to anchor the pole with a weight.

TABLE 1

Surface Reflectance for Calm Water

$R = aH^b$
R = reflectance = I_o / I_o
H = height of sun = above horizon

	Clear Sky	Low cloud		<10,000 ft	High cloud		>10,000 ft
		1-5/10	6-9/10	10/10	1-5/10	6-9/10	10/10
a	1.18	2.17	0.78	0.20	2.20	1.14	0.51
b	-0.77	-0.96	-0.68	-0.30	-0.98	-0.68	-0.58

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Berger F. Arch. Meteorol. Geophys. Biolklimatol. 1961. B Vol 11 pp224

Smith RC. J Mar Res. 1969. Vol 27 pp341

Anderson ER. Tech. Dept. Circ. U.S. Geol. Surv. 1952. Vol 229 pp7