

LI-COR Underwater Radiation Sensors

Instruction Manual



LI-192 Underwater Quantum Sensor
LI-193 Spherical Quantum Sensor

LI-COR Underwater Radiation Sensors

Instruction Manual

LI-COR[®]

Biosciences

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Publication Number 984-08307
Printing History: 1st Printing June, 2006

Printing History

New editions of this manual will incorporate all material since the previous editions. Update packages may be used between editions which contain replacement and additional pages to be merged into the manual by the user.

The manual printing date indicates its current edition. The printing date changes when a new edition is printed. (Minor corrections and updates which are incorporated at reprint do not cause the date to change).

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Table of Contents

Section 1. Underwater Sensors – General Information

Type SA Sensors	1-1
Sensor Recalibration	1-2
Getting Started	1-2
Relationship Between the Calibration Constant and Calibration Multiplier.....	1-2
Connecting to Non-LI-COR Metering Devices	1-3
Using the 2009S Lowering Frame	1-4

Section 2. Factory Calibration Procedures

LI-192 Underwater Quantum Sensor and LI-193 Spherical Quantum Sensor.....	2-1
---	-----

Section 3. Using Underwater Quantum Sensors

LI-192 Underwater Quantum Sensor	3-1
Immersion Effect	3-2
Cosine Response	3-2
Cosine Correction Properties	3-3
Spectral Response	3-4
LI-193 Spherical Quantum Sensor.....	3-5
Immersion Effect	3-5
Angular Response	3-6
Azimuth Response	3-6
Spectral Response	3-6
Errors.....	3-6
Mathematical Definitions	3-7

Section 4. Cleaning and Maintenance

Precautions.....	4-1
------------------	-----

Section 5. Underwater Sensor Accessories

2222UWB Underwater Cable	5-1
2009S Lowering Frame	5-1
100L Lubricant	5-1

Section 6. Bibliography

Bibliography	6-1
Other LI-COR Reports	6-1

Appendix A. Specifications Warranty

Section 1. Underwater Sensors - General Information

Type SA Sensors

Type "SA" sensors (e.g. LI-192SA) have a coaxial cable that terminates with a BNC connector. The 2222UWB Underwater Cables used with LI-COR underwater sensors are terminated with this type of connector, which allows for direct connection to the LI-COR LI-250A Light Meter or the LI-1400 DataLogger. Figure 1-1 shows a typical SA type sensor.

This connector also allows the sensor to be used with older (discontinued) instruments, including the LI-189 Quantum/Radiometer/Photometer, LI-250 Light Meter, the two current channels of the LI-1000 Datalogger, or with older LI-COR integrators.

Type SA underwater sensors include the LI-192SA Underwater Quantum Sensor and the LI-193SA Underwater Quantum Sensor.



Figure 1-1. "SA" type sensors are terminated with only a BNC connector on the end of the coaxial cable.

When a LI-COR Light Meter or data logger is not used, type SA sensors can be used with other millivolt recorders or data loggers by connecting a millivolt output conversion adapter. See Section 5 for more information.

Note that all LI-COR underwater sensors produce a *current* signal, not voltage.

Sensor Recalibration

Recalibration of LI-COR radiation sensors is recommended every two years. Sensors can be returned to LI-COR for this service – please contact our technical support staff for more information.

Getting Started

Relationship between the Calibration Constant and the Calibration Multiplier

All LI-COR radiation sensors produce a current proportional to the radiation intensity. During factory calibration, sensor output (in microamps) is measured while the sensor is exposed to a standard lamp of known intensity. The sensor output at this intensity has general units of microamps per radiation unit and is called the **Calibration Constant** (Calconstant). Each sensor has a slightly different output at a given radiation intensity and will therefore have a unique Calconstant.

LI-COR Light Meters and dataloggers measure the current output of the sensor in units of microamps, and convert the measured current to units of radiation. To make this conversion, LI-COR instruments use the sensor **Calibration Multiplier**. The Calibration Multiplier is the negative reciprocal of the Calconstant.

$$\text{Multiplier} = \frac{-1}{\text{Calconstant}}$$

The LI-192 and LI-193 calibration certificates contain calibration multipliers for both in air and in water operation. The in water multiplier includes an immersion effect correction.

To use a type SA sensor with the LI-250, the calibration multiplier is entered in configuration mode, using the up and down arrow keys to scroll the multiplier value(s).

When using the LI-1400 DataLogger, the calibration multiplier must be entered into the software as described in the Instruction Manual.

When a LI-COR light meter or data logger is not used, your sensor can be used with other millivolt recorders or data loggers by connecting a millivolt adapter. The LI-192SA and LI-193SA underwater sensors require the 2291 Millivolt Adapter, which has a resistance of 1210 Ohms.

The millivolt adapter connects to the BNC connector of the sensor, and the wire leads of the adapter are connected to the data logger. Sensor output (in millivolts) when using the millivolt adapter can be computed using "Ohm's Law" (Voltage = Current X Resistance).

Example: Calculate the millivolt output of an LI-192 Underwater Quantum Sensor which has a calibration constant of $8.0 \mu\text{A}/1000 \mu\text{mol s}^{-1} \text{m}^{-2}$. Assume the 2290 millivolt adapter is used with the sensor.

$$\frac{8.0 \text{ A}}{1000 \mu\text{mol s}^{-1} \text{m}^{-2}} \times \frac{1 \text{ A}}{10^6 \text{ A}} \times 604 \text{ Ohm} = \frac{0.004832 \text{ volts}}{1000 \mu\text{mol s}^{-1} \text{m}^{-2}} = \frac{4.83 \text{ mV}}{1000 \mu\text{mol s}^{-1} \text{m}^{-2}}$$

The multiplier to use in your data acquisition system is the reciprocal of this result. For example,

$$\frac{1}{\frac{4.83 \text{ mV}}{1000 \mu\text{mol s}^{-1} \text{m}^{-2}}} = 207 \mu\text{mol s}^{-1} \text{m}^{-2}/\text{mV}$$

If the calibration constant for your sensor has been lost or misplaced, it can be obtained from LI-COR by providing the serial number of the sensor.

IMPORTANT: When using the sensor under water, the "in water" calibration constant should be used to calculate the millivolt output of the sensor. The "in water" sensor calibration includes an immersion effect correction.

Connecting to Non-LI-COR Metering Devices

The use of the millivolt adapter with a recorder or data logger other than LI-COR instruments is often acceptable for radiation levels down to 10% of full sunlight. Below 10%, the recorder must be very sensitive to pick up the small voltage signal. The recorder should have a high impedance input (>1 megohm, such as potentiometric types), and the range adjustment should be 0-10 mV, or a more sensitive range. For low light levels, the sensor should be connected directly to a LI-COR readout device (without using the millivolt adapter).

In LI-COR underwater cables the inner white wire is positive and the black wire is negative. The center pin of the BNC connector has a negative signal. This is done because the trans-impedance amplifier used in LI-COR light meters requires a negative signal.

For data logger or millivolt applications where the millivolt adapter is needed, the positive (green) lead should be connected to the low impedance (common terminal) when plus or minus signal capability is available on the data logger or recorder. This will minimize noise.

If plus or minus capability is not available on the data logger or recorder, the green lead should be connected to the positive input and the blue lead to the

negative input. If noise difficulties are encountered, consult LI-COR for special wiring instructions.

Using the 2009S Lowering Frame

It is recommended that the LI-COR 2009S Lowering Frame (or equivalent) be used with the sensor for underwater applications.

IMPORTANT: Do not use LI-COR 2222UWB Underwater Cable to support the sensor and lowering frame, as damage to the cable can result. An auxiliary cable should be used to support the lowering frame and sensor. In addition, the 2222UWB cable should not be bent sharply near the sensor.

NOTE: For cable lengths over 75 m (225 ft.), care should be exercised in its use since movement of the cable within the water can cause excessive signal noise.

The 2009S Lowering Frame provides for the placement of two cosine sensors, one each for upwelling and downwelling radiation, or a single underwater spherical sensor (Figure 1-2). Each LI-COR underwater sensor has three 6-32 tapped mounting holes on the underside of the sensor for connection to the mounting ring. Corrosion resistant mounting screws are included with each sensor. A replacement screw and insulating washer kit is available from LI-COR (p/n 9901-220).

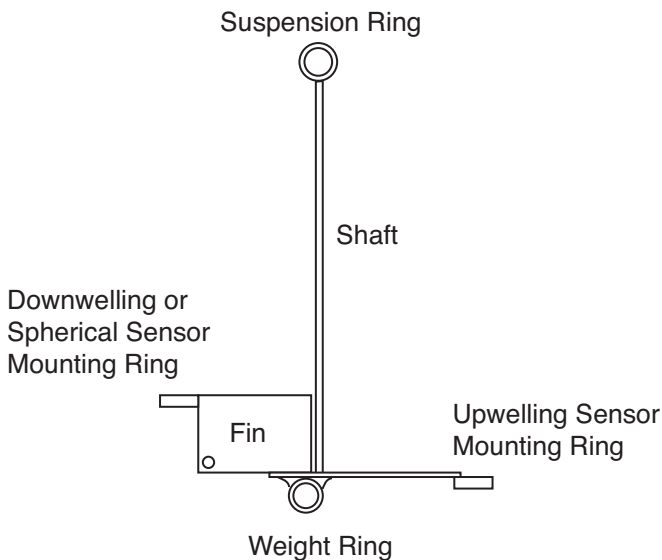


Figure 1-2. 2009S Lowering Frame.

When two sensors are used, the frame is well balanced and will work well in mild currents without twisting the cables. The sensor for downwelling radiation is always attached using the mounting ring on the fin. Likewise, the sensor for upwelling radiation is attached to the opposite mounting ring. Depending on the speed of the current, the frame will tilt a few degrees, but this can be minimized by hanging a compact weight from the weight ring. Moderate weights will often suffice (4 kg). Weights over 25 kg should be avoided.

The use of a single cosine sensor will require a small weight (0.2 kg) attached at the empty mounting ring or a moderate weight from the weight ring, or possibly both, depending upon the speed of the current.

The underwater cable(s) should be attached to the frame such that approximately 25 cm of cable forms a smooth arc to the underwater sensor connector and is restrained from being flexed or supporting any weight.

LI-COR underwater cable is not recommended as a support cable, although it can be used as a lowering cable providing it is properly attached and the attached weights do not exceed 5 kg. The cable(s) must be attached as described above. Additionally, the cable must be securely attached to the shaft of the lowering frame at multiple points so that the cable does not slip and put strain on the sensor connector. However, the cable cannot be clamped so tightly as to damage it. Possible methods to use are numerous nylon cable clamps along the length of the shaft, or a tight wrap of light cord around the shaft and cables, starting at the suspension ring and extending downward at least 25 cm.

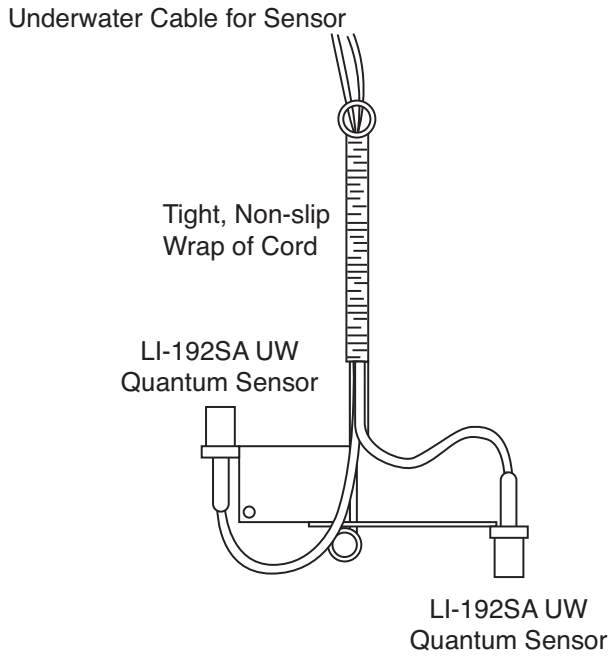
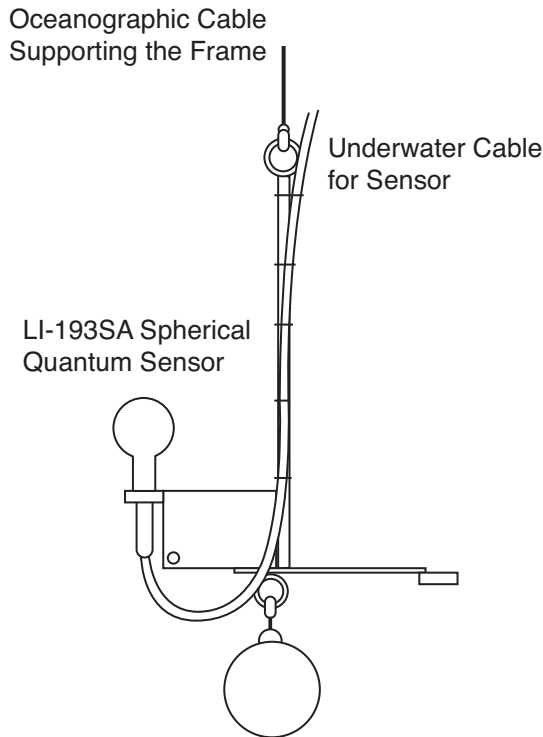


Figure 1-3. Attach the cable to the lowering frame at several points.



Moderate Weight (dense)

Figure 1-4. Attach a small weight to the lowering frame when using a single sensor.

For long-term immersion or use in heavily ionic water, it may be necessary to provide electrical insulation between the underwater sensor(s) and the lowering frame to prevent galvanic corrosion. This is accomplished by slipping an insulating flat washer over the mounting screws down to the heads, followed by a 1/2" (13 mm) length of thin tubing over the screw threads. This tubing insulates the screws from the mounting ring.

Next, place a large flat insulating washer between the sensor and the mounting ring (with three holes for the screws). Use the "insulated" screws to attach the sensor in place. In this way, neither the screws nor sensor have electrical contact with the frame.

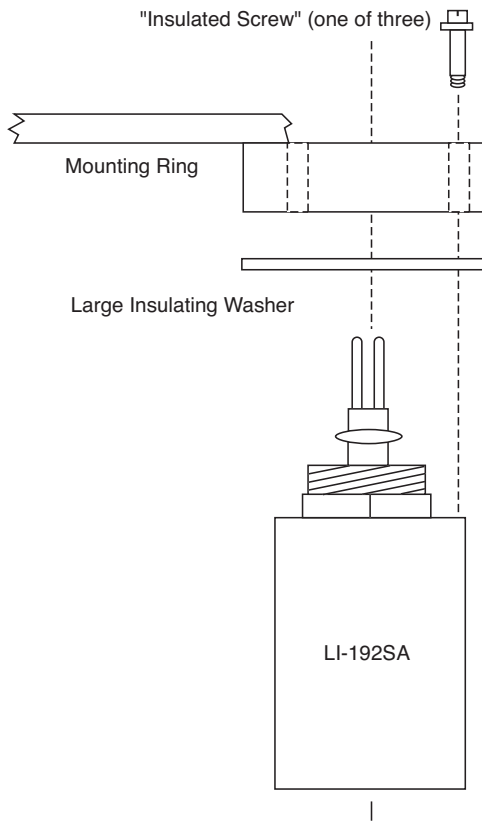


Figure 1-5. Use an insulating washer in heavily ionic water.

Section 2. Factory Calibration Procedures

LI-192 Underwater Quantum Sensor, and LI-193 Spherical Quantum Sensor

LI-COR quantum sensors are calibrated using a standard light source calibrated against a National Institute of Standards and Technology (NIST) lamp. The photon flux density from the standardized lamp is known in terms of micromoles $s^{-1} m^{-2}$ where one micromole = 6.022×10^{17} photons. The uncertainty of the calibration is $\pm 5\%$.

The lamp used in LI-COR's calibration is a high intensity standard of spectral irradiance (G.E. 1000 watt type DXW quartz halogen) supplied with a spectral irradiance table.

The following procedure is used to calculate the quantum flux output from the lamp. The lamp flux density (ΔE) in watts m^{-2} , in an increment at a wavelength can be expressed as

$$\Delta E = E(\lambda)\Delta\lambda$$

where $E(\lambda)$ is the spectral irradiance of the lamp at wavelength λ .

The number of photons $s^{-1} m^{-2}$ in $\Delta\lambda$ is

$$\text{Photons } s^{-1} m^{-2} = \left[\frac{\lambda}{hc} \right] E(\lambda)(\Delta\lambda)$$

where h is Planck's constant and c is the velocity of light. This can be summed over the interval of 400-700 nanometers (nm) to give

$$\text{Photons } s^{-1} m^{-2} = \left[\frac{\lambda}{hc} \right] \int_{400}^{700} E(\lambda)\Delta\lambda$$

The result is adjusted to $\mu\text{mol } s^{-1} m^{-2}$ by dividing by 6.022×10^{17} .

IMPORTANT NOTE: Make sure that the underwater cable is inserted fully over the “rib” of the sensor connector before tightening the white collar on the end of the underwater cable. If the cable is not inserted far enough, the sensor leads can be damaged when the collar is threaded over the sensor connector. In addition, the connector pins are small and care should be taken when mating the connectors.

The quantum sensor has three 6-32 tapped holes on the underside of the sensor which are used for mounting the sensor to the 2009S Lowering Frame.

To maintain appropriate cosine correction the vertical edge of the diffuser must be kept clean. Periodically inspect the sensor for foreign deposits on the upper surfaces during prolonged submerged operation.

Immersion Effect

A sensor with a diffuser for cosine correction will have an immersion effect when immersed in water. The radiation entering the diffuser scatters in all directions within the diffuser with more of the radiation lost through the water-diffuser interface than in the case where the sensor is in air. This results because the air-diffuser interface offers a greater ratio of the indexes of refraction than the water-diffuser interface. Thus, a greater percentage of radiation entering the diffuser in air reaches the photodiode than in the case where the LI-192 is in water. Therefore, a normal underwater reading would need to be multiplied by this effect if the sensor is used in water.

The LI-192 calibration certificate contains calibration multipliers for both in air and in water operation. The in water multiplier includes the immersion effect correction.

Cosine Response

Measurements intended to approximate radiation impinging upon a flat surface (not necessarily level) from all angles of a hemisphere are most accurately obtained with a cosine corrected sensor.

A sensor with a cosine response (follows Lambert's cosine law) allows measurement of flux densities through a plane surface. This allows the sensor to measure flux densities per unit area (m^2). A sensor without an accurate cosine correction can give a severe error under diffuse radiation conditions within a plant canopy, at low solar elevation angles, under fluorescent lighting, etc.

The cosine relationship can be thought of in terms of radiant flux lines impinging upon a surface normal to the source (Figure 3-1A) and at an angle of 60° from normal (Figure 3-1B). Figure 2-1A shows 6 rays striking the unit area, but at a 60° angle, only 3 rays strike the same unit area. This is illustrated mathematically as

$$S = (I) (\cosine\ 60^\circ)\ \text{per unit area}$$

$$3 = (6) (0.5)\ \text{per unit area}$$

where S = vertical component of solar radiation; I = solar radiation impinging perpendicular to a surface and $\cosine\ 60^\circ = 0.5$.

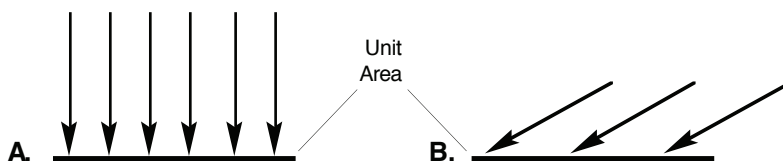


Figure 3-1. Lambert's Cosine Law.

Cosine Correction Properties

A comparison of the underwater sensor's cosine response curve in air and in water can be found in the "Immersion Effect and Cosine Collecting Properties of LI-COR Underwater Sensors" Report (Application Note #110, available from LI-COR). Engineering requirements result in different correction characteristics for air and water. Over-compensation occurs in air and undercompensation occurs in water. The better response was selected for air, because in water, the direct incident solar radiation does not exceed the critical angle of 48.6° (a result of the air-water interface).

Spectral Response

The spectral response is similar to that of the LI-190 Quantum Sensor (Figure 3-2).

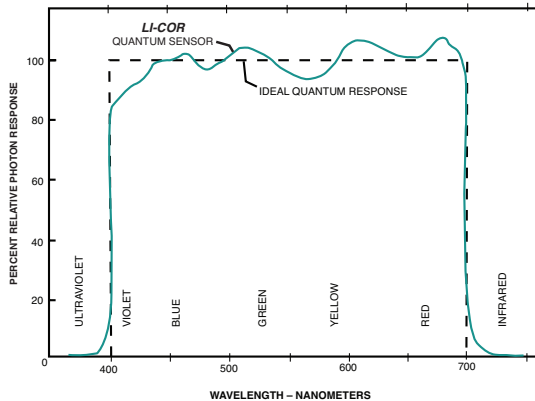


Figure 3-2. Typical spectral response of LI-COR Quantum Sensors vs. Wavelength and the Ideal Quantum Response (equal response to all photons in the 400-700 nm waveband).

The spectral response of the quantum sensor is obtained by use of a light source and a monochromator. A sensor which has a known spectral response over the spectral range of interest is used to determine the monochromator output in energy flux density, $W(\lambda)$, at the wavelength setting λ . If $Q(\lambda)$ is the sensor output at wavelength λ when exposed to the monochromator output, $W(\lambda)$, then $Q(\lambda)$ can be approximated by

$$Q(\lambda) = R(\lambda) W(\lambda)$$

where $R(\lambda)$ is the sensor spectral response at the wavelength setting λ . The above approximation assumes that the monochromator bandwidth, $\Delta\lambda$, is much less than the wavelength setting λ . The normalized sensor spectral response $r(\lambda)$, is determined by

$$r(\lambda) = R(\lambda)/R_m$$

where R_m is the maximum value of $Q(\lambda)/W(\lambda)$ over the range of wavelengths measured.

LI-193 Spherical Quantum Sensor

The LI-193 Spherical Quantum Sensor is used for measuring Photosynthetically Active Radiation (PAR) in aquatic environments, and specifically the Photosynthetic Photon Flux Fluence Rate (PPFFR). The LI-193 gives an added dimension to underwater PAR measurements in that it measures PAR from all directions. The LI-193 Sensor can also be used in air.



Because PPFFR can be defined as those photons having a wavelength between 400 and 700 nm that are incident per unit time on the surface of a sphere divided by the cross-sectional area of the sphere, the LI-193 Spherical Quantum Sensor (and all other LI-COR quantum sensors) is designed to respond equally to photons between 400 and 700 nm. Because the energy of a photon is inversely proportional to its wavelength, a sensor which responds equally to photons will have a linear energy response with wavelength. Therefore, an ideal PPFFR sensor would have a linear energy response between 400 and 700 nm, and would have a slope of 1% per 7 nanometers (nm) if it were normalized to 100% at 700 nm.

Immersion Effect

Because of the difference of index of refraction between air and water, the calibration constant of the LI-193 when used in water will be different than the calibration constant when used in air. This phenomenon is known as the immersion effect. The air/water ratio of the calibration constants is equal to the sensor output in air divided by the sensor output in water for the same PPFFR. This ratio is greater than one, and the approximate

air/water ratio for normal incident radiation (0°) can be calculated by dividing the "in water" cal constant (listed on the calibration certificate) by the "in air" calconstant.

For an explanation of the immersion effect as well as methods that can be used to determine it, a report entitled "Immersion Effect and Cosine Collecting Properties of LI-COR Underwater Sensors" is available from LI-COR (Application Note #110).

Angular Response

The LI-193 sensor uses an acrylic diffuser to obtain an angular response error of less than $\pm 4\%$ for angles of incidence up to 90° from the normal. Testing is done with a collimated beam of radiation to verify these limits.

Azimuth Response

With a collimated beam of radiation at an angle of incidence of 90° from normal, the sensor is rotated about its normal axis. The maximum acceptable variation in response under these conditions is $\pm 3\%$.

Spectral Response

The spectral response is comparable to that of the LI-190 Quantum Sensor, (Figure 4-1), as both use computer-tailored filter glasses to closely approximate the ideal linear energy response (flat photon response) from 400 to 700 nm. This response ideally produces an equal output for equal PPFRR even if the spectral irradiance varies within the cutoff points of 400 and 700 nm.

Measurement of the spectral response requires a stabilized light source, monochromator, and calibrated reference detector. Measurements taken with the test sensor and reference detector at many wavelengths yield data points used to plot a relative spectral response. For details, the "Description of Calibration Procedures" application note is available from LI-COR.

Errors

The spatial error of the LI-193 Sensor is due to variations in the diffusing sphere, (negligible), and the sphere area "lost" because of the sensor base. This error is less than -10% for totally diffuse radiation, but is usually smaller than this because the upwelling radiation is smaller than the downwelling radiation.

In highly turbid waters the sensor will indicate high quanta values due to the displacement of water by the sensor sphere volume. This is because the point of measurement is taken to be at the center of the sphere, but the attenuation which would have been provided by the water within the

sphere is absent. This error is typically +6.3% for water with an attenuation coefficient of 3 m^{-1} .

Mathematical Definitions

The mathematical definition of photon flux fluence rate (PFFR) is

$$\text{PFFR} = \int_{4\pi} L d\Omega$$

where L is the photon flux radiance and Ω is the solid angle. Since $d = \sin\Theta d\Theta d\phi$, this can be rewritten as

$$\text{PFFR} = \int_{\phi=0}^{2\pi} \int_{\Theta=0}^{\pi} L(\phi, \Theta) \sin\Theta d\Theta d\phi$$

The mathematical definition of photon flux density (PFD) as measured by a cosine-corrected sensor is

$$\text{PFD} = \int_{\phi=0}^{2\pi} \int_{\Theta=0}^{1/2\pi} L(\phi, \Theta) \sin\Theta \cos\Theta d\Theta d\phi$$

If $\Theta' = 2\Theta$, then $\sin\Theta \cos\Theta = 1/2 \sin\Theta'$ and $d\Theta = 1/2 d\Theta'$. Also, the limits of Θ' are 0 to π . Then

$$\text{PFD} = 1/4 \int_{\phi=0}^{2\pi} \int_{\Theta'=0}^{\pi} L(\phi, \Theta') \sin\Theta' \cos\Theta' d\Theta' d\phi$$

In a uniform radiance distribution, $L(\phi, \Theta) = L(\phi, \Theta') = L$ (a constant). Then

$$\begin{aligned} \text{PFFR} &= 4\pi L \\ \text{PFD} &= \pi L \\ \text{or PFFR} &= (4)(\text{PFD}) \end{aligned}$$

A small spherical collecting surface which exhibits the properties of a cosine collector at every point of its surface would measure the limit of the ratio of total photon flux onto a spherical surface to the area of the surface, as the radius of the sphere tends toward zero. Mathematically, the "photon flux $I(\Theta, \phi)$ per unit solid angle" in the direction (Θ, ϕ) that is intercepted by a spherical surface using the cosine law is

$$I(\Theta, \phi) = L(\Theta, \phi) \int_{\text{hemi}} \cos\psi dA$$

where ψ is the angle between the normal of dA and the direction (Θ, ϕ) .

Now, $\int_{\text{hemi}} \cos\psi \, dA = \pi r^2$ where r = radius of the hemisphere (hemi).

Therefore, the total photon flux (F) intercepted by the sphere is

$$F = \int_{\phi=0}^{2\pi} \int_{\Theta=0}^{\pi} I(\Theta, \phi) d\Omega = \pi^2 \int_{\phi=0}^{2\pi} \int_{\Theta=0}^{\pi} L(\Theta, \phi) d\Omega = \pi^2 \text{PFFR}$$

This spherical collecting surface would then measure

$$\frac{F}{4\pi r^2} = (1/4)(\text{PFFR})$$

that is, $\text{PFFR} = 4$ times the associated quantity measured by a small spherical collecting surface which exhibits the properties of a cosine collector at every point of its surface in a uniform radiance distribution.

From this fact and also the fact that the cross-sectional area of a sphere = $1/4$ the surface area, one could define PFFR as the limit of the ratio of total photon flux onto a spherical surface to the cross-sectional area.

In a uniform collimated beam of radiation, the following conditions of photon flux radiance hold

$$L(\phi, \Theta < \Theta^*) = L \text{ (a constant)}$$

$$L(\phi, \Theta > \Theta^*) = 0$$

where Θ^* is small such that $\sin\Theta \cong \Theta$ and $\cos\Theta \cong 1$.

Then

$$\text{PFFR} = \int_{\phi=0}^{2\pi} \int_{\Theta=0}^{\pi} L(\phi, \Theta) \sin\Theta \, d\Theta \, d\phi$$

$$\cong 2\pi L \int_{\Theta=0}^{\Theta^*} \Theta \, d\Theta$$

$$\cong \pi L (\Theta^*)^2$$

Also,

$$\begin{aligned}
 \text{PFD} &= \int_{\phi=0}^{2\pi} \int_{\Theta=0}^{1/2\pi} L(\phi, \Theta) \sin \Theta \cos \Theta \, d\Theta \, d\phi \\
 &\cong 2\pi L \int_{\Theta=0}^{\Theta^*} \Theta \, d\Theta \\
 &\cong \pi L (\Theta^*)^2
 \end{aligned}$$

Therefore, $\text{PFFR} \cong \text{PFD}$

Photon flux fluence rate = photon flux density in a uniform collimated beam if the beam is normal to the cosine collector. One might also note that if the beam is perfectly collimated ($\Theta^*=0$), then the radiance L must be infinite in order for flux to be transmitted.

One could use an alternate approach. The total flux (does not need to be collimated) impinging onto a sphere is

$$F = \pi r^2 \text{ PFFR}$$

where r is the radius of the sphere, and PFFR is the photon flux fluence rate. If the flux is collimated and covers the entire sphere, then the flux density of the beam would be $F/\pi r^2$, where πr^2 is the cross-sectional area of that portion of the beam that is intercepted by the sphere, and F is the total flux in the beam that is intercepted by the sphere. If the beam is uniform, then the flux density is $F/\pi r^2$ everywhere in the beam. If a cosine-corrected collector is put into the beam, it will measure the flux density times the cosine of the angle between the beam and the normal of the collector. If that angle is zero, then the cosine-collector will measure the flux density ($F/\pi r^2$) even if its cross sectional area is less than πr^2 . Therefore, the cosine-collector will measure the photon flux density to be equal to the photon flux fluence rate measured by the sphere in a uniform collimated beam of radiation.

Section 4. Cleaning and Maintenance

DO NOT use alcohol, organic solvents, abrasives, or strong detergents to clean the diffuser element on LI-COR light sensors.

The acrylic material used in LI-COR light sensors can be crazed by exposure to alcohol or organic solvents, which will adversely affect the cosine response of the sensor.

Clean the sensor **only** with water and/or a mild detergent such as dishwashing soap. LI-COR has found that vinegar can also be used to remove hard water deposits from the diffuser element, if necessary.

Keep the sensors clean and treat them as a scientific instrument in order to maintain the accuracy of the calibration. The vertical edge of the LI-192 diffuser must be kept clean in order to maintain appropriate cosine correction.

Note that the LI-192 and LI-193 sensors are not designed for continuous, long-term deployment. Sensor output degradation due to the effects of internal humidity will occur over time during long-term deployment.

Other factors such as mineral content, salinity, turbidity, and those factors that may promote algae growth, can affect the function of the light collecting diffuser and degrade performance.

Section 5. Underwater Sensor Accessories

2222UWB Underwater Cable

This 2-wire shielded cable is used with underwater sensors and has a waterproof connector on the sensor end. The other end of the cable is fitted with a BNC connector for attaching the cable directly to the readout instrument for type "SA" sensors. Standard cable lengths are 3, 10, 30, 50 and 100 meters.

2009S Lowering Frame

The 2009S provides for the placement of two LI-192SA Underwater Quantum sensors, one each for downwelling or upwelling radiation, or a single LI-193SA Spherical Quantum Sensor. The 2009S provides stability for proper orientation of the sensor(s), minimizes shading effects, and features a lower mounting ring for attaching a stabilizing weight, if necessary.



100L Lubricant

A lubricant that is used to displace water from connectors. A silicone lubricant (Dow Corning 111) is also available from LI-COR (p/n 210-01958-1) that provides lubrication between the sensor and the underwater cable.

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Other LI-COR Reports

LI-COR has a number of more publications that contain more detail about radiation measurement, including factory calibration procedures, terminology, measurement errors, units conversions, and radiation theory. These publications are available on request from LI-COR; many of them can also be downloaded from LI-COR's web site at <http://www.licor.com>.

Principles of Radiation Measurement – a report on terminology, measurement errors, conversion between radiometric and photometric units, units and conversions used for quantum, photometric, and radiometric data, and condensed LI-COR calibration procedures.

Radiation Measurements and Instrumentation – a more detailed discussion of radiation theory, terminology, radiation measurement, and colorimetry.

Calibration Procedures for LI-COR Spectroradiometers, Radiation Sensors, and Lamps.

Immersion Effect and Cosine Collecting Properties of LI-COR Underwater Sensors.

Appendix A. Specifications

LI-192 Specifications

Absolute Calibration: $\pm 5\%$ in air traceable to NIST.

Sensitivity: Typically $4 \mu\text{A}$ per $1000 \mu\text{mol s}^{-1} \text{m}^{-2}$ in water.

Linearity: Maximum deviation of 1% up to $10,000 \mu\text{mol s}^{-1} \text{m}^{-2}$.

Stability: $< \pm 2\%$ change over a 1 year period.

Response Time: $10 \mu\text{s}$.

Temperature Dependence: $\pm 0.15\%$ per $^{\circ}\text{C}$ maximum.

Cosine Correction: Optimized for both underwater and atmospheric use.

Azimuth: $< \pm 1\%$ error over 360° at 45° elevation.

Detector: High stability silicon photovoltaic detector (blue enhanced).

Sensor Housing: Corrosion resistant metal with acrylic diffuser for saltwater and freshwater applications. Waterproof to withstand 800 psi (54 bars).

Size: $3.18 \text{ Dia.} \times 4.62 \text{ cm H}$ ($1.25" \times 1.81"$).

Weight: 227 g (0.50 lb.).

Mounting: Three $6-32$ holes are tapped into the base for use with the 2009S Lowering Frame or other mounting devices.

Cable: Requires 2222UWB Underwater Cable.

LI-193 Specifications

Absolute Calibration: $\pm 5\%$ in air traceable to NIST.

Sensitivity: Typically $7 \mu\text{A}$ per $1000 \mu\text{mol s}^{-1} \text{m}^{-2}$ in water.

Linearity: Maximum deviation of 1% up to $10,000 \text{ mmol s}^{-1} \text{m}^{-2}$.

Stability: $< \pm 2\%$ change over a 1 year period.

Response Time: $10 \mu\text{s}$.

Temperature Dependence: $\pm 0.15\%$ per $^{\circ}\text{C}$ maximum.

Cosine Correction: Acrylic diffuser.

Angular Response: $< \pm 4\%$ error up to $\pm 90^{\circ}$ from normal axis.

Azimuth: $< \pm 3\%$ error over 360° at 90° from normal axis.

Detector: High stability silicon photovoltaic detector (blue enhanced).

Sensor Housing: Corrosion resistant metal for both saltwater and freshwater applications with an injection molded, impact resistant, acrylic diffuser. Units have been tested to 500 psi (34 bars) with no failures.

Size

Globe: 6.1 cm Dia. ($2.4"$).

Housing: 3.18 cm Dia. ($1.25"$).

Overall Height: 10.7 cm ($4.2"$).

Weight: 142 g (0.31 lb.).

Mounting: Three $6-32$ mounting holes are tapped into the base for use with the 2009S Lowering Frame or other mounting devices.

Cable: Requires 2222UWB Underwater Cable.

Warranty

Each LI-COR, inc. instrument is warranted by LI-COR, inc. to be free from defects in material and workmanship; however, LI-COR, inc.'s sole obligation under this warranty shall be to repair or replace any part of the instrument which LI-COR, inc.'s examination discloses to have been defective in material or workmanship without charge and only under the following conditions, which are:

1. The defects are called to the attention of LI-COR, inc. in Lincoln, Nebraska, in writing within one year after the shipping date of the instrument.
2. The instrument has not been maintained, repaired or altered by anyone who was not approved by LI-COR, inc.
3. The instrument was used in the normal, proper and ordinary manner and has not been abused, altered, misused, neglected, involved in an accident or damaged by act of God or other casualty.
4. The purchaser, whether it is a DISTRIBUTOR or direct customer of LI-COR or a DISTRIBUTOR'S customer, packs and ships or delivers the instrument to LI-COR, inc. at LI-COR inc.'s factory in Lincoln, Nebraska, U.S.A. within 30 days after LI-COR, inc. has received written notice of the defect. Unless other arrangements have been made in writing, transportation to LI-COR, inc. (by air unless otherwise authorized by LI-COR, inc.) is at customer expense.
5. No-charge repair parts may be sent at LI-COR, inc.'s sole discretion to the purchaser for installation by purchaser.
6. LI-COR, inc.'s liability is limited to repair or replace any part of the instrument without charge if LI-COR, inc.'s examination disclosed that part to have been defective in material or workmanship.

There are no warranties, express or implied, including but not limited to any implied warranty of merchantability or fitness for a particular purpose on underwater cables or on expendables such as batteries, lamps, thermocouples, and calibrations.

Other than the obligation of LI-COR, inc. expressly set forth herein, LI-COR, inc. disclaims all warranties of merchantability or fitness for a particular purpose. The foregoing constitutes LI-COR, inc.'s sole obligation and liability with respect to damages resulting from the use or performance of the instrument and in no event shall LI-COR, inc. or its representatives be liable for damages beyond the price paid for the instrument, or for direct, incidental or consequential damages.

The laws of some locations may not allow the exclusion or limitation on implied warranties or on incidental or consequential damaged, so the limitations herein may not apply directly. This warranty gives you specific legal rights, and you may already have other rights which

vary from state to state. All warranties that apply, whether included by this contract or by law, are limited to the time period of this warranty which is a twelve-month period commencing from the date the instrument is shipped to a user who is a customer or eighteen months from the date of shipment to LI-COR, inc.'s authorized distributor, whichever is earlier.

This warranty supersedes all warranties for products purchased prior to June 1, 1984, unless this warranty is later superseded.

DISTRIBUTOR or the DISTRIBUTOR's customers may ship the instruments directly to LI-COR if they are unable to repair the instrument themselves even though the DISTRIBUTOR has been approved for making such repairs and has agreed with the customer to make such repairs as covered by this limited warranty.

Further information concerning this warranty may be obtained by writing or telephoning Warranty manager at LI-COR, inc.

IMPORTANT: Please return the User Registration Card enclosed with your shipment so that we have an accurate record of your address. Thank you.

LI-COR[®]

Biosciences

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