# LI-COR Radiation Sensors

# Instruction Manual

## Terrestrial Type SA:

- **LI-190SA Quantum Sensor**
- **LI-200SA Pyranometer Sensor**
- **LI-210SA Photometric Sensor**
- **LI-191SA Line Quantum Sensor**

LI-COR

# LI-COR Terrestrial Radiation

# Sensors, Type SA

# Instruction Manual

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# How to Use this Manual

This manual contains the operation and maintenance information for <u>all</u> LI-COR terrestrial, type SA sensors.

The first section of the manual contains general information which relates to all LI-COR terrestrial sensors (i.e. operation, recalibration, etc).

After the general information, specific information is given for each sensor.

When reading through the manual, read the general information first and then read the specific information for your sensor (i.e. the LI-190SA Quantum Sensor, LI-200SA Pyranometer Sensor, etc).

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# General Information

## Type "SA" Sensors

LI-COR SA type sensors are characterized by having the coaxial sensor cable terminated with a BNC connector. Figure 1 shows a typical SA type sensor.

Type SA terrestrial sensors include the LI-190SA Quantum Sensor, the LI-191SA Line Quantum Sensor, the LI-200SA Pyranometer Sensor, and the LI-210SA Photometric sensor. The SA type underwater sensors include the LI-192SA Underwater Quantum Sensor, and the LI-193SA Underwater Quantum Sensor.


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

## Sensor Recalibration

Recalibration of LI-COR radiation sensors is recommended every two years. Sensors may be returned to LI-COR for recalibration or recalibrated using the LI-COR 1800-02 Optical Radiation Calibrator (**NOTE:** the LI-200SA Pyranometer Sensor and LI-191SA Line Quantum Sensor must be returned to LI-COR for recalibration).

# Operation

The sensor cable is terminated with a BNC connector. This connector allows the sensor to be used with the LI-189 Quantum/Radiometer/ Photometer, the two current channels of the LI-1000 Datalogger, or with older LI-COR integrators, including the LI-510B and the LI-550B.

To use a type SA sensor with the LI-189 Quantum/Radiometer/Photometer, the calibration multiplier is entered by using the calibrate keys and dialing in the calibration multiplier using the calibration screw (see LI-189 manual). The calibration multiplier is given on the certificate of calibration and on the sensor calibration tag.

To use type SA sensors with the LI-1000, the calibration constant must be entered into the LI-1000 in the form of a multiplier. The multiplier (entered as a1 in the polynomial $Y = a0 + a1X + a2X^2 + a3X^3 + a4X^4 + a5X^5$ with LI-1000 version 2.02 software) is given on the certificate of calibration. For complete information on configuring the LI-1000 please consult the LI-1000 Instruction manual.

To use a type SA sensor with LI-COR light meters such as the LI-185B, LI-188B or LI-1776, a factory installed calibration connector is required. Other LI-COR light meters and integrators including the LI-170, LI-185, LI-185A, LI-188, LI-510, and LI-550 require the use of the 9901-014 connector conversion cable. Contact LI-COR for further details.

When a LI-COR Light Meter or data logger is not used, the sensors can be used with other millivolt recorders or data loggers by connecting a millivolt adapter. Table 1 lists the millivolt adapters required for each sensor and the resistance of each adapter.

**Table 1.** Millivolt adapters for "SA" type sensors.

| Sensor | Millivolt Adapter | Resistance |
|---|---|---|
| LI-190SA | 2290S | 604 Ohm |
| LI-200SA | 2220S | 147 Ohm |
| LI-210SA | 2290S | 604 Ohm |
| LI-191SA | 2290S | 604 Ohm |

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 "Ohms Law" (Voltage = Current $\times$ Resistance).

**Example:** Calculate the millivolt output of an LI-190SA Quantum Sensor which has a calibration constant of 8.0 µA/1000 µmol $s^{-1}$ $m^{-2}$. Assume the 2290S millivolt adapter is used with the sensor.

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

Or, = 4.83 mV/1000 µmol $s^{-1}$ $m^{-2}$

The shield of the coaxial cable on LI-COR light sensors is positive and the center conductor is negative. (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 used, 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. The negative (blue) lead is connected to the signal input. This will minimize noise.

If plus or minus capability is not available on the data logger or recorder, the red lead should be connected to the positive input and the black lead to the negative input. If noise difficulties are encountered, consult LI-COR for special wiring instructions.

The BNC connector and millivolt adapter are not weatherproof. If the millivolt adapter is attached to the sensor for connection to a data logger or millivolt recorder, this connection should be made at the recorder end (indoors). This eliminates thermocouple effects caused by exposing the BNC connector and millivolt adapter to rapidly changing direct solar radiation. These effects are not noticeable when the connectors are used indoors out of direct radiation.

If a longer cable is needed for your application, use LI-COR extension cable (2222SB or 2222SB-100), or coaxial (RG174) cable. Cables ≤ 700 feet (213 m) can be used if the signal is not degraded by electrical interference from electromagnetic fields (i.e., from radio transmitters). If you need to use a cable longer than 700 feet, use a heavier gauge coaxial cable (i.e., RG122). The total DC resistance of the extension cable used with the LI-200SA must be ≤ 75Ω. *The voltage developed across the sensor's photodiode should not exceed 20 mV.* Calculate the voltage according to

[Total cable resistance + mV adapter resistance (Ω)] × sensor output (µA) = mV.

If extension cable is used where the BNC termination will be exposed outdoors or on a conductive surface, the BNC connection should be insulated by wrapping it with tape. This is done to avoid ground loops.

# 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 2A) and at an angle of 60° from normal (Figure 2B). Figure 2A 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

$$S = (I)\ (\text{cosine } 60°) \text{ per unit area}$$
$$3 = (6)\ (0.5) \text{ per unit area}$$

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

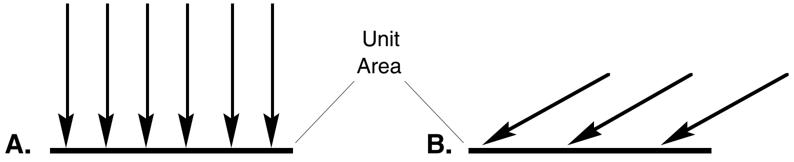



**Figure 2.** Lambert's Cosine Law.

# Cosine Correction Properties

Cosine corrected LI-COR terrestrial type sensors are all designed for the same cosine response characteristics. The percent of true cosine response is presented in Figure 3. The error is typically less than ± 5% for angles less than 80° from the normal axis of the sensor. At 90° a perfect cosine collector response would be zero and at that angle any error is infinite.

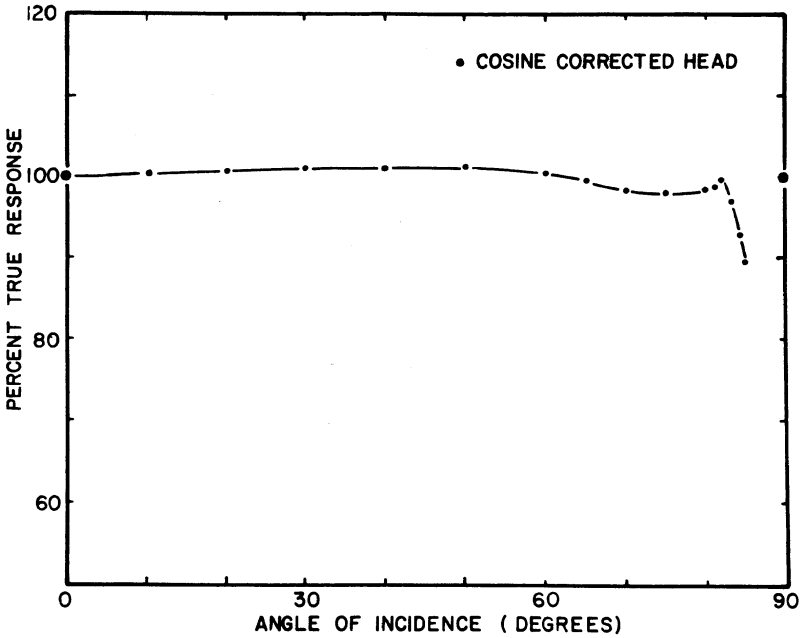



**Figure 3.** Cosine response of LI-COR terrestrial type sensors.

# Cleaning Information

***DO NOT*** use alcohol, organic solvents, abrasives, or strong detergents to clean the diffusor 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 diffusor element, if necessary.

# LI-190SA Quantum Sensor

## Use of the Quantum Sensor

LI-COR quantum sensors measure photosynthetically active radiation (PAR) in the 400 to 700 nm waveband. The unit of measurement is micromoles per second per square meter * ($\mu$mol $s^{-1}$ $m^{-2}$).

The quantum sensor is designed to measure PAR received on a plane surface. The indicated sensor response (Figure 4) is selected because it approximates the photosynthetic response of plants for which data is available. A silicon photodiode with an enhanced response in the visible wavelengths is used as the sensor. A visible bandpass interference filter in combination with colored glass filters is mounted in a cosine corrected head. Error calculations indicate that under sun-and-sky radiation, and various natural or artificial light sources found in environmental research, the relative errors are less than ±5%.

Measuring PAR within plant canopies, greenhouses, controlled environment chambers, confined laboratory conditions, or at remote environmental monitoring sites are all typical applications for this sensor.

The LI-190SA can be hand held or mounted at any required angle. In its most frequent application, the quantum sensor is set on a level surface free from any obstruction to direct or diffuse radiation. The sensor may be conveniently leveled by using the LI-COR 2003S Mounting and Leveling Fixture.

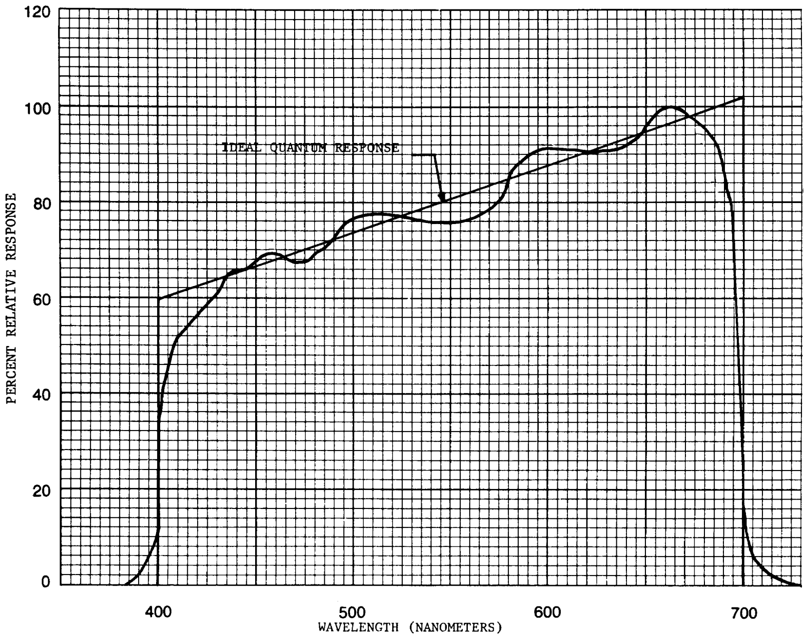
Keep the sensor clean and treat it as a scientific instrument in order to maintain the accuracy of its calibration. The vertical edge of the diffuser must be kept clean in order to maintain appropriate cosine correction.

## LI-190SA Spectral Response

In 1976, LI-COR had sensor calibration data verified by the National Research Council of Canada (NRC), one of the major standards laboratories in the world.

* Units currently in use are photons, moles and einsteins. 1 $\mu$mol $s^{-1}$ $m^{-2}$ = 6.02 x $10^{17}$ photons = 1 $\mu$E $s^{-1}$ $m^{-2}$. Full sun plus sky PPFD is approximately 2000 $\mu$mol $s^{-1}$ $m^{-2}$ or 2000 $\mu$E $s^{-1}$ $m^{-2}$.

**Figure 4.** LI-190SA Sensor Response Curve.




The spectral response of the quantum sensor is obtained by use of a light source and a monochromator. A thermopile or calibrated silicon photodiode 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 $\lambda$. If $Q(\lambda)$ is the sensor output at wavelength $\lambda$ 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 $\lambda$. The above approximation assumes that the monochromator bandwidth, $\Delta\lambda$, is much less than the wavelength setting $\lambda$. The normalized sensor spectral response $r(\lambda)$, is determined by

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

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

## Calibration

The NRC performed an absolute calibration of the LI-COR Quantum Sensor. Information concerning these tests is available from LI-COR.

The calibration is obtained at LI-COR by using a standard light source calibrated against a National Bureau of Standards lamp. The photon flux density from the standardized lamp is known in terms of micromoles $s^{-1}$ $m^{-2}$ where one micromole = $6.022 \times 10^{17}$ photons.

The LI-190SA Quantum Sensor has been calibrated against a standard lamp. The uncertainty of the calibration is ± 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 was used to calculate the quantum flux output from the lamp. The lamp flux density ($\Delta E$) 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 $\lambda$.

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

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

The result is adjusted to μmol $s^{-1}$ $m^{-2}$ by dividing by $6.022 \times 10^{17}$ .

# LI-190SA Specifications

**Absolute Calibration:** ± 5% traceable to the U.S. National Institute of Standards and Technology (NIST).
**Sensitivity:** Typically 8 µA per 1000 µmol $s^{-1}$ $m^{-2}$.
**Linearity:** Maximum deviation of 1% up to 10,000 µmol $s^{-1}$ $m^{-2}$.
**Stability:** < ± 2% change over a 1 year period.
**Response Time:** 10 µs.
**Temperature Dependence:** ± 0.15% per °C maximum.
**Cosine Correction:** Cosine corrected up to 80° angle of incidence.
**Azimuth:** < ± 1% error over 360° at a 45° elevation.
**Tilt:** No error induced from orientation.
**Detector:** High stability silicon photovoltaic detector (blue enhanced).
**Sensor Housing:** Weatherproof anodized aluminum case with acrylic diffuser and stainless steel hardware.
**Size:** 2.38 Dia. x 2.54 cm H (0.94" x 1.0").
**Weight:** 28 g (1 oz.)
**Cable Length:** 3.0 m (10 ft.)
**Accessories:** 2003S Mounting and Leveling Fixture, 2222SB Extension Cable.

# LI-200SA Pyranometer Sensor

## Use of the Pyranometer Sensor

A pyranometer is an instrument for measuring solar radiation received from a whole hemisphere. It is suitable for measuring global sun plus sky radiation.

Solar radiation varies significantly among regions. Season and time of day are major considerations, but surrounding terrain elevation, man-made obstructions, and surrounding trees can also cause large variations in locations of a small area. Often, the most required measurement is the energy flux density of both direct beam and diffuse sky radiation passing through a horizontal plane of known unit area (i.e. global sun plus sky radiation).

The silicon photodiode has made possible the construction of simple pyranometers of reasonable accuracy where the photodiode is stable. The response of the silicon photodiode sensor (Figure 5) is not ideal, (equal spectral response from 280-2800 nm) but does not cause serious error provided the photodiode is used only for solar radiation and not under conditions of altered spectral distribution. **IMPORTANT:** For this reason, we do not recommend its use under artificial lighting, within plant canopies or to measure reflected radiation.

The LI-COR pyranometer may be handheld or mounted at any required angle, provided that reflected radiation is not a significant portion of the total. In its most frequent application, the pyranometer sensor is set on a level surface free from any obstruction to either direct or diffuse radiation. The sensor may be most conveniently leveled by using the 2003S Mounting and Leveling Fixture.

Keep the sensor clean and treat it as a scientific instrument in order to maintain the accuracy of its calibration. The vertical edge of the diffuser *must be kept clean* in order to maintain appropriate cosine correction.

The LI-COR pyranometer sensor is a miniaturized version of the pyranometer developed by Kerr, Thurtell and Tanner[4].

# LI-200SA Spectral Response

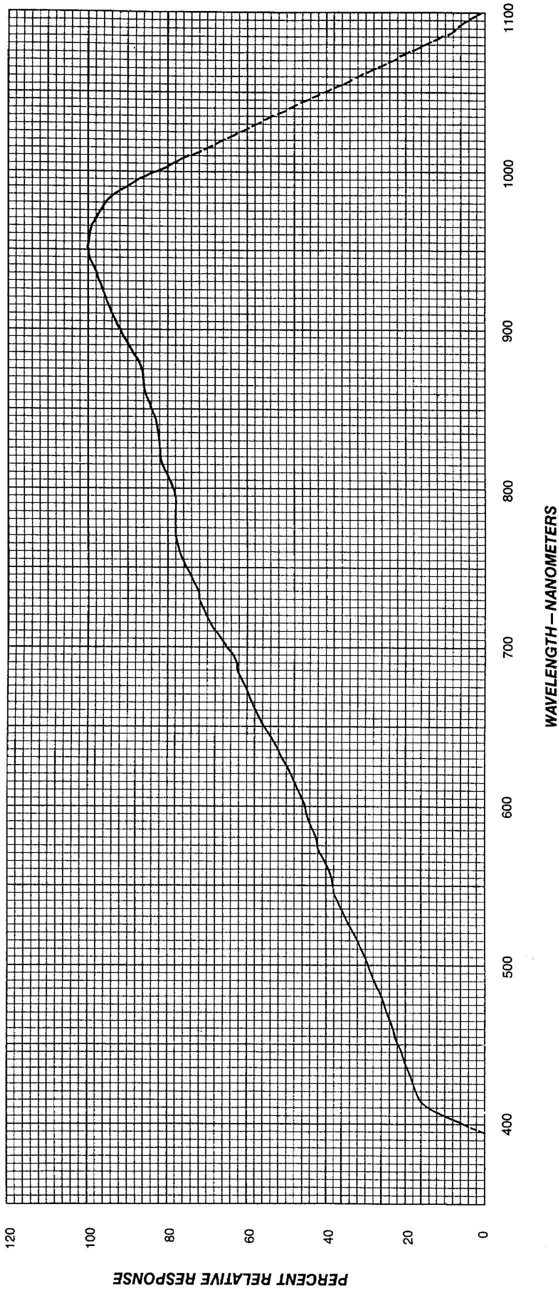
The relative spectral response of the silicon photodiode does not extend uniformly over the full solar radiation range. A typical response curve is presented in Figure 5. The response is very low at 0.4 µm and increases nearly linear to a maximum at about 0.95 µm and then decreases nearly linear to a cutoff near 1.2 µm. Changes in the spectral distribution of the incident light, coupled with the non-uniform spectral response, can cause errors in the photodiode output. Hull[3] shows that in the 0.4 to 0.7 µm range, the spectral distribution of sun plus sky radiation on a horizontal surface is remarkably constant even when clear and overcast days are compared. However, Gates[2] indicates that the major change in spectral distribution of solar radiation occurs in the near infrared where water vapor absorption takes place on cloudy days. Data collected at low solar elevations can show significant error because of altered spectral distribution which changes in atmospheric transmission. This is a small part of the daily total so the possible observed error usually has an insignificant effect on daily integrations.

The area under the spectral irradiance curve of the source is directly proportional to the energy received by a horizontal surface. Under specific but typical conditions, energy received on a completely overcast day has been estimated to be 11.3% of that received on a clear day. When both spectral distributions are weighted according to a typical response curve of a silicon photodiode, the response on this cloudy day is 12.6%. Therefore, errors incurred under different sky conditions, due to the spectral response of the photodiode, will be small. The field tests of Federer and Tanner[1] and Kerr, Thurtell and Tanner[4] confirm this conclusion.

# Calibration

The LI-200SA Pyranometer has been calibrated against an Eppley Precision Spectral Pyranometer (PSP) of which the calibration is periodically confirmed. The calibration was performed under daylight conditions by a computer sampling of instantaneous readings from the Eppley and LI-COR pyranometers. Instantaneous readings were taken continuously for 10 minutes and then averaged. Sequential ten minute averaging periods were run from sunup to sundown for 3-4 days. These ten minute averages were then evaluated and used to compute an average calibration constant. The uncertainty of calibration is ± 5%.

**Figure 5.** LI-200SA Spectral Response Curve.



# LI-200SA Specifications

**Calibration:** Calibrated against an Eppley Precision Spectral Pyranometer (PSP) under natural daylight conditions. Absolute error under these conditions is ± 5% maximum, typically ± 3%.

**Sensitivity:** Typically 80 µA per 1000 W $m^{-2}$ .

**Linearity**: Maximum deviation of 1% up to 3000 W $m^{-2}$.

**Stability:** < ± 2% change over a 1 year period.

**Response Time:** 10 µs.

**Temperature Dependence:** ± 0.15% per °C maximum.

**Cosine Correction:** Cosine corrected up to 80° angle of incidence.

**Azimuth:** < ± 1% error over 360° at 45° elevation.

**Tilt:** No error induced from orientation.

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

**Sensor Housing:** Weatherproof anodized aluminum case with acrylic diffuser and stainless steel hardware.

**Size:** 2.38 Dia. x 2.54 cm H (0.94" x 1.0").

**Weight:** 28 g (1 oz.).

**Accessories:** 2003S Mounting and Leveling Fixture, 2222SB Extension Cable.

**Cable Length:** 3 meters (10 ft) standard. LI-200SA-50: 50 ft.

# LI-210SA Photometric Sensor

## Use of the Photometric Sensor

The LI-210SA Photometric Sensor is designed to measure illumination in terms of lux (1 footcandle = 10.764 lux). This is radiation as the human eye sees it. The spectral response is shown in Figure 6.

This sensor may be handheld or mounted at any angle. In its most frequent application, the sensor is set on a level surface. It is most conveniently leveled by using the 2003S Mounting and Leveling Fixture.

Keep the sensor clean and treat it as a scientific instrument in order to maintain the accuracy of its calibration. The vertical edge of the diffuser must be kept clean in order to maintain appropriate cosine correction.

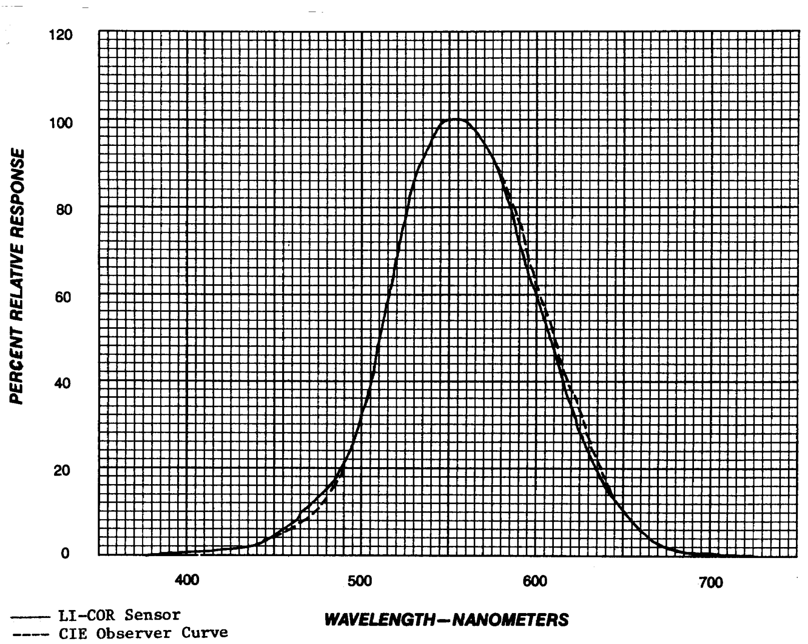



**Figure 6.** Spectral response of the LI-210SA.

# Photometric Terms

Although characteristics of the human eye vary from person to person, standard luminosity coefficients for the eye were defined by the Commission Internationale de Eclairage (C.I.E., International Commission on Illumination) in 1931. An absolute "sensitivity" figure established for the standard eye relates photometric units and radiant power units. At 5550 angstroms (555 nm) the wavelength of the maximum sensitivity of the eye, one watt of radiant power corresponds to 680 lumens.

The sensitivity of the eye outside the wavelength limits defined by the C.I.E. is very low but not actually zero. Studies with intense infrared sources have shown that the eye is sensitive to radiation of wavelength at least as long as 10500 angstroms. According to Goodeve[5] the ultraviolet sensitivity of the eye extends to between 3125 and 3023 angstroms. Below this level the absorption of radiation by the proteins of the eye lens apparently limits further extension of vision into the ultraviolet. Radiation having a wavelength of 3023 angstroms is detected by its fluorescent effect in the front part of the eye.

Photometry deals with the measurement of radiation in reference to the effect produced on the theoretical standard C.I.E. observer. Measurements are made by visual comparison, or by some equivalent photoelectric method. Units, standards, and systems of measurement have been developed to correspond to the effect as observed by the eye.

Luminous intensity (or candle-power) is a measure of a light source which describes its luminous flux per unit solid angle in a particular direction. For many years, the standard measure of luminous intensity was the international candle established by a group of carbon-filament lamps at the Bureau of Standards. In 1948 the International Commission of Illumination agreed on the introduction of a new standard of luminous intensity and recommended the adoption of the name candela to distinguish it from the international candle. The term candela is now widely used abroad and is in general use in the United States; the older term candela is sometimes used but refers to the new candle or candela.

The candela is defined by the radiation from a black body at the temperature of solidification of platinum. A candela is one-sixtieth of the luminous intensity of one square centimeter of such a radiator. The major advantage of the new standard is that it may be reproduced in any laboratory. The effective change in the value of the candle as a result of the 1948 agreement is of the order of tenths of one percent and, therefore, is negligible in practical measurements.

Luminous flux is the time rate of flow of light energy that is characteristic of radiant energy which produces visual sensation. The unit of luminous flux is the lumen, which is the flux emitted in units per solid angle by a uniform point of source of one candela. Such a source produces a total luminous flux of $4\pi$ lumens.

A radiant source may be evaluated in terms of luminous flux if the radiant energy distribution of the source is known. If $W(\lambda)$ is the total radiant power in watts per unit wavelength, total radiant power over all wavelengths is

$$\int_0^\infty W(\lambda)d\lambda$$

and the total luminous flux L in lumens can be expressed as

$$L = \int_0^\infty [680W(\lambda)][y(\lambda)]d\lambda$$

where $y(\lambda)$ represents the luminosity coefficient as a function of wavelength and $d\lambda$ is a differential of wavelength.

Illuminance is the density of luminous flux incident on a surface. A common unit of illuminance is the lux, which is the illumination produced by one lumen uniformly distributed over an area of one square meter. It follows that a source of one candela produces an illuminance of one lux at a distance of one meter. A footcandle is one candela at a distance of one foot.

# Spectral Response

The spectral response of a typical LI-COR LI-210SA Photometric Sensor compared to the C.I.E. standard observer curve is presented in Figure 6. In 1976, LI-COR had sensor calibration data verified by the National Research Council of Canada (NRC), one of the major standards laboratories in the world. Information concerning these tests is available from LI-COR.

# Calibration

The LI-210SA Photometric Sensor has been calibrated against a standard lamp. The uncertainty of the calibration is ± 5%.

Beginning June 1, 1978, all LI-COR photometric sensors have been calibrated using 683 lumens per watt as the value of spectral luminous efficacy at a wavelength of 555 nm, rather than the previously accepted C.I.E. standard value of 680 lumens per watt.

This change was made to conform to the recommendations of the International Committee for Weights and Measures (CIPM) adopted at their September, 1977, meeting. The new value is considered to be the one that best relates the photometric and radiometric units currently maintained by the major national laboratories. It was adopted after considering the preferred values submitted by the national laboratories of nine countries. Therefore, measurements taken with LI-COR sensors calibrated after the above date will give illuminance values of 0.4% higher than would be obtained with the sensors calibrated at the old standards.

## LI-210SA Specifications

**Absolute Calibration:** ± 5% traceable to NBS.
**Sensitivity:** Typically 20 µA per 100 klux.
**Linearity:** Maximum deviation of 1% up to 100 klux.
**Stability:** < ± 2% change over a 1 year period.
**Response Time:** 10 µs.
**Temperature Dependence:** ± 0.15% per °C maximum.
**Cosine Correction:** Cosine corrected up to 80° angle of incidence.
**Azimuth:** < ± 1% error over 360° at 45° elevation.
**Tilt:** No error induced from orientation.
**Detector:** High stability silicon photovoltaic detector (blue enhanced).
**Sensor Housing:** Weatherproof anodized aluminum case with acrylic diffuser and stainless steel hardware.
**Size:** 2.38 Dia. x 2.54 cm H (0.94" x 1.0").
**Weight:** 28 g (1 oz.)
**Cable Length:** 3.0 m (10 ft.)
**Accessories:** 2003S Mounting and Leveling Fixture, 2222SB Extension Cable.

# LI-191SA Line Quantum Sensor

## Use of the Line Quantum Sensor

The LI-191SA Sensor is designed for measuring PAR (photosynthetically active radiation) in applications where the radiation to be measured is spatially non-uniform (such as within plant canopies). To achieve this, the sensor features a sensing area that is one meter in length. The LI-191SA has the quantum (photon) response through the wavelength range of 400-700 nm for PPFD (photosynthetic photon flux density) as generally preferred for PAR measurements, and has an output in units of moles where

$$1\ \mu\text{mol s}^{-1}\ \text{m}^{-2} \equiv 1\ \mu\text{E s}^{-1}\ \text{m}^{-2} \equiv 6.02 \times 10^{17}\ \text{photons s}^{-1}\ \text{m}^{-2}$$

Error can be introduced by the user when using a single small sensor to characterize the radiation profile within a crop canopy or growth chamber. The flux density measured on a given plane can vary considerably due to shadows and sunflecks. To neglect this in measurements can introduce errors up to 1000%. Multiple sensors or sensors on track scanners can be used to minimize this error. The LI-191SA Line Quantum Sensor, which spatially averages radiation over its 1 meter length, minimizes the error and allows one person to easily make many measurements in a short period of time. The sensor can also be used for permanent monitoring of radiation within the crop canopy. The sensor is fully weatherproof (except the BNC connector) and can be left unattended.

Normal use by a single user when measuring radiation within a crop canopy is done by supporting the sensor with one hand and cantilevering it into the canopy. The sensor should be maintained in a level position as much as possible. Since radiation levels vary considerably, the user error introduced by not leveling exactly is usually very small in correspondence to the total radiation error which might occur due to variations within the canopy. If the user desires to permanently mount the unit in the field, this can be done by using common laboratory supply clamps in conjunction with ring stands.

The LI-191SA can be used for absolute measurements above the canopy, but if precise absolute measurements above the canopy are desired, the LI-190SA Quantum Sensor should be used.

Do not immerse the LI-191SA in water or other liquids. If the LI-191SA is mounted to a support, make provisions to allow water drainage away from it. The LI-191SA is sealed against normal weather conditions, but may leak if submerged.

The LI-191SA may be cleaned with a mild detergent and water, but care should be observed to avoid disturbing the silicone rubber seal which is adjacent to the diffuser. Do not attempt to disassemble the sensor, as the weatherproof seal will be broken and the calibration and spatial response will be affected.

An anodized aluminum "nose cone" is provided which can be screwed into the 1/4-20 threaded hole on the end of the sensor. This will allow easier insertion of the sensor into dense foliage. **WARNING:** Do not drop the sensor since the point of the nose cone could cause injury!

# Cosine Correction Properties

Due to the large non-symmetrical sensing area of 1 meter by 12.7 mm, the LI-191SA cannot be compensated completely for true cosine response. Figure 7 shows the approximate cosine error for collimated light at angles of incidence from 0° (normal) to 90°. Under conditions of partial or full diffuse radiation the errors will generally be negligible.

Since the sensing area is a flat acrylic diffuser, the response at a given angle of incidence is fairly constant as the azimuth angle around the sensor is varied. It is specified at less than ± 2% at a 45° angle of elevation for 360° of sensor rotation.

# Surface Variation Errors

The response uniformity along the 1 meter sensing length is specified to vary less than ± 7% when tested with a beam of light that is one inch in width. It is determined by the diffuser and internal optical design.

# Spectral Response

The spectral response of the LI-191SA is comparable to that of the LI-190SA Quantum Sensor. All LI-COR quantum sensors use computer tailored filter glasses to achieve a response that closely approximates the desired ideal quantum response. See Figure 4.

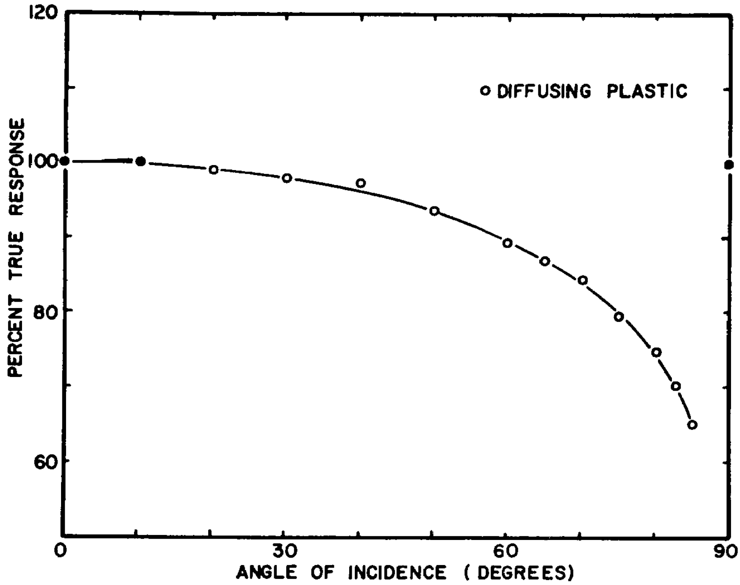



**Figure 7.** Cosine Response of LI-191SA Line Quantum Sensor

Measurement of the spectral response requires a stabilized light source, monochromator, lock-in amplifier and calibrated reference detector. Measurements taken with the test sensor and reference detector at many wavelengths yield data points used to plot the relative spectral response.

# Absolute Calibration

The uncertainty of the calibration is ± 10% due primarily to basic calibration limitations and a transfer error when calibrating the LI-191SA against a reference quantum sensor in a spatially uniform light beam. This method is due to the large physical size of the LI-191SA.

Calibration of the reference quantum sensor is performed on a specially equipped optical bench containing a high intensity quartz-halogen lamp traceable to NIST (National Institute of Standards and Technology) standard lamps. The photon flux density and irradiance produced by the lamp in the bandwidth of 400-700 nm is known.

# LI-191SA Specifications

**Absolute Calibration:** ± 10% traceable to NIST. The LI-191SA is calibrated via transfer calibration using a reference LI-190SA Quantum Sensor. Transfer error is ± 5% (included in the ± 10%).
**Sensitivity:** Typically 3 µA per 1000 µmol $s^{-1}$ $m^{-2}$
**Linearity:** Maximum deviation of 1% up to 10,000 µmol $s^{-1}$ $m^{-2}$.
**Stability:** < ± 2% change over a 1 year period.
**Response Time:** 10 µs.
**Temperature Dependence:** ± 0.15% per °C maximum.
**Cosine Correction:** Acrylic diffuser.
**Azimuth:** < ± 2% error over 360° at 45° elevation.
**Sensitivity Variation over Length:** ± 7% maximum using a 1" wide beam from an incandescent light source.
**Sensing Area:** 1 meter L x 12.7 mm W (39.4" x 0.50").
**Detector:** High stability silicon photovoltaic detector (blue enhanced).
**Sensor Housing:** Weatherproof anodized aluminum case with acrylic diffuser and stainless steel hardware.
**Size:** 116 L x 2.54 W x 2.54 cm D (45.5" x 1.0" x 1.0").
**Weight:** 1.8 kg (4.0 lb..)
**Cable Length:** 3.1 m (10.0 ft.)

# Appendix

## References


1. Federer, C.A., and C.B. Tanner, 1965. A simple integrating pyranometer for measuring daily solar radiation. J. Geophys. Res. 70, 2301-2306.

2. Gates, D.M., 1965. Radiant energy, its receipt and disposal. Meteor. Monogr., 6, No. 28, 1-26.

3. Hull, J.N., 1954. Spectral distribution of radiation from sun and sky. Trans. Illum. Eng. Soc. (London), 19:21-28.

4. Kerr, J.P., G.W. Thurtell, and C.B. Tanner, 1967. An integrating pyranometer for climatological observer stations and mesoscale networks. Journal of Applied Meteorology, 6, 688-694.

5. Goodeve, D.F., 1934. Visions in the ultraviolet, Nature.


## Accessories

**2003S Mounting and Leveling Fixture.** The 2003S is for use with all LI-COR terrestrial type sensors (2.38 cm Dia.). The base is anodized aluminum with stainless steel leveling screws and a weatherproof spirit level for leveling the sensors during operation.

**2222SB Extension Cable.** For use with LI-COR terrestrial sensors. Standard length is 50 ft (15.2 m) or 100 ft (30.4 m). Custom lengths up to 1000 ft (304 m) may be ordered

**1800-02 Optical Radiation Calibrator.** The 1800-02 is a self contained optical radiation calibrator for on-site spectral irradiance, irradiance, photon flux, or illuminance calibrations in the 300-1100 nm wavelength range. The 1800-02 combines a quartz tungsten halogen lamp and a highly regulated power supply into a portable calibration system.

Sensor calibrations are performed using the sensor mounting fixture which holds the sensor in a precise location and eliminates the need to align the sensor within the calibration system. Both terrestrial and underwater sensors can be calibrated using the appropriate mounting and leveling fixture.

# 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 of 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®

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