LI-COR Terrestrial Radiation Sensors

Instruction Manual

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

LI-COR®
Biosciences

LI-COR Terrestrial Radiation Sensors

Instruction Manual

LI-COR®

Biosciences

NOTICE

The information contained in this document is subject to change without notice.

LI-COR MAKES NO WARRANTY OF ANY KIND WITH REGARD TO THIS MATERIAL, INCLUDING, BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. LI-COR shall not be liable for errors contained herein or for incidental or consequential damages in connection with the furnishing, performance, or use of this material.

Publication Number 984-08308
Printing History: 1st Printing December, 2005

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).

LI-COR, Inc. • 4421 Superior Street • Lincoln, Nebraska 68504
Phone: 402-467-3576 • FAX: 402-467-2819
Toll-free: 1-800-447-3576 (U.S. & Canada)
E-mail: envsales@licor.com
In Germany – LI-COR GmbH: +49 (0) 6172 17 17 771
www.licor.com

Table of Contents

Section 1. LI-COR Radiation Sensors - Applications

Section 2. Sensor Configurations

Section 3. Calibration Constants and Multipliers

Section 4. Cosine Response and Error

Section 5. Factory Calibration Procedures

Section 6. Using Quantum Sensors

Section 7. Using Pyranometers

Section 8. Using Photometric Sensors

Section 9. Cleaning and Maintenance

Section 10. Accessories

Section 11. References and Bibliography

Appendix A. Specifications

Section 1. LI-COR Radiation Sensors - Applications

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 1-1) is selected because it approximates the photosynthetic response of plants for which data are 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.

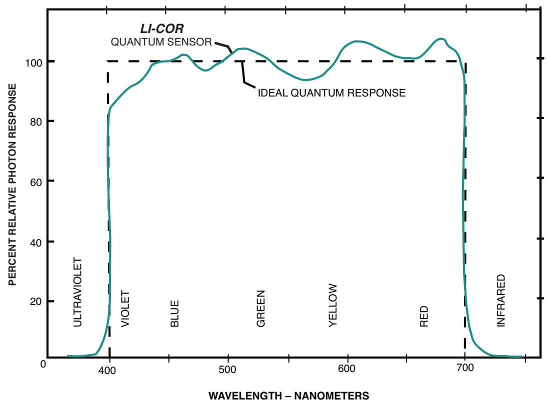


***Figure 1-1**. Typical spectral response of LI-COR Quantum Sensors vs. Wavelength and the Ideal Quantum Response (equal response to all photons in the 400-700 nm waveband).*

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

Pyranometer

The LI-200 Pyranometer is designed for field measurement of global solar radiation in agricultural, meteorological, and solar energy studies. The LI-200 features a silicon photovoltaic detector mounted in a fully cosine-corrected miniature head. Current output, which is directly proportional to solar radiation, is calibrated against an Eppley Precision Spectral Pyranometer (PSP) under natural daylight conditions in units of watts per square meter ($W\ m^{-2}$). Under most conditions of natural daylight, the error is <5% (4).

The spectral response of the LI-200 does not include the entire solar spectrum, so it must be used in the same lighting conditions as those under which it was calibrated. ***Therefore, the LI-200 should only be used to measure unobstructed daylight. It should not be used under vegetation, artificial lights, in a greenhouse, or for reflected solar radiation.***

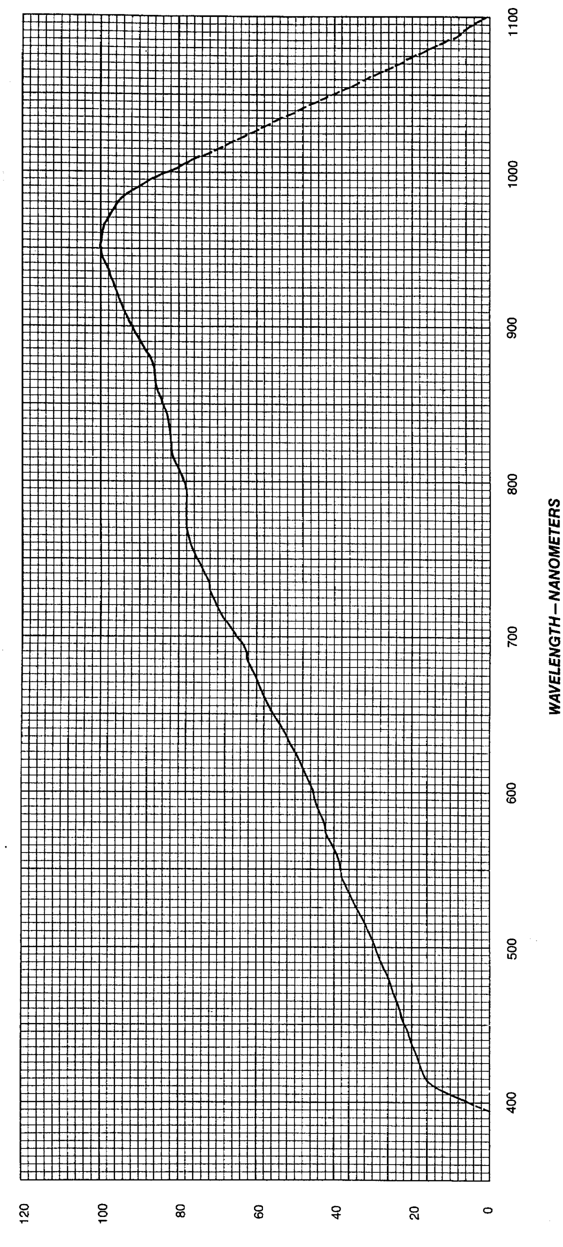


Figure 1-2. *LI-200SA Spectral Response Curve.*

Photometric Sensor

The LI-210 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. Some of the applications for the LI-210 Photometric Sensor include interior and industrial lighting, outdoor illuminance, passive solar energy, architecture and lighting models, illumination engineering, and biological sciences that require illuminance measurements. The spectral response is shown in Figure 1-3.

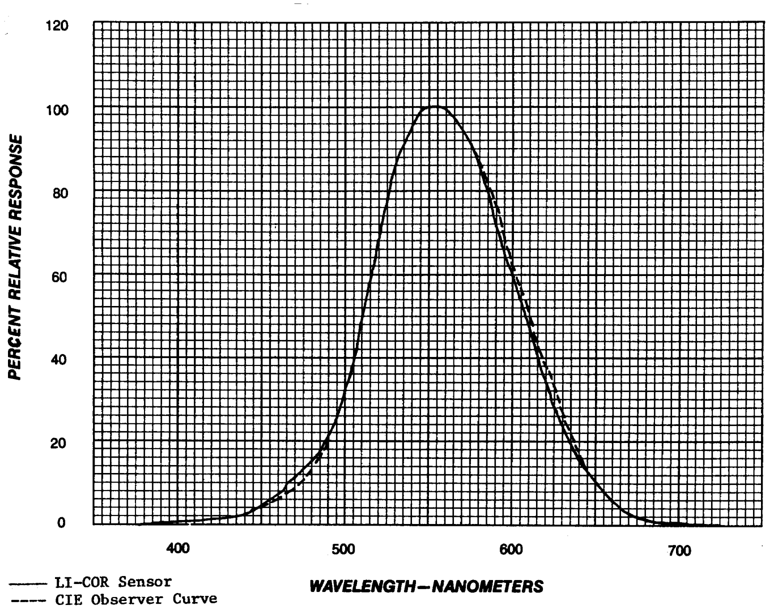


Figure 1-3. *Spectral response of the LI-210.*

Section 2. Sensor Configurations

LI-COR currently offers three sensor configurations; the designators “SA”, “SZ”, and “SL” refer to the type of connectors (or lack thereof) which terminate the sensor cable. The appropriate connector is determined based on the readout device to which the sensor will be connected. Note that type “SA” and “SZ” sensors produce a *current* signal, not voltage. Type “SL” sensors produce at mV signal at their termination.

Type SA Sensors

Type “SA” sensors (e.g. LI-190SA) have a coaxial cable that terminates with a BNC connector. This type of connector allows for direct connection to the LI-COR LI-250A Light Meter or the LI-1400 DataLogger. Figure 2-1 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 LI-1200 Minimum Data Set Recorder, or with older LI-COR integrators.

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.

Figure 2-1. *"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 3 for more information.

Type SZ Sensors

LI-COR "SZ" type sensors are characterized by having the sensor cable terminated with the two bare wire leads of the coaxial cable. Figure 2-2 shows a typical SZ type sensor.

Type SZ terrestrial sensors include the LI-190SZ Quantum Sensor and the LI-200SZ Pyranometer Sensor.

Figure 2-2. *"SZ" type sensors have no connector and are terminated with only the bare wire leads of the coaxial cable.*

The bare wires on the "SZ" sensors allow them to be used with the two *current* channels of the LI-1400 Datalogger located on the screw-down terminals (I4, I5) of the 1400-301 terminal block. The shield of the coaxial cable is positive and the center conductor is negative. This is done because the trans-impedance amplifier used in LI-COR light meters requires a negative signal.

To use type SZ sensors with the LI-1400, the calibration constant must be entered into the LI-1400 in the form of a multiplier. The multiplier is given on the certificate of calibration. For complete information on configuring the LI-1400 please consult the LI-1400 Instruction manual.

When a LI-COR Light Meter or data logger is not used, the sensor can be used with other millivolt recorders or data loggers by connecting a resistor across the leads of the coaxial cable. See Section 3 for more information.

Type SL Sensors

Type “SL” sensors (e.g. LI-190SL) have a coaxial cable that terminates with a BNC connector. The BNC connector is coupled to a millivolt adapter containing a variable resistor. This resistance is adjusted to each sensor’s current output to provide a standardized millivolt output. The end of the millivolt adapter is terminated with bare wire leads for connection to other manufacturer’s data loggers or data acquistion systems. Figure 2-3 shows a typical type SL sensor.

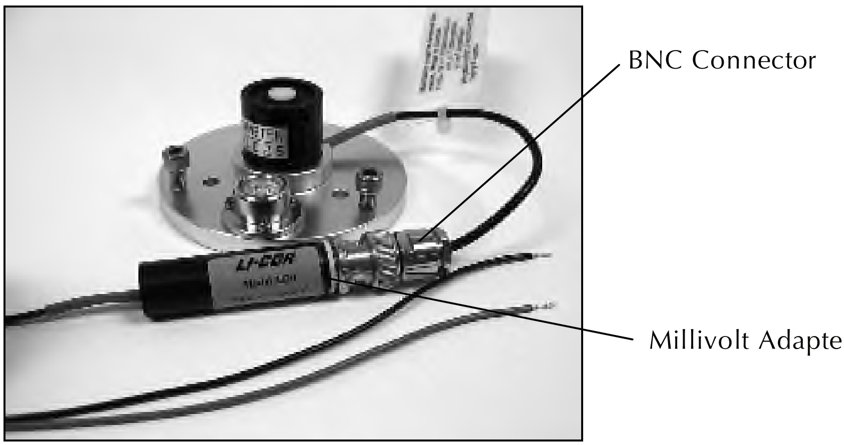


***Figure 2-3**. "SL" type sensors are terminated with a BNC connector and millivolt adapter on the end of the coaxial cable.*

Each type SL sensor is calibrated with its corresponding millivolt adapter to provide a standardized sensor output, with a range of 0-10 mV full scale. Standardizing the output allows sensors to be changed out in the field without the need to enter unique calibration constants or multipliers. Because of this, each sensor can be used only with the millivolt adapter that is supplied with it (i.e., the serial numbers must match). Type SL sensors are offered for terrestrial radiation sensors, but not for underwater sensors, which have different outputs for terrestrial and underwater measurements.

The standardized output for each of the available SL sensor types is given in Section 3.

Section 3. Calibration Constants and Multipliers

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 Calibration Multiplier is always a negative number (because the shield of the coaxial cable of the sensor carries the positive signal instead of the negative signal), and is expressed in radiation units per microamp.

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.

Using Other Manufacturer's Meters or Data Loggers with LI-COR Sensors

Type SA Sensors

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 adapter, available from LI-COR. Table 3-1 lists the millivolt adapters required for each sensor and the resistance of each adapter.

Table 3-1. Millivolt adapters for "SA" type sensors

Sensor	Millivolt Adapter	Resistance
LI-190SA	2290	604 Ohm
LI-191SA	2290	604 Ohm
LI-192SA	2291	1210 Ohm
LI-193SA	2291	1210 Ohm
LI-200SA	2220	147 Ohm
LI-210SA	2290	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 "Ohm's Law" (Voltage = Current X Resistance).

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

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

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

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

Type SZ Sensors

Type SZ sensors can be used with other millivolt recorders or data loggers by connecting a resistor across the leads of the coaxial cable. Choosing the value of the resistor is important, since it can affect the operation of the sensor. Choosing a resistance that is too large can result in a non-linear response from the sensor. The value of the resistor used in LI-COR millivolt adapters and the maximum recommended output for each sensor (in millivolts) is shown in Table 3-2.

Table 3-2. Recommended resistor values for "SZ" type sensors

Sensor	Resistance	Maximum Output
LI-190SZ	604 Ohm	10 mV/2000 µmol s^{-1} m^{-2}
LI-200SZ	147 Ohm	10 mV/1000 W m^{-2}

Sensor output when using a resistor with type SZ sensors is computed using "Ohms Law" as described above.

Type SL Sensors

Type "SL" sensors are available for the LI-190, LI-191, LI-200, and LI-210 Sensors. The Type SL Sensor produces a standardized millivolt output, and may be used in place of the Type SA Sensor and Millivolt Adapter. Table 3-3 shows the standardized output for type "SL" sensors.

Table 3-3. Standardized output for "SL" type sensors

Sensor	Standardized Output
LI-190SL	10 mV/2000 µmol s^{-1} m^{-2}
LI-191SL	10 mV/2000 µmol s^{-1} m^{-2}
LI-200SL	10 mV/1000 W m^{-2}
LI-210SL	10 mV/100 klux

Section 4. Cosine Response and Error

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 4-1A) and at an angle of 60° from normal (Figure 4-1B). Figure 4-1A 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°) per unit area
3 = (6) (0.5) per unit area

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

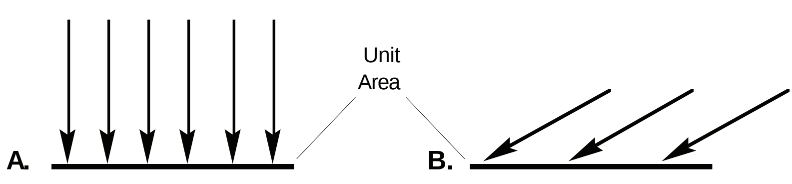


Figure 4-1. *Lambert's Cosine Law.*

Cosine Correction Properties

Cosine corrected LI-COR terrestrial type sensors are all (with the exception of the LI-191 Line Quantum Sensor) designed for the same cosine response characteristics. The percent of true cosine response is presented in Figure 4-2. 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.

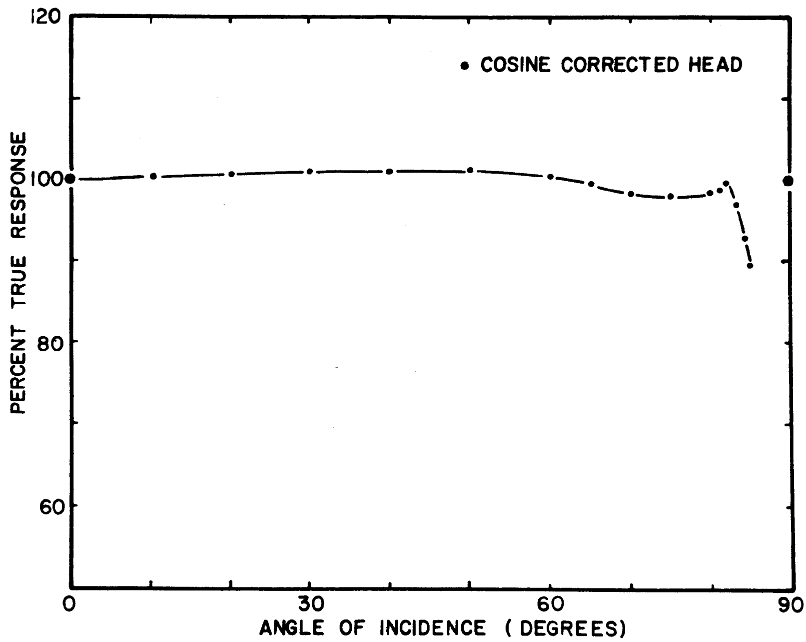


Figure 4-2. *Cosine response of LI-COR terrestrial type sensors.*

LI-191 Cosine Correction Properties

Due to the large non-symmetrical sensing area of 1 meter by 12.7 mm, the LI-191 cannot be compensated completely for true cosine response. Figure 4-3 shows the approximate cosine error for collimated light at angles of incidence from 0° (normal) to 90°.

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.

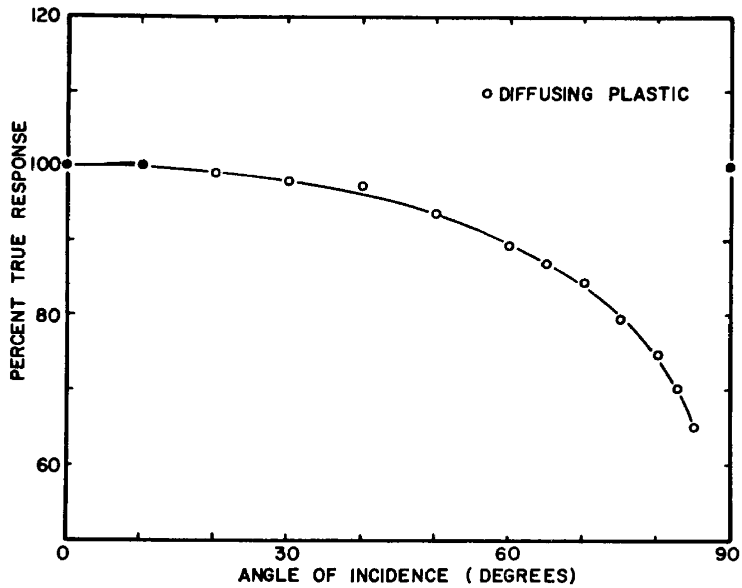


Figure 4-3. *Cosine Response of LI-191 Line Quantum Sensor*

Section 5. Factory Calibration Procedures

LI-190 Quantum Sensor

The LI-190 calibration is obtained at LI-COR 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 ± 5%.

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

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

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

LI-191 Line Quantum Sensor

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

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-200 Pyranometer

The LI-200 Pyranometer is calibrated against an Eppley Precision Spectral Pyranometer (PSP) of which the calibration is periodically confirmed. The calibration is performed under daylight conditions by a computer sampling of instantaneous readings from the Eppley and LI-COR pyranometers. Instantaneous paired sensor and reference readings are taken every minute throughout the day for several days. Manual and statistical methods are used to select data from which the calibration constant is derived. The uncertainty of calibration is ± 5%.

LI-210 Photometric Sensor

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

All LI-COR photometric sensors are calibrated using 683 lumens per watt as the value of spectral luminous efficacy at a wavelength of 555 nm. This value conforms to the recommendations of the International Committee for Weights and Measures (CIPM).

Section 6. Using Quantum Sensors

Terrestrial Quantum Sensors

LI-190 Quantum Sensor

The LI-190 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 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-191 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-191 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-191 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 is sealed against moisture (except the BNC connector); *the sensor should be mounted, however, so that water does not pool around the sensor.*

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

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

The LI-191 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!

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-191 is comparable to that of the LI-190 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 1-1.

Section 7. Using Pyranometers

LI-200 Pyranometer

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 1-2) 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.

LI-200 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 1-2. 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.

References, Section 11

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.

Section 8. Using Photometric Sensors

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.

References, Section 11

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 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 4π lumens.

A radiant source may be evaluated in terms of luminous flux if the radiant energy distribution of the source is known. If W(λ) 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(λ) represents the luminosity coefficient as a function of wavelength and dλ 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-210 Photometric Sensor compared to the C.I.E. standard observer curve is presented in Figure 1-2. LI-COR has had sensor calibration data verified by the National Research Council of Canada (NRC), one of the major standards laboratories in the world.

Section 9. Cleaning and Maintenance

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.

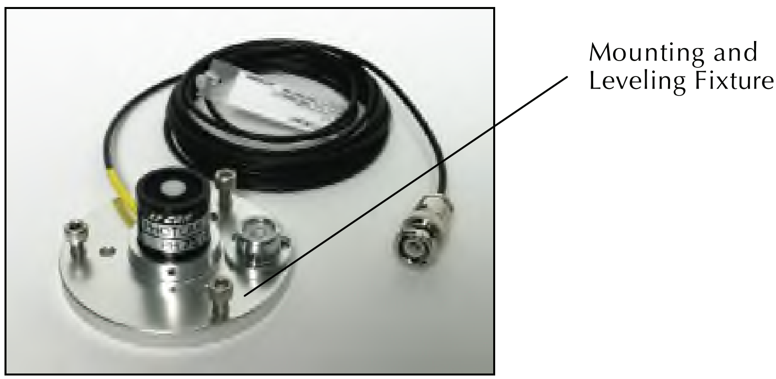
Keep the sensors clean and treat them as a scientific instrument in order to maintain the accuracy of the calibration. The vertical edge of the diffuser must be kept clean in order to maintain appropriate cosine correction.

Section 10. Sensor Accessories

Accessories for Terrestrial Sensors

2003S Mounting and Leveling Fixture

The 2003S is for use with LI-COR terrestrial type sensors (2.38 cm Dia.). The base is anodized aluminum with stainless steel leveling screws and a weatherproof spirit level.



2222SB Extension Cable

This cable is for use with LI-COR terrestrial type sensors. Standard length is 15.2 m (50 ft.). A 100 ft. (30.4 m) cable is also available under p/n 2222SB-100. Cable lengths up to 1000 feet can be used with LI-COR readout instruments.

Millivolt Adapters

Used for connecting sensors to other manufacturer's datalogger or stripchart recorder.

2290 Millivolt Adapter

For the LI-190SA Quantum Sensor, LI-191SA Line Quantum Sensor, or LI-210SA Photometric Sensor (604 Ohm resistance).

2220 Millivolt Adapter
For the LI-200SA Pyranometer Sensor (147 Ohm resistance).

2291 Millivolt Adapter
For the LI-192SA Underwater Quantum Sensor or LI-193SA Spherical Quantum Sensor (1210 Ohm resistance).

Section 11. References and Bibliography

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.

Bibliography

Combs, W.S., Jr. 1977. The measurement and prediction of irradiance available for photosynthesis by phytoplankton in lakes. University of Minnesota Ph.D. Thesis, Limnology.

Incoll, L.D., S.P. Long and M.R. Ashmore. 1977. SI units in publications in plant science. Commentaries in Plant Science (No. 28). Published in: Current Adv. Plant Science 9:331-343.

Jerlov, N.G. 1968. Optical Oceanography. Elsevier.

McCree, K.J. 1979. Radiation.

NBS Technical note 910-1, 1976. Self-study manual on optical radiation measurements.

Shibles, R. 1976. Committee Report: Terminology pertaining to photosynthesis. Crop Sci. 16: 437-439.

Tyler, J.E., and R.W. Preisendorfer. 1962. Light in the sea, p. 399-400. In M.N. Hill (ed.), The Sea, V.I. Interscience.

Appendix A. Specifications

LI-190 Specifications

Absolute Calibration: ± 5% traceable to the U.S. National Institute of Standards and Technology (NIST).
Sensitivity: Typically 5 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.) standard. 50 ft. cable length available.
Accessories: 2003S Mounting and Leveling Fixture, 2222SB Extension Cable.

LI-191 Specifications

Absolute Calibration: ± 10% traceable to NIST. The LI-191 is calibrated via transfer calibration using a reference LI-190 Quantum Sensor. Transfer error is ± 5% (included in the ± 10%).
Sensitivity: Typically 7 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.)
Accessories: 2222SB Extension Cable.

LI-200 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 90 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.).
Cable Length: 3 meters (10 ft) standard. 50 ft. cable length available.
Accessories: 2003S Mounting and Leveling Fixture, 2222SB Extension Cable.

LI-210 Specifications

Absolute Calibration: ± 5% traceable to NIST.
Sensitivity: Typically 30 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.

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®
Biosciences

4421 Superior Street ● P.O. Box 4425 ● Lincoln, NE 68504 USA
North America: 800-447-3576 ● International: 402-467-3576 ● FAX: 402-467-2819
In Germany - LI-COR GmbH: +49 (0) 6172 17 17 771
envsales@licor.com ● envsupport@licor.com ● www.licor.com

984-08308