US-SQS
Spherical Micro Quantum Sensor

Instruction Manual

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1 Safety Instructions

1.1 General Safety Instructions

1. Read the safety instructions and the operating instructions before using the instrument.
2. Pay attention to all the safety warnings.
3. Keep electronic parts of the device away from water or high moisture areas.
4. Keep the device away from dust, sand and dirt.
5. Always ensure there is sufficient ventilation.
6. Do not put the device anywhere near sources of heat.
7. Connect the device only to the power source indicated in the operating instructions or on the device.
8. Clean the device only according to the manufacturer’s recommendations.
9. Ensure that no liquids or other foreign bodies can find their way inside the device.
10. The device should only be repaired by qualified personnel.

2 Introduction

The Spherical Micro Quantum Sensor US-SQS is designed to measure photosynthetically active radiation (PAR) in suspension cuvettes, and specifically the photosynthetic photon fluence rate (PPFR, *see* chapter 7). The sensor consists of a 3.7 mm Ø highly scattering plastic sphere, which detects light from all directions. It is connected to a 2 mm Ø plastic fiber, which guides the light to a blue enhanced silicon photodiode equipped with a special filter set for the selection of photosynthetically active radiation between 380 nm and 710 nm.

The US-SQS/L basic sensor comes with a 3 m coaxial cable and a BNC connector. It is connectable to any data logger with micro-Ampere current measuring function. WALZ offers the ULM-500 (Universal Light Meter 500) for data acquisition.

In conjunction with various mechanical and electrical accessories the US-SQS is suitable for different applications and instruments.

3 Sensor Characterization

3.1 Spectral Response

Figure 1a shows the typical response between 350 nm and 1100 nm of an US-SQS sensor. The solid line shows the ideal response of a photon fluence sensor for photosynthetically active radiation (PAR, defined for the 400-700 nm wavelength range; for definitions see chapter 7). For comparison Figure 1b, shows the absolute response to energy fluence rate from 350-750 nm.

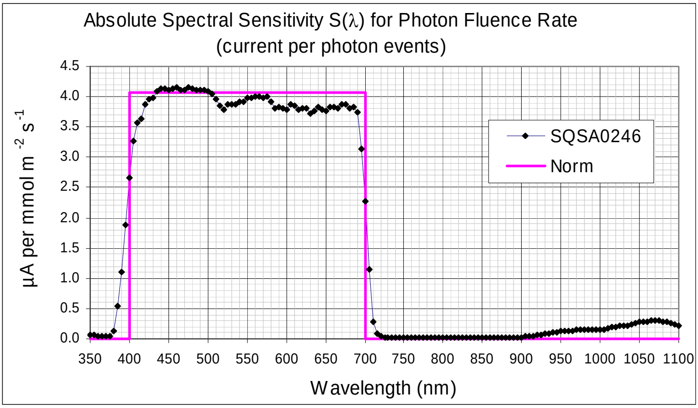


Fig. 1a: Absolute spectral sensitivity for Photon Fluence Rate

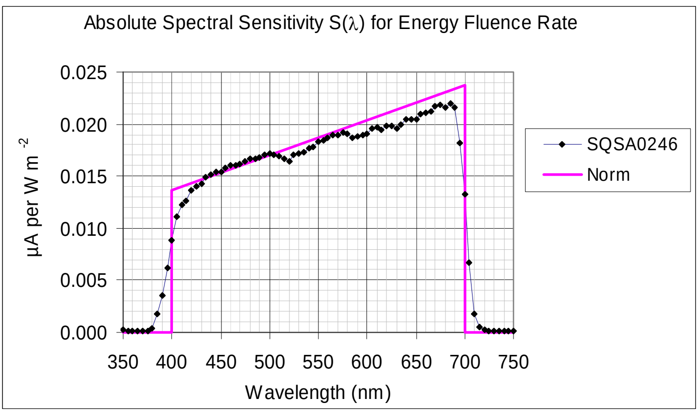


Fig. 1b: Absolute spectral sensitivity for Energy Fluence Rate

3.2 Angular Response

The US-SQS sensor uses a plastic diffuser to obtain an angular response error of less than ± 5 % (-100°..100° angle).

Figure 2 shows a typical angular response curve.

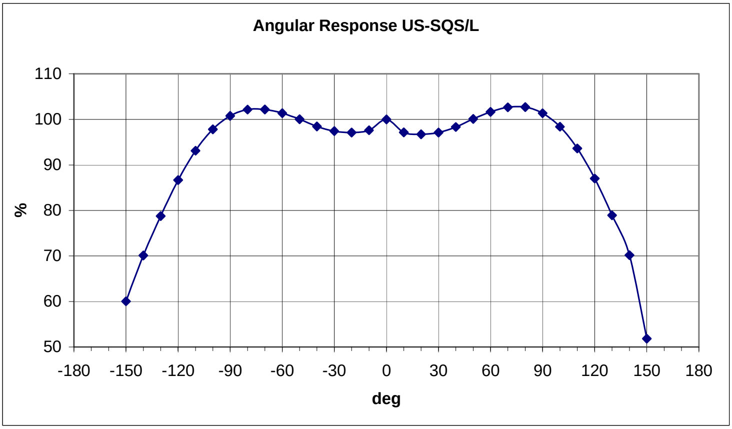


Fig. 2: Angular response

3.3 Immersion Effect

Because of the different refraction indices of air and water, the calibration constant of the US-SQS in water differs from that in air. This phenomenon is known as the immersion effect. The air/water ratio of the calibration constant is equal to the sensor output in air divided by the sensor output in water for the same radiation.

The immersion effect correction factor was determined experimentally according to Roemer and Hoagland (1976).

A collimated beam was directed perpendicularly upon the sensor. The response of the sensor was recorded in air and in distilled water at discrete water depths.

The response in water relative to the response in air in dependence of depth was fitted with a least squares regression line and extrapolated to a depth of 0 mm (see Fig. 3).

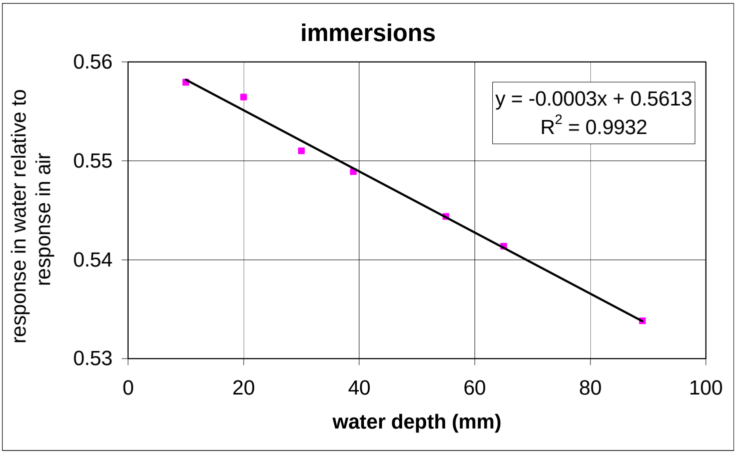


Fig. 3: Determination of immersion factor

The obtained relative response for zero depth was corrected for 2% radiation loss at the air-water interface. The reciprocal of the obtained value results in the immersion correction factor given in the calibration certificate. For example for the regression line shown in Fig. 3 the immersion correction factor is 1.75.

For more information on the dependence of the immersion factor on the refraction index *see* Austin (1976) and the refraction index of the sea water, *see* Austin and Halikas (1976).

The immersion factor in the calibration certificate is given for distilled water.

4 Calibration

4.1 Calibration Procedure

US-SQS sensors are calibrated using a LI-COR working standard calibration lamp. The LI-COR standard lamp has been calibrated against a reference standard lamp traceable to the National Institute of Standards and Technology USA (NIST). The lamp is a 200 W tungsten halogen lamp operated at a color temperature of 3150° Kelvin. The lamp is mounted in a LI-COR optical radiation calibrator Model 1800-02. Calibration accuracy of the optical radiation calibrator is ± 4 % from 350-1000 nm.

Spectral sensitivity is calibrated using a Bentham TMc300F Monochromator system and a reference diode. The reference diode is calibrated against a standard diode traceable to the NIST. Accuracy from 380 - 900 nm is ± 5 %.

The calibration constant given in the calibration sheet, takes into account the spectral difference between the calibration lamp and natural sun light. The spectrum used for natural sun light is ASTM G-173-03-global tilt (ISO 9845-1, 1992). As a result the reading for the PPFR value is most accurate in natural sun light.

4.2 Calibration Certificate

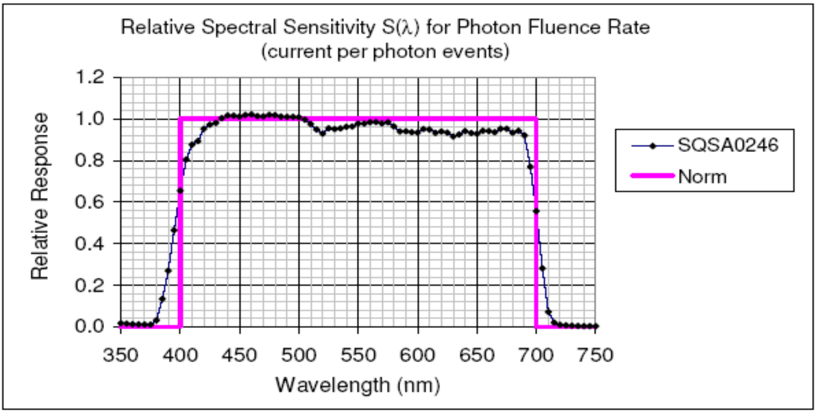
Every US-SQS is accompanied by a certificate. Figure 4 shows a typical certificate of calibration.

The Calibration Multiplier given in the certificate is the value that needs to be entered into the ULM-500 for the direct reading of PPFR values in calibrated units: µmol m^{-2} s^{-1}.

There are two Calibration Multipliers given, one for the usage in air, the other for the usage in water.

CERTIFICATE OF CALIBRATION

Sensor Type	**US-SQS/L**	
Serial Number	**SQSA0246**	
Order Number	**A07-00382**	
Calibration Constant AIR:	**4.06**	**µA per 1000 µmol m^{-2} s^{-1}**
Calibration Multiplier AIR:	**-246.02**	**µmol m^{-2} s^{-1} per µA**
Calibration Const. WATER (aq. dest.):	**2.39**	**µA per 1000 µmol m^{-2} s^{-1}**
Calibration Mult. WATER (aq. dest.):	**-418.23**	**µmol m^{-2} s^{-1} per µA**



Calibration References

Immersion Factor (aqua dest.)	1.7	
Calibration Lamp	ORL1202	
PPFD of CAL-lamp	213.5	µmol m^{-2} s^{-1}
Monochromator Serial Number	TMc300 6055	
Reference Diode Serial Number	MD-37SiUV33 4737	
Date of Calibration	15.10.07	

By

Alfred Dauer

Please consult the instruction manual for further information on the calibration constant and calibration multiplier. Recalibration is recommended every two years.

Fig. 4a: First page of a typical calibration certificate

Numerical Values of Spectral Sensitivity

(nm)	μA/(mmol m^{-2} s^{-1})
350	7.24E-02
355	6.21E-02
360	5.41E-02
365	4.78E-02
370	4.23E-02
375	4.26E-02
380	1.30E-01
385	5.46E-01
390	1.09E+00
395	1.89E+00
400	2.66E+00
405	3.27E+00
410	3.56E+00
415	3.63E+00
420	3.87E+00
425	3.95E+00
430	3.99E+00
435	4.08E+00
440	4.13E+00
445	4.13E+00
450	4.11E+00
455	4.14E+00
460	4.16E+00
465	4.12E+00
470	4.12E+00
475	4.14E+00
480	4.14E+00
485	4.11E+00
490	4.11E+00
495	4.11E+00
500	4.10E+00
505	4.05E+00
510	3.96E+00
515	3.86E+00
520	3.78E+00
525	3.88E+00
530	3.87E+00
535	3.88E+00
540	3.91E+00
545	3.91E+00
550	3.97E+00
555	3.97E+00
560	4.00E+00
565	4.01E+00
570	3.98E+00
575	4.00E+00
580	3.92E+00
585	3.82E+00
590	3.82E+00
595	3.80E+00
600	3.79E+00
605	3.86E+00
610	3.86E+00
615	3.79E+00
620	3.82E+00
625	3.80E+00
630	3.72E+00
635	3.76E+00
640	3.83E+00
645	3.79E+00
650	3.77E+00
655	3.83E+00
660	3.83E+00
665	3.81E+00
670	3.87E+00
675	3.87E+00
680	3.80E+00
685	3.83E+00
690	3.74E+00
695	3.13E+00
700	2.26E+00
705	1.14E+00
710	2.92E-01
715	8.22E-02
720	4.14E-02
725	2.98E-02

(nm)	μA/(mmol m^{-2} s^{-1})
730	2.42E-02
735	1.85E-02
740	1.43E-02
745	1.39E-02
750	1.53E-02
755	1.69E-02
760	1.82E-02
765	1.89E-02
770	1.91E-02
775	1.89E-02
780	1.83E-02
785	1.77E-02
790	1.74E-02
795	1.74E-02
800	1.76E-02
805	1.80E-02
810	1.86E-02
815	1.95E-02
820	2.05E-02
825	2.15E-02
830	2.23E-02
835	2.33E-02
840	2.44E-02
845	2.56E-02
850	2.68E-02
855	2.79E-02
860	2.86E-02
865	2.92E-02
870	2.95E-02
875	2.89E-02
880	2.71E-02
885	2.47E-02
890	2.36E-02
895	2.42E-02
900	2.71E-02
905	3.30E-02
910	4.09E-02
915	5.07E-02
920	6.12E-02
925	7.15E-02
930	8.16E-02
935	9.27E-02
940	1.04E-01
945	1.14E-01
950	1.21E-01
955	1.26E-01
960	1.33E-01
965	1.38E-01
970	1.42E-01
975	1.46E-01
980	1.47E-01
985	1.49E-01
990	1.53E-01
995	1.53E-01
1000	1.53E-01
1005	1.60E-01
1010	1.74E-01
1015	1.89E-01
1020	2.00E-01
1025	2.09E-01
1030	2.18E-01
1035	2.25E-01
1040	2.41E-01
1045	2.64E-01
1050	2.75E-01
1055	2.82E-01
1060	2.88E-01
1065	2.95E-01
1070	2.97E-01
1075	2.98E-01
1080	2.91E-01
1085	2.80E-01
1090	2.63E-01
1095	2.43E-01
1100	2.13E-01

Fig. 4b: Second page of a typical calibration certificate

For a particular light source with known spectrum, the accuracy of the reading can be increased by using the supplied information for the relative sensitivity ($S(\lambda)$).

For example for an LED light with a narrow spectrum peaking at 640 nm the correction can be done as follows: If the reading is 1000 µmol m^{-2} s^{-1} divide the reading by 0.93 (see graph in Fig. 4a) resulting in 1073 µmol m^{-2} s^{-1}.

5 Making Measurements

5.1 General Information

Before you start the measurement, connect the sensor to your display or data-logging device and remove the clear acrylic protection shield. Make sure the calibration factor is entered correctly in the data logger, when using the US-SQS/L or US-SQS/IB (see below). The US-SQS/WB and the US-SQS/B come with an amplifier. The sensor specific calibration factor is set within this amplifier during manufacturing and can not be changed by the user (see below).

5.2 PAM Applications

The basic sensor US-SQS/L can be combined with special amplifiers for different PAM instruments. For PAM applications with suspension cuvettes, we provide a version with an adjustable black hood.

5.2.1 US-SQS/L

The US-SQS/L consists of the sensor with a 3 m cable and BNC connector. It can be connected to the ULM-500 or other data loggers.

5.2.2 US-SQS/IB

The US-SQS/IB has an adjustable black hood. The ULM-500 or another external data logger is required. The US-SQS/IB is recommended for the use with a PAM-100 or XE-PAM.

5.2.3 US-SQS/WB

The US-SQS/WB has a hood and an amplifier box. With this amplifier box the light sensor can be connected to several PAM instruments. Technically the connection for the US-SQS/WB is the same as for the leaf-clip holder 2030-B. In particular the possible connections are:

PAM Control Unit of WATER-PAM (Aux Input),
PDA-100 of PAM-100 or XE-PAM (Aux Input),
Dual-PAM-100 (AUX),
ULM-500 (AUX)

but also:

PAM-2100 (Leaf Clip),
Mini-PAM (Leaf Clip)

The amplifier of the US-SQS/WB is adjusted to the particular calibration factor of the sensor for the use in water. Therefore the displayed values are only correct, if the sensor is submersed in water. This is always the case, no matter whether the sensor is connected to a PAM-Control Unit or Mini-PAM.

The displayed value is 0 to 20 000 µmol m^{-2} s^{-1} PAR, if the switch is set to x1. The setting x10 amplifies the signal and displayed value ten-fold and can only be used for low light intensities (0...100 µmol m^{-2} s^{-1}). Above 100 µmol m^{-2} s^{-1} the setting x10 leads to erratic data readings.

5.2.4 US-SQS/B

The US-SQS/B has a hood and an amplifier box, which contains a battery.

It can be connected to the Phytoplankton Analyzer PHYTO-PAM. The US-SQS/B connects to the AUX-INPUT port on the front side of the Power-and-Control-Unit.

The amplifier of the US-SQS/B is adjusted to the particular calibration factor of the sensor for the use in water. Displayed values are only correct, if the sensor is submersed in water.

5.2.4.1 Exchanging Battery

For exchanging the battery, unscrew all four screws at the top of the amplifier-housing. Take out the battery. Exchange it and put everything back together.

5.2.5 Black Hood for Suspension Cuvettes

The adjustable black hood for suspension cuvettes has two configurations: with or without inner ring. With inner ring, it fits the Emitter-Detector Unit PHYTO-ED for round cuvettes. Without inner ring, it fits the Optical Unit for Suspensions ED-101US/MD for squared cuvettes.

To remove the inner ring, unscrew the indicated screws. Afterwards use the screws to fix the upper plate to the threaded holes of the hood.

The threaded holes of the hood are in a 90° position to the unthreaded holes.

The hood is provided with a small positioning help, which can be left on the shaft of the sensor, when the hood is removed.

6 Cleaning Information

Do not use organic solvent, abrasives or strong detergents to clean the diffuser. Clean the sensor only with water and/or a mild detergent such as dish washing soap or mild diluted window cleaner. Never use acetone.

7 Terminology

PAR: Photosynthetically Active Radiation

Photosynthetically active radiation is usually defined as radiation between 400 and 700 nm. Radiation can be used energy based (W) or photon event based (µmol/s). In photosynthesis most effects are dependent on the amount of photons rather than the energy incident on the system. Therefore, we characterize the sensors in photon event based units (µmol/s).

Sometimes PAR has been used weighted according to the plant's photosynthetic response similar to the unit lux, which is weighted according to the standard human eye's sensitivity. We do not use PAR weighted, (*see* norm-curve in Fig. 1), because PAR is expressed in SI-units, which is not weighted per definition. Furthermore, correct weighting would depend on the pigmentation of the organism, which varies between different plants and between different types of phytoplankton in particular.

Photon Flux

Number of photons per time interval (Braslavsky, 2007). Unit: s^{-1} or µmol s^{-1}

Photon Irradiance

Number of photons per time interval incident from all upward directions on a small element of surface containing the point of consideration divided by the area of the element (Braslavsky, 2007). The term "all upward directions" expresses the fact that the receiver is not a sphere but a flat surface and only beams from one hemisphere take effect, of which beams not perpendicular to the surface only contribute with the cosine of the angle between the beam and the surface normal. Unit: µmol m^{-2} s^{-1}.

PPFD: Photosynthetic Photon Flux Density.

The term photon flux density is often used equivalent to photon irradiance (see above for exact definition, compare Björn 2008).

The photosynthetic photon flux density is restricted to the range of wavebands between 400 and 700 nm. Unit: µmol m^{-2} s^{-1}.

PPFD is measured with cosine corrected sensors having a plane surface (e.g. the Micro quantum sensor MQS).

PPFR: Photosynthetic Photon Fluence Rate.

The photon fluence rate is defined as total number of photons incident per time interval from all directions on a small sphere divided by the cross-sectional area of the sphere (Braslavsky, 2007). It has also been called photon spherical irradiance, scalar irradiance or photon flux fluence rate.

The photosynthetic photon fluence rate is restricted to the range of wavebands between 400 and 700 nm. Unit: µmol m^{-2} s^{-1}

PPFR is measured with spherical sensors.

8 Literature

Austin R.W. (1976) Air-water radiance calibration factor. Scripps Institution of Oceanography, La Jolla, CA. Tech. Memo. ML-76-004T 8 pp.

Austin R.W. and Halikas G. (1976) The index of refraction of seawater. Scripps Institution of Oceanography, La Jolla, CA. SIO Reference 76-1, 64 pp.

Björn L.O. (2008) Principles and nomenclature for the quantification of light (chapter 2). In: Photobiology. The Science of Life and Light. Springer-Verlag, Berlin, Heidelberg, New York, 42-49

Braslavsky S.E. (2007) Glossary of terms used in photochemistry, 3rd edition (IUPAC Recommendations 2006). Pure and Applied Chemistry 79, 293-465

Roemer S.C. and Hoagland K.D. (1976) Immersion effect and cosine collecting properties of Li-Cor underwater sensors. School of Life Sciences, University of Nebraska, Lincoln, Nebraska 11pp.

9 Technical data

Table 1: Technical data, of the sensor itself (US-SQS/L, US-SQS/IB, US-SQS/WB, US-SQS/B)

Design of sensor:	3.7 mm Ø white plastic diffusing sphere connected via 2 mm Ø plastic fiber to detector
Signal detection:	High stability silicon photovoltaic detector (blue enhanced) with filter set for PAR correction (380 – 710 nm)
Response time of photodiode	Rise and fall time of photocurrent (R_L=50 Ω, V_R= 5V; λ=850nm I_P=800µA): 25 ns
Temperature coefficient of photodiode	0.18% / K
Absolute calibration	in air, with correction for the spectral difference between the calibration lamp and sun light: ±5%
Angular Response	< 5% error up to 100° from normal axis
Azimuth	< 5% error over 360° at 90° from normal axis
Sensor Housing	stainless steel
Power supply:	not required
Operating temperature:	- 5 °C ... + 45 °C
Submersible:	up to 2.8 m (the sensor plus its cable, not the connector)

Subject to change without prior notice.

Table 2: Technical data of the different sensor setups

Setup:	**US-SQS/L**	**US-SQS/IB**	**US-SQS/WB**	**US-SQS/B**
Application:	ULM-500 or Datalogger	Suspension cuvette PAM-100 or XE-PAM, requires additional data logger**:**	WATER-PAM PAM-100 (PDA-100) XE-PAM (PDA-100) Dual-PAM-100	PHYTO-PAM
Accessories		Hood for suspension cuvette	Hood for suspension cuvette, Amplifier for Aux. Input	Hood for suspension cuvette, Amplifier for Aux. Input, Amplifier-box contains battery
Signal outputs (analog output):	typical 3.5 µA / 1000 µmol $m^{-2}s^{-1}$ in air	typical 3.5 µA/1000 µmol $m^{-2}s^{-1}$ in air	Setting x1: 0...2.5 V DC / 0...1000 µmol $m^{-2}s^{-1}$ or 0...2.5 V DC / 0...20.000 µmol $m^{-2}s^{-1}$ automatic adjustment Setting x10: 0...2.5 V DC / 0...100 µmol $m^{-2}s^{-1}$	0...2.3 V DC / 0...172.5 µmol $m^{-2}s^{-1}$ 0...2.3 V DC / 0...3450 µmol $m^{-2}s^{-1}$ automatic adjustment
Cable length:	3 m	3 m	3 m + 0.5 m	3 m + 1.5
Size: (L * W * H)	Ø 1 x 11 cm	sensor Ø 1 x 11 cm hood Ø 3.4 x 3.2 cm	sensor Ø 1 x 11 cm hood Ø 3.4 x 3.2 cm amplifier: 5 x 5 x 3 cm	sensor Ø 1 x 11 cm hood Ø 3.4 x 3.2 cm amplifier: 10.5 x 5.5 x 4.5 cm
Weight:	62 g	85 g	175 g	450 g

Subject to change without prior notice.

10 Warranty conditions

All products supplied by the Heinz Walz GmbH, Germany, are warranted by Heinz Walz GmbH, Germany to be free from defects in material and workmanship for one (1) year from the shipping date (date on invoice).

The warranty is subject to the following conditions:

1. This warranty applies if the defects are called to the attention of Heinz Walz GmbH, Germany, in writing within one year (1) of the shipping date of the product.
2. This warranty shall not apply to any defects or damage directly or indirectly caused by or resulting from the use of unauthorized replacement parts and/or service performed by unauthorized personnel.
3. This warranty shall not apply to any product supplied by the Heinz Walz GmbH, Germany which has been subjected to misuse, abuse, abnormal use, negligence, alteration or accident.
4. This warranty does not apply to damage caused from improper packaging during shipment or any natural acts of God.
5. This warranty does not apply to underwater cables, connectors, batteries, fiberoptic cables, lamps, gas filters, thermocouples, fuses or calibrations.

To obtain warranty service, please follow the instructions below:

1. The Warranty Registration form must be completed and returned to Heinz Walz GmbH, Germany.
2. The product must be returned to Heinz Walz GmbH, Germany, within 30 days after Heinz Walz GmbH, Germany has received written notice of the defect. Postage, insurance, custom duties, and/or shipping costs incurred in returning equipment for warranty service are at customer expense.
3. All products being returned for warranty service must be carefully packed and sent freight prepaid.
4. Heinz Walz GmbH, Germany is not responsible or liable, for missing components or damage to the unit caused by handling during shipping. All claims or damage should be directed to the shipping carrier.