Resources

Overview: Resources

Our Know-how = More Resources for You

Find out more about our products, experience and support through the following:

Live Demonstrations
Each year we exhibit at nearly 50 trade shows around the world (OceanOptics.com/TradeShows.asp). At home, we conduct formal seminars and can customize training sessions to your requirements.

Science Curricula
Our *Educational Spectroscopy Grant Program* rewards educators and researchers for their use of spectroscopy in curricula or research. Information about grant-winning projects is posted at OceanOptics.com/Applications/GrantWinners.asp.

R&D Services
Our Applications Group will take ownership of your most challenging application needs. The Group provides optical and electronic design services, software engineering and spectral modeling, testing and validation, and rapid prototyping capabilities.

Reference Library
We have amassed nearly 300 technical papers featuring our spectrometers and accessories. Citations are on our website at OceanOptics.com/Applications.asp.

American Standard Robotics in St. Petersburg, Fla., prepares one of their VGTV-Xtreme Reconnaissance Vehicle robots equipped with an Ocean Optics spectrometer to identify the chemical involved in a simulated hazardous-material tanker trailer.

Technical Information on the Web

We believe in easy access to information. That's why we don't hide our prices and that's why we provide easily accessible technical documentation on our website, so that you can view manuals before you buy the instrument. We also include the manufacturer's name and the model number of components that go into our instruments. We want to provide you with all of the information you need not only to make the right purchasing decision, but also to get the best performance out of your Ocean Optics products.

- **OceanOptics.com/Technical.asp.** Choose the TECHNICAL button on our website to view and download information about our products and technology, including manuals and operating instructions, software downloads and system specifications.
- **Operating Instructions.** We provide hundreds of pages of easy-to-access operating instructions and specifications of our products so that you can read before you buy at OceanOptics.com/Technical/OperatingInstructions.asp.
- **Software Downloads.** Easily download the latest operating and application software, device drivers and code, utility programs and microcode at OceanOptics.com/Technical/SoftwareDownloads.asp.
- **Spectrometer System Specifications.** Spectrometer system performance depends on a host of factors, such as the detector, optical bench, grating, entrance aperture size and sampling optics, just to list a few. To help you understand how to configure spectrometer systems, visit OceanOptics.com/Technical/SystemSpecifications.asp.
- **Applications Database.** Choose the APPLICATIONS button from any Ocean Optics webpage to view an up-to-date bibliographic listing of journal and magazine articles that reference our products. Visit OceanOptics.com/Applications/References.asp.

55,000+ Spectrometers, 1,000s of Applications

We've sold over 55,000+ Ocean Optics optical-sensing systems since 1992, which has provided us with a body of applications knowledge that is unmatched in the industry. Our spectrometers are used in applications such as these:

- Air and soil in situ monitoring
- Astronomy
- Biological and chemical warfare agent detection
- Biotechnology
- Blood oximetry
- Cancer detection
- Chemistry
- Color measurement
- Crystal growth
- Display technologies
- Dissolved oxygen
- Elemental analysis
- Endpoint detection
- Exhaust emission analysis
- Flow injection analysis
- Fluorescence of corals
- Food processing
- Forensics
- Gemstone grading
- General R&D
- Headspace monitoring
- Laser characterization
- LED quality control
- Life sciences
- Manufacturing
- Medical research
- Non-destructive testing
- Optical filter transmission
- pH monitoring
- Pharmaceuticals
- Physics/Optics
- Physiological applications
- Plasma monitoring
- Process control
- Radiometry
- Raman spectroscopy
- Reaction kinetics
- Semiconductor processing
- Shelf life of food and beverages
- Stack emissions
- Thin film thickness
- Tissue composition

The ABCs of Absorbance

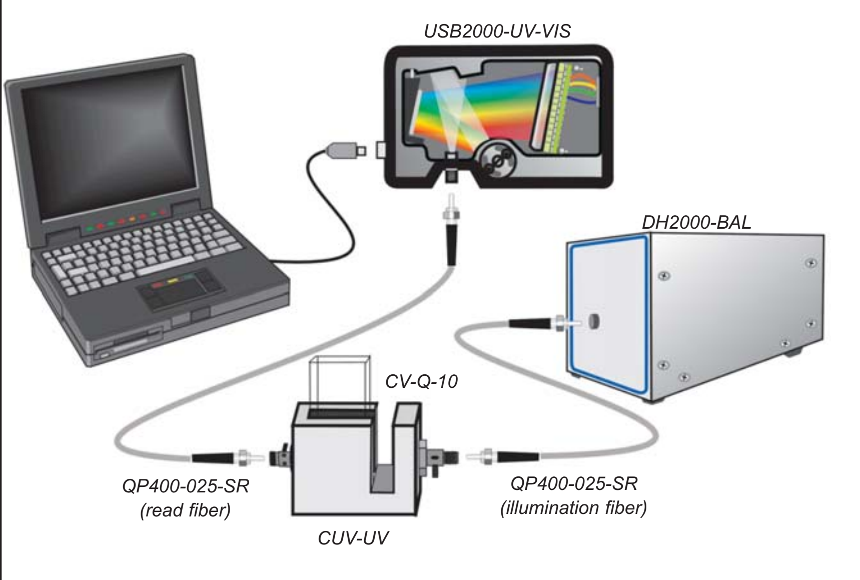
Like thousands of other educators, chemists at Miami (Ohio) University have equipped their labs with Ocean Optics spectrometers and accessories for basic spectroscopic measurements such as solutions absorbance.

Of particular interest is a PC-based setup for measuring the UV-VIS absorption spectrum of iodine crystals from 500-580 nm. This experiment is readily performed using an S2000 Spectrometer, LS-1 Tungsten Halogen Light Source, fiber optic patch cords and a 10-cm pathlength cuvette holder. Substitute a USB2000 Spectrometer (see drawing at right) to eliminate the external A/D card that completes the Miami University system.

Another option is the CHEMUSB2-UV-VIS Lab Spectrophotometer, which consists of a 200-850 nm USB-interface spectrometer, a combination deuterium tungsten halogen light source and 1-cm cuvette holder, high-speed electronics and software.

Solutions absorbance experiments are not limited to cuvette holder setups. Flow cells, on-line dip probes and other sampling optics are available, with the latter especially useful for in situ applications. For example, one Ocean Optics customer uses a UV-VIS spectrometer and dip probe to measure the absorbance of vanadium oxytrichloride (VOCl3), a potentially toxic liquid used in the production of rubber (the absorptivity of VOCl3 relates to its stability). Because the VOCl3 reacts with moisture in the air and forms vanadic and hydrochloric acids, it must be measured in a moisture-free environment. In situ measurements eliminate the need for potentially risky sample collection.

Setup: Solutions Absorbance



Overview

Absorbance measurements are used to quantify the concentration of gases and solutions (the latter is described here) that absorb light in a media that transmits light. The signal in absorbance units is proportional to the molar absorptivity, pathlength and concentration of the sample (see Beer's Law, page 178).

Spectrometer

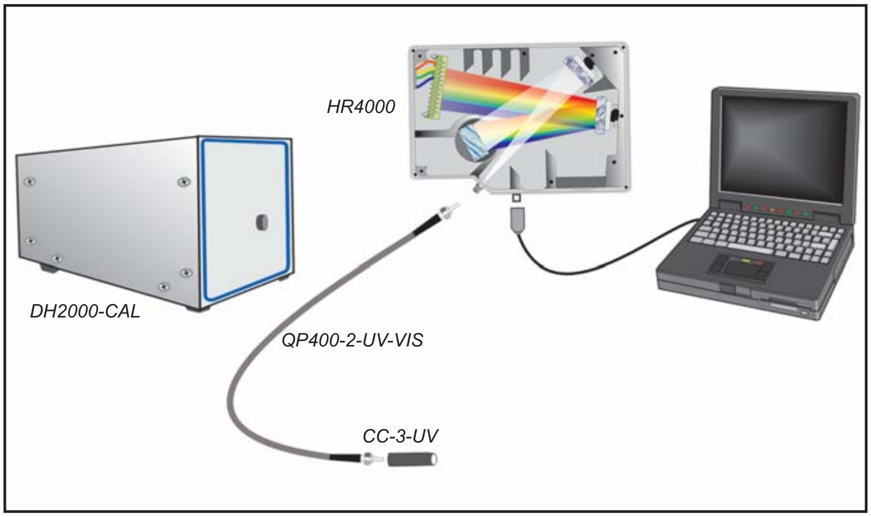
The USB2000-UV-VIS Spectrometer is ideal for absorbance measurements from 200-850 nm. The spectrometer is configured with Grating #1, which has peak efficiency at 300 nm. This configuration provides adequate resolution (~1.5 nm FWHM) for most solutions absorbance measurements. The built-in OFLV-200-850 Order-sorting Filter eliminates second-and third-order effects that otherwise yield false peaks in absorbance spectra. The preferred light source is the DH2000-BAL Deuterium Tungsten Halogen Light Source. The DH2000 is a less expensive source, but lacks the filtering technology that eliminates problems associated with the D-alpha line in the deuterium source.

Sampling Optics

For absolute absorbance measurements, use the 1-cm pathlength CUV-UV Cuvette Holder and the CV-Q-10 Quartz Cuvette. For relative absorbance, direct-attach USB accessories, dip probes and flow cells are available. We recommend QP400-025-SR Premium-grade Solarization-resistant Optical Fibers as illumination and read fibers. Use NIST-traceable STAN-ABS Photometric Absorbance Standards to provide certifiable results.

Components	Page	Price
1. USB2000-UV-VIS General Lab Spectrometer	34	$2,649
Grating #1, 200-850 nm range	44	included
25 μm Slit as entrance aperture	42	included
OFLV-200-850 Order-sorting Filter	43	included
UV2 Detector Upgrade	43	included
2. DH2000-BAL Deuterium Tungsten Halogen Light Source	120	$3,303
3. (2) QP400-025-SR Premium-grade SR Assemblies	140	$238
4. CUV-UV Cuvette Holder	90	$399
5. CV-Q-10 Quartz Cuvette	93	$75
6. STAN-ABS-UV Photometric Absorbance Standards	93	$335
7. SpectraSuite Spectroscopy Platform Software	76	$199
8. ASP Annual Service Package	193	$250
	Total:	**$7,448**

Setup: Upwelling/Downwelling



Overview
Upwelling radiation is radiation -- either reflected solar or emitted terrestrial -- that is directed upward from the earth's surface. Downwelling radiation is radiation that is directed toward the earth's surface from the sun or atmosphere. The relationship between the two (albedo) can be used to derive spectral information from vegetation, forest canopies, seabeds and more.

Spectrometer
An HR4000 Spectrometer with an HC-1 grating provides an elegant solution for upwelling and downwelling measurements. The HC-1 is a variable-blazed grating that covers the 200-1100 nm wavelength range; optical resolution is ~1.5 nm (FWHM) with a 50 μm slit as the entrance aperture. An OFLV-H4 Order-sorting Filter eliminates second- and third-order effects.

Sampling Optics
The spectrometer connects to a patch cord that screws into the CC-3-UV Cosine Corrector. The CC-3-UV can be used as part of a configuration for measuring absolute spectral irradiance. You'll need a DH2000-CAL (or LS-1-CAL for 300-1050 nm only) to calibrate the absolute spectral response of the system and OOIIrrad-C Software to calculate spectral intensity and photopic data in lumens, lux or candela. An alternative to the CC-3-UV is a Gershun tube, which has fixtures for adjusting the area of light from 1° to 28° and attaches directly to the spectrometer or to an optical fiber.

Components	Page	Price
1. HR4000 High-resolution Spectrometer	46	$3,999
Grating HC-1, 200-1100 nm range	52	$600
50 μm Slit as entrance aperture	50	$150
OFLV-H4 Order-sorting Filter	51	$250
UV4 Detector Upgrade	51	$150
2. QP400-2-UV-VIS Premium-grade Patch Cord Assembly	140	$170
3. CC-3-UV Cosine Corrector	144	$129
4. DH2000-CAL Radiometric Calibration Standard	130	$3,148
5. OOIIrrad-C Software (for absolute irradiance measurements)	81	$399
6. SpectraSuite Spectroscopy Platform Software	76	$199
7. ASP Annual Service Package	193	$250
	Total:	**$9,444**

Measuring Mining Effects

In the small Pacific island of New Caledonia, a multinational team of researchers has used Ocean Optics spectrometers to measure the effects of strip mining on coastal erosion, sea grass growth and coral reef health.

The team focused on the relationship between above-water reflectance and turbidity profiles. The latter relates to fluxes in the presence of metals and various pollutants -- and thus, to sea grass growth and coral reef health.

A USB2000 Spectrometer set from 360-1100 nm measures reflectance and irradiance. The USB2000 connects to a patch cord that screws into a Gershun Tube, which has fixtures for adjusting the area of light entering the fiber -- in this case, to reduce the field of view to 3°. Upwelling irradiance and downwelling radiance measurements -- the spectral distribution of the underwater light field -- add valuable data.

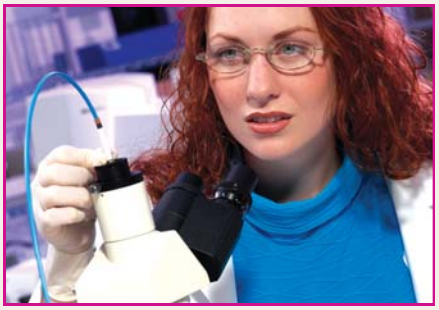
The researchers also have measured the concentration of chlorophyll pigment in coastal waters and the reflectance of sand and mud collected at Caribbean, Mediterranean and Pacific beaches. The sand application used a dual-channel spectrometer for visible (410-900 nm) reflectance measurements of various natural sands. Reflectance spectra were deduced from successive measurements of upwelling irradiance using a Spectralon plate and downwelling radiance captured under natural light.

Ultimately, researchers will use satellite monitoring, spectroradiometric measurements and numerical models to better understand the nature of particulate transport in coral reef lagoons, especially as it relates to erosion rates in coastal areas.

O_2 Medical Diagnostics

Researchers at two Irish universities have monitored dissolved oxygen in cellular media in order to validate the optimum gassing technique to induce hypoxia in irradiated cells.

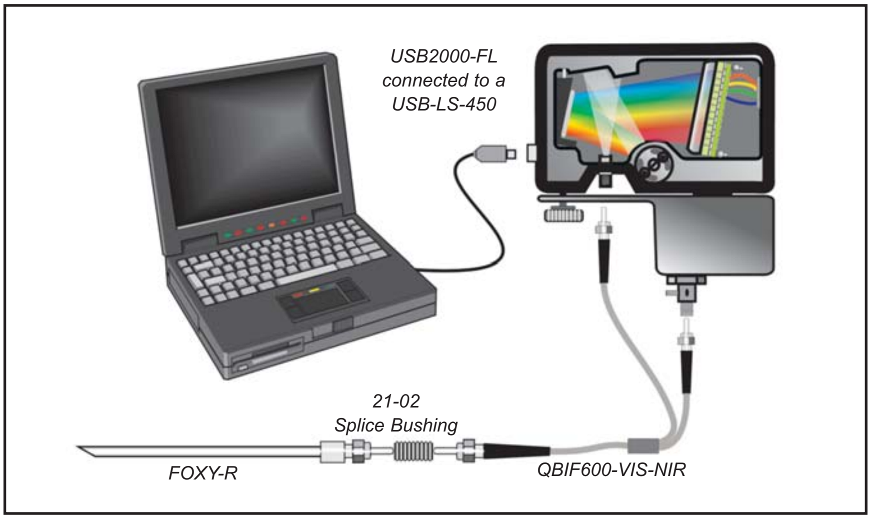
Scientists from University College Cork and Cork University Hospital measured irradiated HeLa cells -- a strain of human cells used for biological studies -- under both oxic (rich in oxygen) and hypoxic (lacking oxygen) conditions. With oxygen present, the irradiation injury to the cells was greater than when optimum levels of hypoxia (~90%) were reached. To induce hypoxia, and thus mitigate any oxygen-enhancement injury, the cells were gassed with nitrogen. This hypoxia was confirmed with a FOXY Fiber Optic Oxygen Sensor and a USB2000 Spectrometer.



The FOXY Sensor has been used for other hypoxia experiments, including an application where clinicians determine how much of a diseased human limb targeted for amputation can be saved; the presence of oxygen correlates to tissue health. Monitoring dissolved oxygen in both human and animal tissue is a common application for the FOXY Sensor, which offers the advantages of being minimally invasive, not consuming the sample, and working well in viscous media.

Ultimately, the cellular hypoxia researchers determined that oxygen measurements of the cellular environment made with the FOXY Sensor matched the predicted hypoxic saturation values, depending on the amount and duration of nitrogen flushed through the sample chamber. The FOXY Sensor proved to be a valuable tool in confirming the desired level of hypoxia.

Setup: Oxygen Sensing



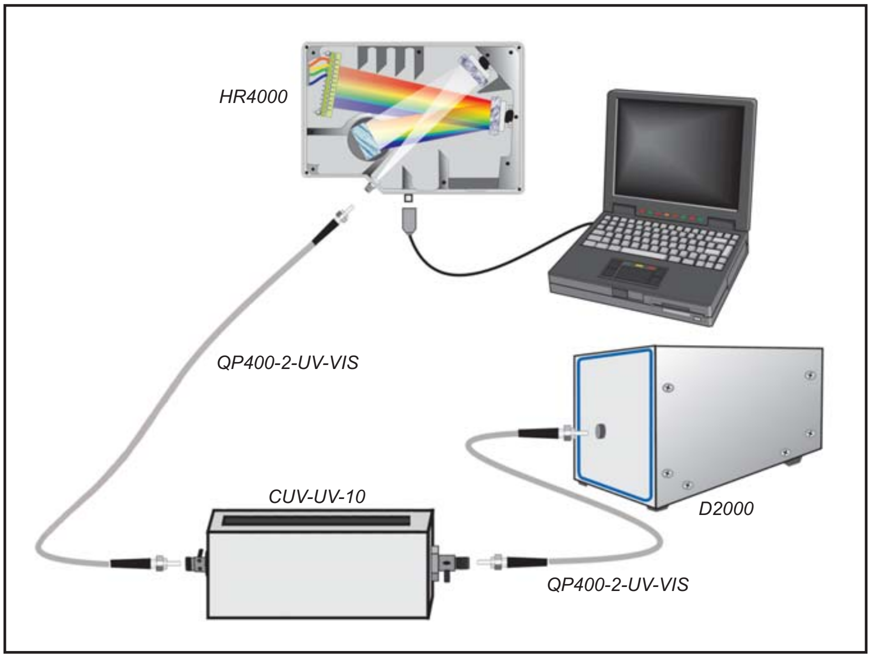
Overview
Oxygen is sensed by measuring the decrease in fluorescence intensity of a fluorophore bound to the tip of an optical fiber. The sensor responds to the partial pressure of oxygen in gases, liquids and even viscous samples.

Spectrometer
Our oxygen-sensing systems include ruthenium-coated probes that use fluorescence quenching to measure the partial pressure of dissolved or gaseous oxygen. For the "typical" oxygen-sensing system we recommend the USB2000-FL-450 Fluorescence Spectrometer, which has a 200 µm Slit and Grating #3 (360-1000 nm), which is blazed at 500 nm. Also included in the optical bench is an L2 Detector Collection Lens to increase light-collection efficiency and reduce stray light.

Sampling Optics
The USB-LS-450 Pulsed Blue LED Excitation Source transmits light at ~475 nm to one leg of a QBIF600-VIS-NIR Bifurcated Optical Fiber Assembly. The bifurcated assembly connects to the oxygen sensor probe -- there are over 12 probes from which to select -- via a 21-02 SMA Splice Bushing. If the excited ruthenium at the probe tip encounters an oxygen molecule, the fluorescence signal decreases. The fluorescence is collected by the probe and is transmitted to the spectrometer via the other leg of the bifurcated assembly. OOISensors Software calculates partial pressure of the oxygen from this signal. For more on sensor operation, see page 65.

Components	Page	Price
1. USB2000-FL-450 Fluorescence Spectrometer (and light source)	33	$3,049
Grating #3, 360-1000 nm range	45	included
200 µm Slit as entrance aperture	42	included
L2 Detector Collection Lens	43	included
2. USB-LS-450 Pulsed Blue LED Excitation Source	129	included
3. QBIF600-VIS-NIR Premium-grade Bifurcated Fiber Assembly	140	$370
4. 21-02 Splice Bushing	156	$13
5. FOXY-R Fiber Optic Oxygen Sensor Probe	66	$499
6. OOISensors Software	81	$199
7. ASP Annual Service Package	193	$250
	Total:	**$4,380**

Setup: Gas Absorbance



Overview

Absorbance measurements are used to quantify the concentration of solutions and gases (as described here) that absorb light in a media that transmits light. The signal in absorbance units is proportional to the molar absorptivity, pathlength and concentration of the sample. (See more on Beer's Law on page 178.)

Spectrometer

A setup for measuring benzene gas, for example, would call for an HR4000 High-resolution Spectrometer with an H7 grating and a 200-300 nm wavelength range. Optical bench accessories include an L4 Detector Collection Lens for increased light throughput, and a UV4 Detector Upgrade to transmit light in the UV. With a 5 μm slit, optical resolution of ~0.07 nm (FWHM) is possible. The preferred light source for work in the ultraviolet is the D2000 Deuterium Light Source.

Sampling Optics

The 10-cm pathlength CUV-UV-10 Cuvette Holder, the CV-Q-10 Cylindrical Cell and QP400-025-SR Premium-grade Solarization-resistant Optical Fibers (one fiber illuminates, the other reads signal) comprise the system's sampling optics. For applications requiring shorter pathlengths or open-air monitoring (see sidebar), use an optical fibers-and-collimating lenses configuration.

Components	Page	Price
1. HR4000 High-resolution Spectrometer	46	$3,999
Grating H7, 2400 lines per mm, 200-300 nm range	52	included
5 μm Slit as entrance aperture	50	$150
L4 Detector Collection Lens	51	$150
UV4 Detector Upgrade	51	$150
2. D2000 Deuterium Light Source	124	$2,003
3. CUV-UV-10 Cuvette Holder	90	$549
4. CV-Q-100 Cylindrical Cell	93	$165
5. (2) QP400-2-UV-VIS Premium-grade Patch Cord Assemblies	140	$340
6. SpectraSuite Spectroscopy Platform Software	76	$199
7. ASP Annual Service Package	193	$250
	Total:	**$7,955**

Volcano Emissions

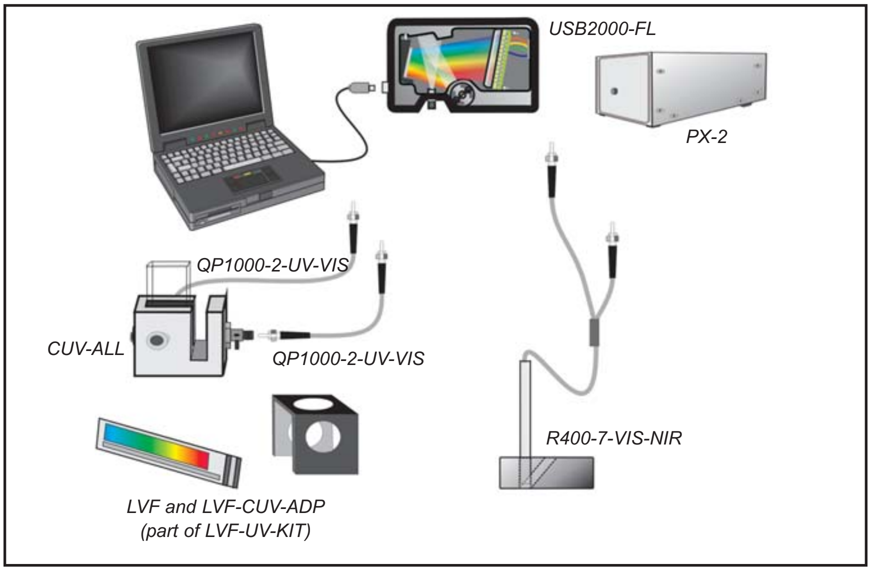
Active volcanoes emit various gases including sulphur dioxide (SO_2), a colorless, pungent gas that can irritate the skin and the mucous membranes of the eyes, nose and throat. Volcanologists regularly monitor SO_2, which absorbs in the UV.

For example, on the Caribbean island of Montserrat, researchers use three S2000 Spectrometers to collect UV absorbance (from 245-380 nm) of SO_2 in gas emissions. The spectrometers are set up at three plume sites, each of which is about 3.5 km from the volcano's dome. The spectrometers are small, making them simple to transport and deploy at the volcano site. The entire setup costs less than $10,000, within most budget limits and almost "disposable" (this is a volcano, after all).

The Montserrat researchers configured a system that makes efficient use of light-collection optics and provides good optical resolution (~3.5 nm FWHM). Each spectrometer is connected to a 1000 μm optical fiber, which screws into a telescope mount.

At the Montserrat Volcano Observatory (www.mvo.ms) sampling sites, spectra are collected every 4-6 seconds and transmitted to researchers at the observatory via modem; one complete scan of the plume takes 4-6 minutes. Depending on wind direction, data from two of the three spectrometers is used to calculate plume height, by comparing the angles at which peaks in the SO_2 plume are measured.

Setup: Fluorescence



Overview

Fluorescence measurements require a sensitive detector and an effective filter for discriminating between powerful excitation source wavelengths and weak spectral emissions from the sample.

Spectrometer

We offer several spectrometers useful for fluorescence, but recommend the high-sensitivity, preconfigured USB2000-FL Spectrometer for most general fluorescence applications. The USB2000-FL is set to 360-1000 nm and comes with a 200-μm slit and an L2 Detector Collection Lens for increased light throughput.

Sampling Optics

Your standard excitation source option is our PX-2 Pulsed Xenon Source. Our proprietary LVF Linear Variable Filters are excellent tools for spectrally shaping the excitation energy from broadband sources used for fluorescence. Various sampling optics are available for detecting picomolar-range concentrations of fluorophores from surfaces and in solutions and powders.

Spectrometer Components	Page	Price
1. USB2000-FL Spectrofluorometer	33	$2,499
Grating #3, 380-1000 nm range	44	included
200 μm Slit as entrance aperture	42	included
L2 Detector Collection Lens	43	included
SAG+UPG Mirrors	44	$250

Components for Use with Solutions	Page	Price
2. PX-2 Pulsed Xenon Source	125	$769
3. CUV-ALL-UV 4-way Cuvette Holder	90	$809
4. LVF-UV-KIT Linear Variable Filter Kit	94	$999
6. (2) QP1000-2-UV-VIS Premium-grade Patch Cord Assemblies	140	$720
7. (2) 74-MSP Mirrored Screw Plugs	90	$198
8. SpectraSuite Spectroscopy Platform Software	76	$199

Components for Use with Solids	Page	Price
2. PX-2 Pulsed Xenon Source	125	$769
3. R400-7-VIS-NIR Reflection/Backscattering Probe	146	$499
4. SpectraSuite Spectroscopy Platform Software	76	$199

All That Glitters . . .

By some accounts, fluorescence of minerals has been observed for more than a century. For early miners, fluorescence of minerals such as calcite helped to target drilling operations to the richest bodies of ore. For amateur geologists, mineral fluorescence is a more esoteric pursuit: samples that fluoresce simply look really cool.

Consider genthelvite, an opaque mineral that fluoresces bright green under UV radiation and remains phosphorescent for a short period. In 2003, mineralogists Earl Verbeek and Herb Yeates measured fluorescence of both genthelvite and willemite (another fluorescent mineral) found in deposits at a site in New Jersey.

In a paper submitted to the Franklin-Ogdensburg Mineralogical Society, Verbeek and Yeates described using a USB2000-VIS-NIR Spectrometer (350-1000 nm), a high-power UV excitation source and a 600 μm probe to observe emission peaks of 511 nm for genthelvite and 528 nm for willemite.

Spectrometer integration times were set for 1000 ms to measure the dim (although visible to the naked eye) genthelvite fluorescence, compared with a 10 ms integration to measure the brighter willemite fluorescence.

To ensure that the light emitted from the samples came from the minerals themselves, Verbeek and Yeates measured the samples in a light-tight enclosure and filtered out excitation source wavelengths and ambient light.

Why does genthelvite fluoresce? Verbeek and Yeates identified the cause as divalent manganese -- a substitute for zinc in the genthelvite structure that is also responsible for the color in amethyst.

Setup: LED Analysis

Overview

To measure the absolute spectral intensity and color of LEDs, specify the configuration described here or see page 16.

Spectrometer

We suggest a USB2000 Spectrometer with a 25 μm Slit and Grating #2 (350-1000 nm). An L2 Detector Collection Lens increases light-collection efficiency and reduces stray light. An OFLV-350-1000 Order-sorting Filter eliminates second- and third-order effects. This optical bench configuration maximizes system sensitivity, mitigating the light loss inherent with use of an integrating sphere -- the sampling optic of choice for most LED applications. (You also can collect LED signal with a CC-3-UV Cosine Corrector and fiber.)

Sampling Optics

The LED is mounted in the NIST-traceable LED-PS-NIST LED Power Supply, which provides a white background for the LED and a controlled drive current to characterize LED output. The FOIS-1 Integrating Sphere is placed over the LED-PS-NIST and collects the LED output. The attached optical fiber collects the light energy from the LED and transmits it to the spectrometer. The power and color of the LED is determined by comparing the LED to a radiant standard -- the LS-1-CAL-INT Calibrated Source, which fits into the sample port of the FOIS-1. OOIIrrad-C Irradiance and Color Software calculates absolute irradiance and spectral features such as dominant, central and centroid wavelength, and colorspace values such as X,Y,Z and L*, a*, b*.

Components	Page	Price
1. USB2000 Plug-and-Play Spectrometer	38	$2,199
Grating #2, 350-1000 nm range	44	included
25 µm Slit as entrance aperture	42	$150
L2 Detector Collection Lens	43	$150
OFLV-350-1000 Order-sorting Filter	43	$150
2. LS-1-CAL-INT Tungsten Halogen Calibrated Light Source	131	$749
3. LED-PS LED Power Supply	107	$499
4. FOIS-1 Integrating Sphere for Emission	108	$499
5. QP400-2-VIS-NIR Premium-grade Patch Cord Assembly	140	$170
6. OOIIrrad-C Irradiance and Color Software	81	$399
7. ASP Annual Service Package	193	$250
	Total:	**$5,215**

QC of LED Curing Lights

High-output LEDs may be a viable alternative to other light sources for curing ceramic materials used in dentistry, according to researchers from the University of Manchester in England.

As researchers Adrian Bennett and David Watts suggested in a 2003 article submitted to the journal *Dental Materials*, LEDs have longer lifetimes, are less prone to degradation and temperature effects, and require less power than tungsten halogen curing units.

To assess LED performance, Bennett and Watts used a radiometrically calibrated USB2000 Spectrometer to measure the absolute spectral output and irradiance of three LED curing units. The spectrometer was radiometrically calibrated using the LS-1-CAL Tungsten Halogen Light Source; a FOIS-1 Integrating Sphere collected the LED output and funneled it to an optical fiber coupled to the spectrometer. The spectral range of the LEDs also was measured.

By most criteria, Bennett and Watts concluded, the LED curing units compared favorably with the tungsten halogen curing units. However, longer curing times may be necessary with LEDs, which have lower irradiance than the tungsten halogen sources.

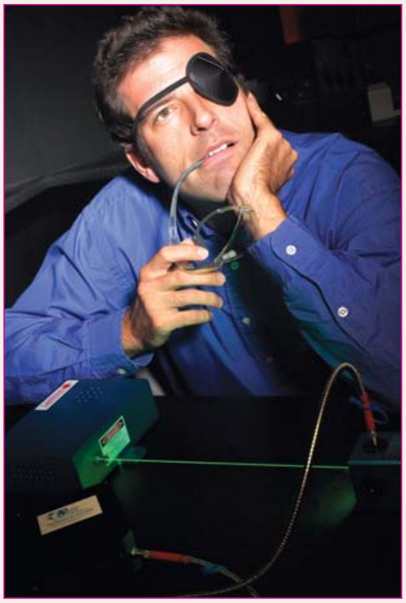
Similar studies also have been performed at the Indiana University School of Dentistry.

Whatever their ultimate application, LEDs can be analyzed for color and absolute spectral intensity very easily and inexpensively with Ocean Optics spectrometers and accessories.

Laser Plume Analysis

Ocean Optics spectrometers and accessories are useful tools for measuring the spectral output and power of lasers, with configurations as simple as the setup shown at right.

But we also provide components for applications involving what happens after the laser fires. Consider laser welding, which is now common to a number of industries. An Ocean Optics customer has used our PC Plug-in Spectrometer and an optical fiber to measure the plume created by a CO_2 laser used in welding metals such as copper and stainless steel alloys. Researchers were particularly interested in the processes related to welding of dissimilar materials.

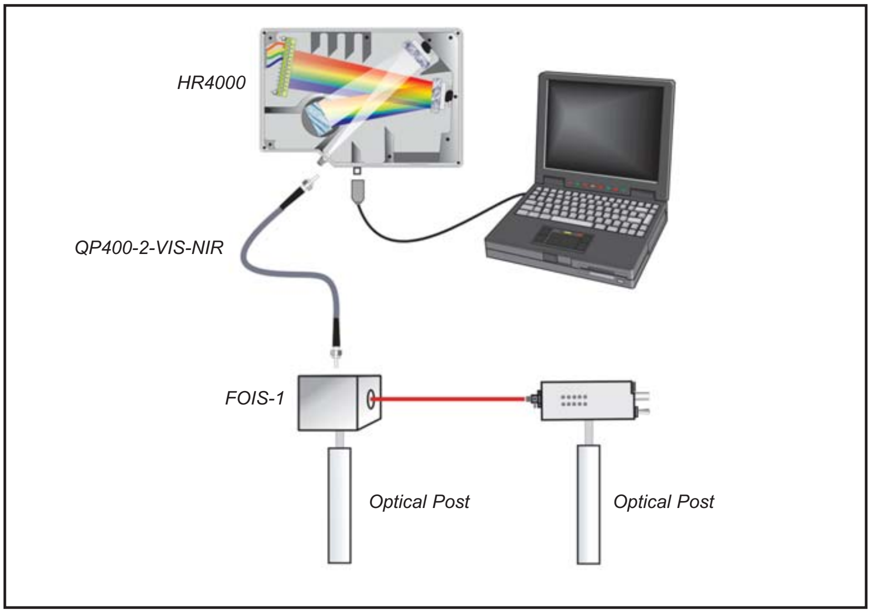


By measuring the concentration of elements within the laser weld plume, as well as the plume temperature, the researchers were able to determine the efficiency of the weld. Species identification is useful in controlling the welding of dissimilar alloys; plume temperature can be correlated to laser power and speed.

The UV-VIS spectrometer used in the study had a wavelength range of 263-523 nm. One leg of a bifurcated optical fiber carried light from a diode laser to the weld site; the other leg sampled the plume emission.

Ultimately, real-time monitoring of the laser weld plume makes it far simpler to correct process problems before large numbers of parts are affected. This increases manufacturing yields and speeds up inspection processes.

Setup: Laser Analysis



Overview

Our HR4000 High-resolution Spectrometer is ideal for measuring the spectral characteristics and intensity of continuous-wave and pulsed lasers. For high-power lasers, an integrating sphere or cosine corrector attenuates the light to avoid saturating the CCD array.

Spectrometer

The HR4000 Spectrometer uses the "HR" Optical Bench, which was designed to yield high optical resolution for resolving fine spectral features. For laser characterization, we recommend a grating with a high groove density, such as the H6 1200 mm-1 grating set to a 750-925 nm wavelength range and with a 5 µm Slit as the entrance aperture. This configuration provides ~0.12 nm resolution (FWHM). For better resolution consider an 1800 mm-1 or 2400 mm-1 grating.

Sampling Optics

There are several possible sampling setups: a CC-3-UV Cosine Corrector with an optical fiber; FOIS-1 Integrating Sphere with a fiber; or fiber assembly coupled to the laser. Optical posts are used to hold fixtures in place.

Measurements

Our operating software can detect the laser wavelength peak; OOIIrrad-C Irradiance and Color Software obtains peak, centroid and central wavelength values, and full-width half-maximum values.

Components	Page	Price
1. HR4000 High-resolution Spectrometer	46	$3,999
Grating #H6, 750-925 nm range	52	included
5 µm Slit as entrance aperture	50	$150
2. FOIS-1 Integrating Sphere for Emission	108	$499
3. OPM-3 Three-inch Optical Post (2)	89	$30
4. QP400-2-VIS-NIR Premium-grade Patch Cord Assembly	140	$170
5. OOIIrrad-C Application Software	81	$399
6. ASP Annual Service Package	193	$250
	Total:	**$5,497**

Setup: LIBS

Overview

The LIBS2000+ Broadband Spectrometer is a detection system for real-time elemental analysis in solids, solutions and gases. This high-resolution system provides full spectral analysis from 200-980 nm, with optical resolution of ~0.1 nm (FWHM), and is particularly useful for elemental identification.

Principle of Operation

An Nd:YAG pulsed laser beam is focused on the sample area. The energy of the laser generates a plasma, in which a trace amount of the sample has been ablated. As the plasma decays or cools, the plasma emits light of wavelengths that are distinct to each element. The emission is collected by a 7-fiber bundle and sent to the spectrometers for analysis.

Spectrometers

The LIBS2000+ uses seven HR2000 High-resolution Spectrometers, each with a 2048-element CCD array. This multiple-spectrometer system connects to a PC via one USB port. All seven spectrometers acquire data simultaneously; software displays the results.

Sampling Optics

The standard laser is a 50 mJ unit from Big Sky Laser, and comes with a power supply. Signal is collected by a fiber bundle comprising (7) 600 µm UV-VIS patch cords, each with a collimating focusing lens built into the fiber termination. The sample chamber has a remote laser safety lock.

Measurements

OOILIBS Software allows users to set operating parameters such as the laser Q-switch delay (the time between the firing of the laser and the beginning of spectral acquisition) and signal averaging of laser pulses.

Components	Page	Price
1. LIBS2000+ Laser-induced Breakdown Spectrometer	20	$30,000
2. LIBS-FIBER-BUN	20	included
3. LIBS-LASER Nd:YAG 50 mJ Laser (from Big Sky Laser)	21	$14,500
4. LIBS-SC Sample Chamber	21	$9,800
5. OOILIBS Software	20	$500
	Total:	**$54,800**

LIBS for Defense

In an earlier LIBS application, closely related spores of the genus *Bacillus* were deposited on silver membrane filters for analysis using broadband Laser-induced Breakdown Spectroscopy (LIBS). The observed spectral differences among the spores -- *Bacillus subtilis*, *Geobacillus stearothermophilus* and *Bacillus pumilus* -- provide evidence of the power of Ocean Optics' LIB2000+ Laser-induced Breakdown Spectrometer in resolving complex biological samples.

The presence of the spores' unique spectral lines, as well as different combinations of spectral lines, provide many opportunities for discrimination. While most of the unique peaks occurred in the *G. stearothermophilus* spectrum, spectral differences were observed in the spectra for all the spores. Spore characteristics such as surface profile and coat mineralization may account for these differences.

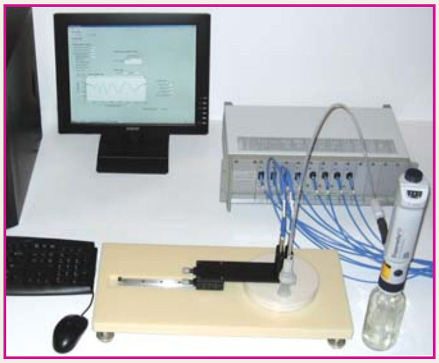
The results reported for the *Bacillus* spores, along with others obtained for biological molecules including nucleic acids and proteins, provide exciting evidence of the discriminating capability of our LIBS2000+. In fact, we are now working with the Army Research Laboratory to develop a man-portable LIBS system for field detection of chemical and biological warfare agents. The system will be able to make a complete analysis every one to two seconds, be small enough to carry in a backpack, and require very little power to operate.

Thin Film Thickness

Product developer Thickness Detection Systems (TDS) of Salt Point, N.Y., has integrated an Ocean Optics multichannel spectrometer into a broadband dissolution rate monitor (DRM) for analyzing very thin resist films used in the semiconductor and optics industries.

DRMs help to determine the thickness of thin film layers and the rate at which the film resist material dissolves -- important parameters in controlling thin film production processes. In its initial testing, Thickness Detection Solutions focused on applications involving films of <300 nm thickness, where existing monochromatic and polychromatic interferometric testing methods have had limited effectiveness.

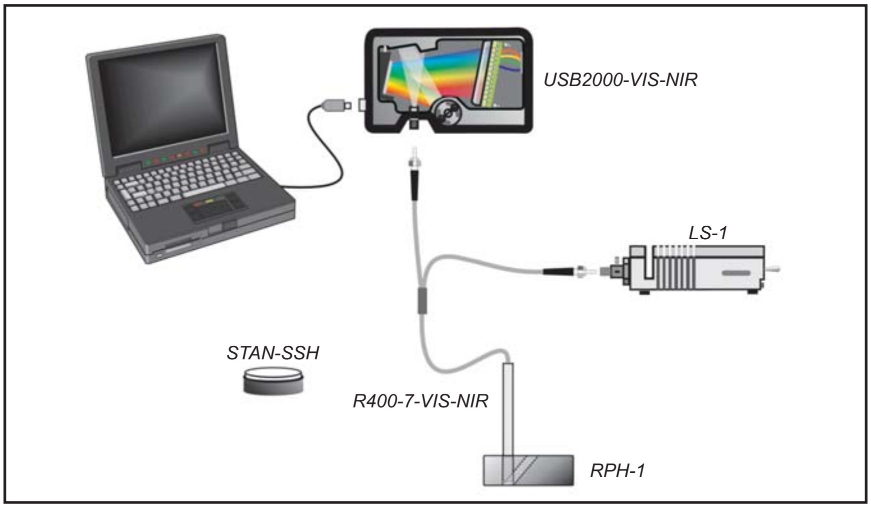
In testing, TDS used an SD2000 Dual-channel Spectrometer. Reflection measurements were performed with an R-series Reflection Probe. As TDS reports on its website, results indicated that multi-wavelength DRMs would be able to determine film thicknesses at discrete time intervals, to monitor photoresist phenomena that are difficult to separate with traditional DRMs, and to provide additional value to the researcher "by eliminating the need for discrete, static optical thickness measurement tools."



Today, TDS offers 1-, 2-, 4- and 8-channel configurations. TDS just recently announced the commercial release of its L-Series DRM product line for photoresist R&D, formulation studies, photoresist manufacturing QC, and polymer resin manufacturing QC.

The L-series line includes multiwavelength and multilayer analysis algorithms, which enable discrete thickness measurements to zero film thickness and provide accurate data of non-linear dissolution rate phenomena. For more details, visit www.thicknessdetection.com.

Setup: Metrology



Overview

A thin film on a substrate can act as an etalon, creating an interference pattern superimposed on the surface reflectivity when viewed in reflection. The spacing of the pattern's sinusoidal peaks, when combined with the refraction index of the material, can be used to calculate the thickness of the material.

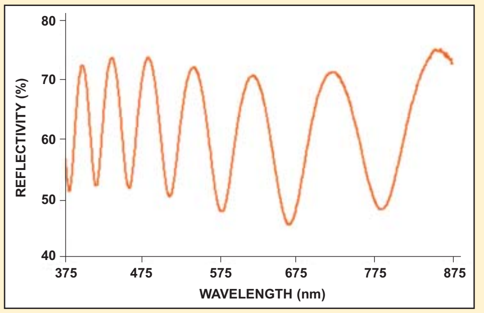
Spectrometer

The USB2000-VIS-NIR (350-1000 nm) is ideal for reflectometry of thin films. The spectrometer is preconfigured with Grating #3, which is blazed at 500 nm; an OFLV-350-1000 Filter to eliminate second- and third-order effects; and a 25 μm slit for optical resolution of ~1.5 nm (FWHM).

Sampling Optics

The R400-7-VIS/NIR Reflection Probe positioned at 90° measures specular reflectance from surfaces such as thin films. An LS-1 Tungsten Halogen Lamp and a STAN-SSH High-reflectivity Specular Reflectance Standard complete the sampling setup.

Interference Pattern of Thin Film

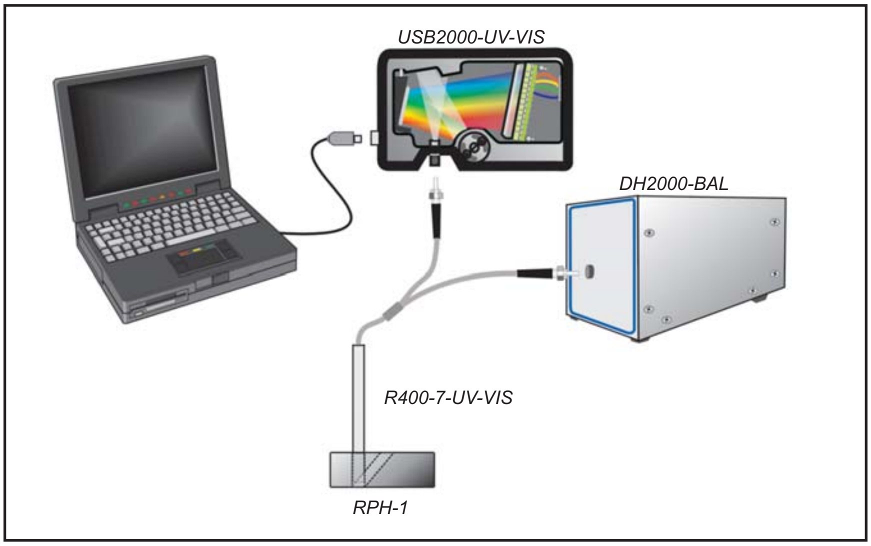


Measurements

Spectra observed in our operating software (see above) reveal oscillations caused by optical interference within the layers of the thin film substrate. Analysis of the wavelength position of the minima or maxima can determine either the thin film's thickness (with the known refractive index of the film) or its refractive index (with the known film thickness). Keep in mind that the thickness of samples may not be uniform; we recommend measuring several locations on the film.

Components	Page	Price
1. USB2000-VIS-NIR General-purpose Spectrometer	34	$2,499
Grating #3, 600 lines per mm, blazed at 500 nm	44	included
25 µm Slit as entrance aperture	42	included
OFLV-350-1000 Order-sorting Filter	43	included
2. LS-1 Tungsten Halogen Light Source	126	$499
3. R400-7-VIS-NIR Reflection/Backscattering Probe	146	$499
4. RPH-1 Reflection Probe Holder	167	$75
5. STAN-SSH High-reflectivity Specular Reflectance Standard	111	$499
	Total:	**$4,071**

Setup: UV-VIS Reflection



Overview
Diffuse reflection measurements can be used to determine information about the chemical content or color (see page 177) of a sample.

Spectrometer
The USB2000-UV-VIS (200-850 nm) is ideal for most UV-VIS reflectometry. The spectrometer is preconfigured with Grating #1, which is efficient in the deep UV; an OFLV-200-850 Order-sorting Filter to eliminate second- and third-order effects; and a 25 μm slit for optical resolution of ~1.5 nm (FWHM).

Sampling Optics
The R400-7-UV-VIS Reflection Probe measures diffuse or specular reflectance from surfaces, or backscattering from translucent materials and fluids. The RPH-1 Probe Holder positions the R400-7 at either 45° for diffuse reflection or 90° for specular reflection. (For reflection measurements with an integrating sphere, see page 109.) For illumination, we recommend the DH2000-BAL Deuterium Tungsten Halogen Light Source. If your application requires portability, use the smaller DT-MINI Deuterium Tungsten Halogen Light Source. (Because the DT-MINI is a low-power source, configure your spectrometer with a 50 μm Slit and an L2 Detector Collection Lens.)

Measurements
Reflectance standards include the WS-1 Diffuse Reflectance Standard (page 110) for diffuse measurements and the STAN-SSH Specular Reflectance Standard (page 111) for specular measurements. Use our software to correct data for deviations from 100% reflectivity of standards, field tiles or NIST-traceable materials.

Components	Page	Price
1. USB2000-UV-VIS General Lab Spectrometer	34	$2,649
Grating #1, 200-850 nm range	44	included
25 µm Slit as entrance aperture	42	included
OFLV-200-850 Order-sorting Filter	43	included
2. DH2000-BAL Deuterium Tungsten Halogen Light Source	120	$3,303
3. R400-7-UV-VIS Reflection Probe	146	$499
4. RPH-1 Reflection Probe Holder	147	$75
5. SpectraSuite Spectroscopy Platform Software	76	$199
6. ASP Annual Service Package	193	$250
	Total:	**$6,975**

Plants and Reflectance

Spectral reflectance measurements of fruits, vegetables and other plants have long been performed using Ocean Optics spectrometers, light sources and fiber optic probes, with applications in the lab and in the field.

For example, researchers at the University of Arkansas at Little Rock have measured spectral reflectance of rice seedlings (pictured) in relation to soil salinity and to the chlorophyll content of individual rice leaves -- two factors related to rice yield. The experiment setup included an S2000 Spectrometer, LS-1 Tungsten Halogen Light Source and R-series Fiber Optic Reflection Probe.

One of our favorite plant applications is a high school science fair-winning project covering similar territory. Then-student Naomi Levine used one of our old S1000 Spectrometers, a tungsten halogen source, and a fiber optic probe to measure the reflection at 90° of philodendron plant leaves. Naomi believed that correlating reflectance to fertilization levels could be useful in detecting over-fertilization in crops.

What Naomi discovered was that plant reflectance at wavelengths >700 nm was insensitive to the stress of over-fertilization (samples were fertilized at 4x the recommended amount), while the peak within the 530-630 nm range was noticeably sensitive to stress (manifest as increased leaf reflection). She concluded that the latter related to a decrease in chlorophyll and to the effects of osmosis. Osmosis caused water to collect between the cell membrane and cell wall and exposed more of the leaf surface, thus increasing reflectance.

As for Naomi, she graduated from Princeton University in 2003.

Nice Asp!

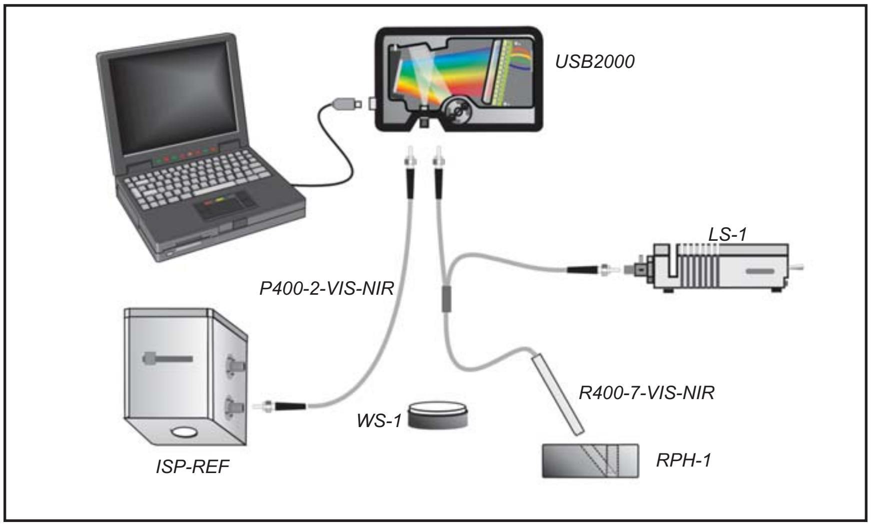
No, it's not an asp, but we couldn't resist. Dr. Ted Rohr -- a wildlife biologist and lecturer at RMIT University in Melbourne, Australia -- is actually holding an Australian Copperhead, which is one of the most venomous snakes in the world.

The Australian Copperhead is a front-fanged snake restricted to the cooler parts of Southeastern Australia. It preys on frogs, lizards, snakes and small mammals.

Rohr is studying the capacity of these snakes to undergo rapid color change -- from several shades of brown or green to black -- on the dorsal surface. Using a USB2000 Spectrometer and a fiber optic probe with a custom shield on its end (the shield helps to maintain a fixed distance to the sample point of interest), Rohr measured the reflectance of individual snake scales, both in the field and in the laboratory.

According to Rohr, the snake's ability to change body color makes sense in a cool-temperate environment, where thermal conditions can change many times during the season and even throughout the day. Changing colors is a perfect mechanism for adapting to fluctuations in temperature. However, body coloration is also important for camouflage. Being black may be great in order to absorb solar radiation, but it makes the snake more obvious to birds of prey -- and wary researchers!

Setup: Reflected Color



Overview

Color measurement involves determining the reflection spectrum of a sample and applying it to a standard illuminant. The amount of light energy the sample reflects is manipulated and reduced to tristimulus values X, Y and Z. These values correspond to the physiological response of the three types of color receptors in the human eye. X, Y and Z values are combined into uniform colorspace values such as L*, a* and b*.

Spectrometer

A USB2000 with a 25 μm Slit and Grating #2 (350-1000 nm) works well for color analysis. For those using an integrating sphere as the sampling optic, we recommend an L2 Detector Collection Lens to improve sensitivity.

Sampling Optics

When taking reflective-color measurements, your data depends on sampling geometry. The R400-7-VIS-NIR Reflection Probe provides illumination and detection from the same direction. If you use the probe at a 45°, it measures diffuse reflection. If you use the probe at a 90°, it measures specular reflection. The distance from the probe to the surface determines the sample size. An alternative is the ISP-REF Integrating Sphere, which provides 180° illumination and detection from flat surfaces for measuring specular and diffuse reflection.

Measurements

Reflectivity is measured against a reference standard such as the WS-1 Diffuse Reflectance Standard. OOIIrrad-C Irradiance and Color Software calculates a variety of colorspace values from the reflection spectra.

Components for Color Measurements	Page	Price
1. USB2000 Plug-and-Play Spectrometer	38	$2,199
Grating #2, 350-1000 nm range	44	included
25 µm Slit as entrance aperture	42	$150
L2 Detector Collection Lens	43	$150
OFLV-350-1000 Order-sorting Filter	43	$150
2. WS-1 Diffuse Reflectance Standard	110	$299
3. OOIIrrad-C Color Application Software	81	$399
4. LS-1 Tungsten Halogen Light Source	126	$499
5. R400-7-VIS-NIR Reflection Probe	146	$499
6. RPH-1 Reflection Probe Holder	147	$75
7. ASP Annual Service Package	193	$250
	Total:	**$4,670**