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CURRENT INSTRUMENTATION FOR CONTINUOUS MONITORING FOR SO<sub>2</sub>

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CURRENT INSTRUMENTATION FOR CONTINUOUS MONITORING FOR SO<sub>2</sub> \*

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In June 1971 the Environmental Instrumentation Group of the Lawrence Berkeley Laboratory received an NSF-RANN (Research Applied to National Needs) grant to carry out a comprehensive survey of instrumentation for environmental monitoring including monitors of air quality, water quality, radiation, and biomedicine. The results of the survey are given as (a) descriptions of the physical and operating characteristics of available instruments, (b) critical comparisons among instrumentation methods and (c) recommendations for producing methodology and development of new instrumentation. The need for such a survey in air can be appreciated when it is realized that for SO<sub>2</sub> alone there are over 60 monitors now commercially available involving 13 distinctly different principles of operation.

A testimony to the fact that this effort is not misplaced lies in the record of 4,000 lives which were taken by a smog incident in London in 1952, and 20 lives lost during a five day smog episode in Donora, Pennsylvania in 1948. Fortunately we now know a great deal more about permissible levels of the various constituents of smog and are approaching the capability of prediction and restriction of this irritatory, and at times dangerous, by-product of our technology.

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Present EPA policies are designed to insure that the Donora or London type incidents will not re-occur. National ambient air quality standards have been established for SO<sub>2</sub>, NO<sub>2</sub>, CO, photochemical oxidants, hydrocarbons, and particulate matter. More important are those regulations which require state implementation plans to achieve and maintain these national ambient air quality standards. In addition, performance standards for new stationary sources have been established. The ability of this approach to protect the citizen is totally dependent upon the ability of monitoring equipment to reliably measure the concentration of pollutants in ambient air or emissions from sources. This article describes the techniques which form the basis of present day commercial instrumentation and remarks on the type of instrumentation likely to be available in the future.

Each of the following descriptions of instrumentation applies principally to an analyzer. An analyzer, the heart of the monitoring system, is where the actual determination of the SO<sub>2</sub> concentration occurs. Depending upon its characteristics, a particular analyzer is usually intended to be either an ambient air or a stationary source monitor. It must be remembered, however, that the analyzer by itself does not complete the monitoring system. Besides the analyzer, a system may need some or all of the following: sampling probes to obtain the sample; sampling lines to transport the sample; conditioning units to dry, heat, cool, or otherwise pretreat the sample before analysis; selective filters to remove gases or particulates that can affect accuracy or operation; pumps to move the sample; calibration devices; and data handling electronics such as strip chart recorders. Some or all of these components may be included with the basic analyzer.

#### Conductimetric Analyzers

The first commercial continuous analyzer for SO<sub>2</sub>, the Thomas Autometer, was developed in 1929. Conductimetric analyzers remain popular today and are still being manufactured, studied, and commonly utilized for ambient air monitoring.

Basically, the conductimetric analyzer measures the conductance of an absorbing solution into which  $\text{SO}_2$  has been dissolved by contact of the solution with air. An increase in conductance is caused by ions formed as  $\text{SO}_2$  combines with the solution. The two kinds of solution used are (1) deionized or distilled water and (2) dilute, acidified hydrogen peroxide solution. The observed increase in conductivity is proportional to the  $\text{SO}_2$  concentration in the air if there are no interferents.

These instruments are popular because of their high sensitivity, fast response, minimal maintenance, and simple operation. Their major disadvantage is susceptibility to interference by non- $\text{SO}_2$  gases that form or remove ions in solution. Conductimetric analyzers can be successfully used if interferent gases are not in sufficiently high concentrations to introduce error or if the interferent gases can be effectively removed from the air sample by selective filters.

#### Colorimetric Analyzers

Colorimetric analyzers measure a solution's optical absorbance spectrophotometrically as an indication of the  $\text{SO}_2$  concentration in the ingested air sample. Within limitations, the absorbance is linearly proportional to the concentration of the colored species in accordance with Beer's Law.

Colorimetric determination is usually dependent upon the ability of  $\text{SO}_2$  to form sulfurous acid. Commercial analyzers use pararosaniline or related dyes to detect the sulfurous acid. Colorimetric analyzers based on the reducing properties of  $\text{SO}_2$  are not yet commercially available; but numerous chemical systems, especially those involving the reduction of ferric to ferrous iron, have been proposed.

In general, the advantages of colorimetric analyzers are simplicity, high sensitivity, and -- with proper controls -- good specificity. To minimize wet chemistry, most analyzers use only one or two solutions. Color intensity is usually sensitive to temperature, pH, development time, purity of reagents, age of solutions, and some atmospheric interferents. Compromises among the various desirable qualities

define the usefulness and limitations of a given colorimetric procedure. A long development time allows the color intensity to approach its asymptotic maximum, but a longer time may introduce fading. A complex, time-consuming procedure may be excellent for specificity but would not allow the fast response needed for monitoring.

#### Amperometric (Coulometric) Analyzers

Amperometric analyzers measure the generating current necessary to maintain a constant halogen concentration; the magnitude of this current is proportional to the amount of absorbed  $\text{SO}_2$ , since  $\text{SO}_2$  reduces halogen to halide. Although commonly called coulometric analyzers, they are more properly referred to as amperometric analyzers because it is the current and not the charge that is measured.

The major advantage of amperometric analyzers is minimal maintenance. Because halogen is nearly completely regenerated, reagent consumption is negligible. Water that is lost through evaporation can be automatically replaced from a reservoir or by condensation from the air. Volatization of halogen is not a problem. Reagent may need replacement monthly, and electrodes may need cleaning yearly--depending upon the model and the sampled atmosphere.

Potential interferences are those species able to react with the halide or halogen. Sulfur compounds are the most noted group of potential interferences: namely,  $\text{H}_2\text{S}$ , organic sulfides, and organic disulfides. Without filters, sensitivities to these sulfur compounds are comparable to the sensitivity to  $\text{SO}_2$ .

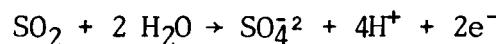
Although commercial amperometric analyzers have not fully exploited this possibility, an advantage of amperometric analyzers may be the capability to measure specific sulfur compounds or total sulfur. Two alternatives are possible to measure specific sulfur compounds. Firstly, since the detector is somewhat sulfur specific, it may be possible to selectively filter the sample for a particular sulfur compound before detection. Secondly, separation of the sulfur compounds may be done by gas

chromatography before detection; if in addition the sulfur compounds are oxidized to SO<sub>2</sub> after separation and before detection, the measurement system need only be calibrated for SO<sub>2</sub>. Sulfur compounds without filtration or separation may be oxidized to SO<sub>2</sub> before detection for total sulfur measurement.

### Electrochemical Transducer Analyzers

Analyzers using electrochemical transducers measure the current induced by the electrochemical oxidation of SO<sub>2</sub> at a sensing electrode. Electrochemical transducer (ECT) analyzers, introduced commercially around 1970, avoid the wet chemistry of the traditional conductimetric, colorimetric, and amperometric analyzers by using a sealed module, the electrochemical transducer, inside which all chemical reactions occur.

Figure 1 shows a simplified schematic of an ECT analyzer. SO<sub>2</sub> diffuses through the semi-permeable membrane into the transducer. The rate of diffusion is proportional to the SO<sub>2</sub> concentration. At the sensing electrode, the SO<sub>2</sub> undergoes electrochemical oxidation according to the following equation:



The production of electrons at the sensing electrode causes this electrode to be at a lower potential relative to the counter electrode. Thus, an electron current can flow from the sensing electrode through the amplifier to the counter electrode. The current is proportional to the sample SO<sub>2</sub> concentration.

Figure 1  
Electrochemical Transducer Analyzer

Advantages of ECT analyzers are extremely simple operation, low maintenance, fast response, and excellent portability. Units are typically light in weight, low in power consumption, and need only transducer replacement. There are no reagents. Multi-parameter capability is possible through different transducers that are easily installed.

Disadvantages may be transducer replacement or rejuvenation, the pushing in-



stead of pulling of the air sample through the transducer, and the calibration requirements. Transducer life is limited by the volatilization of the electrode solvent through the membrane and by contamination of the membrane. Full transducer life may require occasional syringe injections of solvent to avert dehydration. A transducer typically needs replacement or rejuvenation about every six months. A new transducer may cost a few hundred dollars, and rejuvenation by the manufacturer may cost over fifty dollars. Because deterioration of the transducer is gradual, continual calibration is required. The pump should be carefully chosen and maintained so that sample contamination by the pump is minimized. The air sample should be pushed through the transducer, since suction may cause displacement of the membrane away from the thin film electrolyte. Recovery time is probably limited principally by the amount of  $\text{SO}_2$  stored in the transducer membrane and the thin film electrolyte. Species which may be present in the sample and which adhere to or clog the membrane may increase recovery time and deteriorate the membrane.

#### Analyzers Using Flame Photometry or Gas Chromatography-Flame Photometry

Flame photometric detector (FPD) analyzers have a photomultiplier tube to measure the emissions from sulfur compounds introduced into a hydrogen-rich flame. A narrow-band optical filter selects the 394 nm  $\text{S}_2$  emission band. Figure 2 shows a flame photometric detector.

Figure 2  
Flame Photometric Detector

FPD analyzers for air monitoring have been commercially available for less than three years but have already gained general acceptance for  $\text{SO}_2$  monitoring in ambient air. Gas chromatography-FPD (GC-FPD) analyzers that distinguish among the sulfur compounds have appeared more recently. Nearly all FPD and GC-FPD models are intended for ambient air monitoring. A few have been proposed for source monitoring, and these use a dilution system to lower the sulfur concentration to within the detector range.

Models vary in built-in features such as linear output, multi-parameter capability, and performance checking.

In ambient air monitoring, interference from non-sulfur species is essentially nonexistent. However, for  $\text{SO}_2$  monitoring, FPD analyzers are susceptible to interference from other sulfur compounds. Although  $\text{H}_2\text{S}$ ,  $\text{H}_2\text{SO}_4$  aerosols, and mercaptans are commonly found in the atmosphere, their contribution to the total sulfur content is usually 10% or less. Selective filters, available from some manufacturers, may be used to reduce interference. Particulates should be removed to avoid clogging and to prevent scattering of light.

Advantages of FPD analyzers are low maintenance, high sensitivity, fast response, and excellent selectivity for sulfur compounds. There are no solutions, and the only required reagents are hydrogen for the flame and perhaps clean air for dilution. FPD analyzers have good potential for unattended operation.

Disadvantages of FPD analyzers may be the need for a compressed hydrogen supply and the inability to discriminate among sulfur compounds without selective filters. Because the photomultiplier tube output is logarithmically proportional to the sulfur concentration, electronics to convert the logarithmic output to a conventional linear output may be desirable.

GC-FPD analyzers are not ordinarily susceptible to interference. They are suitable for monitoring ambient sulfur compounds because of their ability to separate and measure these compounds with high specificity. Usefulness may be limited by the cycle time or by manual sample injection.

FPD and GC-FPD techniques may be suitable as standard methods for instrumental monitoring of  $\text{SO}_2$  in ambient air. Besides the already mentioned advantages, the simplicity of operation and maintenance makes these techniques extremely attractive.

#### Nondispersive Absorption Spectrometers

A nondispersive absorption spectrometer is an instrument which is based on

broad-band spectral absorption and which is sensitized for a particular gas of interest by means of a detector, a special cell, or a filter. Commercial instruments are available which use this technique in the infrared, ultraviolet, and visible regions. They are commonly used for stationary source monitoring of  $\text{SO}_2$ .

Typical nondispersive infrared (NDIR) analyzers use a double-beam arrangement of the type shown in Figure 3.

Figure 3  
Nondispersive Infrared Analyzer

Infrared radiation from the filaments is directed onto two cells: (1) a reference cell filled with a non-infrared absorbing gas, such as nitrogen or argon, and (2) a sample cell through which the sample air is continuously drawn. The detector consists of a gas-impermeable double chamber with a flexible metal diaphragm as a partition. Both chambers are filled with  $\text{SO}_2$ . The infrared radiation which passes through the reference cell enters one chamber of the detector, and the radiation passing through the sample cell enters the other chamber. The gas in each chamber of the detector is heated by the incoming energy. This heating causes a pressure increase in the two chambers. The pressure rise is greater in the chamber receiving radiation from the reference cell, since a portion of the radiation transmitted through the sample cell has been absorbed by  $\text{SO}_2$  before entering the chamber on the sample cell side. This difference in pressure causes a diaphragm displacement which is electronically measured as a capacitance change. The infrared radiation is chopped by an optical chopper to cause a periodic capacitance change, which modulates a radiofrequency signal from an oscillator. This signal is subsequently demodulated, amplified, and the output is fed to a meter or a recorder.

NDIR instruments are usually subject to interference because other gases (e.g.,  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ , aromatics) absorb in the region of  $\text{SO}_2$  absorption. To eliminate or minimize interference, auxiliary absorption cells or optical filters are incorporated

to remove most of the radiation at wavelengths at which the interfering substances absorb.

All NDIR analyzers use principally the above technique, but the optical and detection arrangements do vary somewhat. One series of NDIR analyzers uses a detector consisting of two chambers in series separated by a diaphragm. Chopped radiation from the reference and sample cells are recombined before reaching the detector. Both detector chambers are filled with  $\text{SO}_2$ .  $\text{SO}_2$  in the forward chamber is heated by the center of the absorption band;  $\text{SO}_2$  in the rear chamber, by the edges of the band.  $\text{SO}_2$  in the sample will absorb primarily in the band center and cause the front chamber to become cooler. The pressure change causes a displacement of the diaphragm, which is measured as an electronic capacitance change.

Two commercial instruments use nondispersive absorption techniques in the ultraviolet region. One instrument employs a double-beam arrangement through two cells (reference and sample) and photomultiplier tubes for detection. The second instrument is based on the measurement of the difference in absorption by the sample at two separate wavelengths, one an absorbing wavelength of  $\text{SO}_2$  and the other a non-absorbing wavelength. A schematic is shown in Figure 4.

Figure 4  
Nondispersive Ultraviolet Analyzer

Nondispersive UV analyzers are somewhat more sensitive than NDIR analyzers and do not suffer from the same interferences as NDIR analyzers. These UV analyzers for  $\text{SO}_2$  may have interference from  $\text{NO}_2$ ; this can be corrected, however, by proper selection of reference and sample wavelengths.

#### Dispersive Absorption Spectrometers

A dispersive absorption spectrometer is an instrument which can be set to pass any small wavelength interval within its range and differs from a nondispersive type instrument which looks at a broad spectral region. The dispersive type instru-

ment is able to measure any gas that absorbs within its spectral region and is not limited to a single, preselected gas as is the case with the nondispersive type instrument. The disadvantage of a dispersive type instrument is that in situations where a number of absorbing gases are present it may be difficult to locate an absorption wavelength for the gas of interest which is in a spectral interval where other gases do not absorb.

Dispersive absorption spectroscopy shows good promise for stationary source monitoring. Usual sensitivities, however, are too limited for ambient air monitoring of  $\text{SO}_2$ . Instruments based on this technique have the advantage of being able to measure a number of gases simultaneously.

#### Correlation Spectrometers

Correlation spectroscopy uses either skylight or artificial light for measurement of selected gases. There are numerous possibilities for ambient air and stationary source monitoring: data may be obtained remotely or on-site and may be long-line average or point values. Long-line data are obtained in units of concentration times distance such as ppm-meters (ppm-m). To convert to conventional ppm data, one divides the ppm-m value by the observed pathlength in meters.

Figure 5 shows a correlation spectrometer for remote sensing of  $\text{SO}_2$ . Skylight is collected by a telescope, collimated, dispersed by a prism or grating, and focussed onto a correlation mask. The pattern of the mask is formed by depositing aluminum on glass and then removing slits of aluminum corresponding to absorption lines of  $\text{SO}_2$ . If the mask and incident spectrum is repeatedly shifted relative to each other, then the photomultiplier tube will observe a minimum when the mask lines correlate with the  $\text{SO}_2$  lines and a maximum when the mask is shifted off. The difference in light intensities seen by the photomultiplier is a measure of the  $\text{SO}_2$  concentration between the light source and the instrument.

If an artificial light source such as quartz iodine or xenon lamp is used,

monitoring across a defined distance is achieved. The distance may be across a stack or across a courtyard. An artificial source also allows monitoring at night when there is insufficient skylight.

Figure 5  
Correlation Spectrometer for Remote Monitoring

Advantages are high specificity and the capability for long-line averaging and remote sensing. There are no reagents, and the potential for unattended, continuous monitoring is good. Long-line data may be more useful than point data for assessing ambient air pollution. And compared to point monitors, fewer long-line air monitors would be needed to survey a given area.

A disadvantage may be the need to know the length of the observed pathlength in order to convert ppm-m data to conventional ppm values. For night monitoring, an artificial light source is required at the remote end. Problems associated with beam attenuation need to be explored.

#### Second Derivative Spectrometers

A second derivative spectrometer electromechanically processes the absorbance versus wavelength function of an ordinary spectrometer to produce an output signal proportional to the second derivative of this function. This second derivative signal is directly proportional to the concentration of the gas in the analysis path.

Second derivative spectroscopy shows good promise for both ambient air and stationary source monitoring. Instruments using this technique are quite new and require field testing before a definitive evaluation can be made.

Figure 6  
Second Derivative Spectrometer

#### Condensation Nuclei Formation Analyzers

A commercial condensation nuclei formation analyzer for SO<sub>2</sub> monitoring is currently available. The unit consists of two parts: a converter for changing

SO<sub>2</sub> molecules into condensation nuclei and a condensation nuclei monitor. In operation, an air sample is drawn through a glass filter into the converter. The glass filter removes condensation nuclei from the sample. In the converter, the SO<sub>2</sub> molecules in the presence of water vapor and ultraviolet radiation are converted into H<sub>2</sub>SO<sub>4</sub> aerosol. The H<sub>2</sub>SO<sub>4</sub> aerosol, which is condensation nuclei, is then drawn into the condensation nuclei monitor where constant volume expansion in the presence of water vapor produces a cloud. The optical transmittance of the cloud indicates the number of condensation nuclei per cubic centimeter (CN/cc). A calibration curve relates the CN/cc value to a corresponding SO<sub>2</sub> concentration value. The calibration curve is approximately linear in a log-log plot. The response time is ~45 seconds, and a new measurement cycle is initiated at approximately one second intervals.

#### New Developments in Air Monitoring Instrumentation

The most promising instrumental developments for air monitoring are those techniques based upon the application of well-known spectroscopic methods. The instruments discussed here are either in early commercial stages or in an advanced prototype stage. They are, in general, capable of monitoring numerous pollutants and, hence, are not limited to monitoring only SO<sub>2</sub>.

The following comments are intended to acquaint the reader with recent developments in air monitoring instrumentation and indicate the type of new commercial instrumentation which will probably be available in the near future.

Mass spectrometers are marketed by many manufacturers, and a few have recently been developed specifically for air pollution monitoring. The sensitivities of such instruments are on the order of 0.1 ppm and response times are less than 1 second.

Instruments based on the chemiluminescence technique are already commercially available for monitoring of NO, NO<sub>x</sub>, and O<sub>3</sub>. The chemiluminescence technique is

also feasible for the detection of other gaseous pollutants. Several manufacturers have prototype instruments in various development stages which should extend the chemiluminescence technique to the monitoring of such air pollutants as SO<sub>2</sub>, CO, H<sub>2</sub>S, and NH<sub>3</sub>.

A sulfur dioxide monitoring instrument based upon a mercury substitution and nucleonic detection technique has been developed. The instrument is based on a stoichiometric substitution of mercury for sulfur dioxide in a reaction cell, the transfer of the mercury into a measurement cell, and the measurement of the mercury by low energy X-radiation absorption.

Laser techniques show good promise for the remote monitoring of air pollutants. Several recent studies have considered the application of laser resonance absorption for air monitoring. Resonance scattering and Raman scattering also show potential use for gaseous air pollution monitoring.

Several other techniques are being studied for their applicability to SO<sub>2</sub> monitoring. These include microwave spectroscopy, Fourier-transform spectroscopy, and ESCA (electron spectroscopy for chemical analysis). Sensitivity and cost presently limit their ability to compete in today's market; however, there are indications that they may have much wider usage in the future.

#### Table of SO<sub>2</sub> Instruments

The Table of SO<sub>2</sub> Instruments summarizes the features of commercial analyzers that are currently available. It can serve as a preliminary guide but should not be used alone in the selection of instruments. Other major factors such as ruggedness, maintenance, and suitability to a specific application must also be assessed. A summary of such information compiled from published and unpublished studies plus remarks by actual users are given in the reference cited in Further Reading.

The instruments are primarily divided into ambient air and stationary source monitors and then according to the principles of operation. The ranges suggest the minimum and maximum concentrations measured; the lower limit of detection is approxi-



mately 1% of the lowest range. Response time is that time necessary for a 90% reading after a step positive input. The cost represents in some cases a complete monitoring system (analyzer, recording devices, sampling equipment, etc.) while in many it represents only the cost of the analyzer. Most units are capable of monitoring gases other than SO<sub>2</sub>; by some analyzers, this is performed simultaneously. Additional equipment is usually necessary for multi-parameter capability.

#### Futher Reading

More complete information on SO<sub>2</sub> analyzer instrumentation and air monitoring in general can be found in Instrumentation for Environmental Monitoring AIR, LBL-1, Vol. 1, available from the Technical Information Division, Lawrence Berkeley Laboratory, Berkeley, CA., 94720. Included are references, reviews of individual instruments, and recommendations for monitoring instrumentation. Similar sections dealing with air monitoring instrumentation for other pollutants will be published periodically.

TABLE OF SO<sub>2</sub> INSTRUMENTS  
AMBIENT AIR MONITORS

<u>Principle of Operation</u>	<u>Manufacturer</u>	<u>Model</u>	<u>Ranges* (ppm)</u>	<u>Response Time</u>	<u>Cost</u>	<u>Multi-Parameter Capability</u>
<u>Conductimetric</u>	Calibrated Instruments	Ultragas U3S	0-0.4, 4.0	1.5 min	\$4900	None
	Devco Engineering	9000	0-1	20 sec		H <sub>2</sub> S, NH <sub>3</sub> , Cl <sub>2</sub> , CO <sub>2</sub>
	Intertech	Picos	0-0.35, 10	60-100 sec	\$5450	NO, NO <sub>x</sub> , H <sub>2</sub> S, etc.
	Kimoto	302-A	0.002-0.2, 0.5	3.9 min	~\$1500	
	Leeds and Northrup	7860	0-0.5, 2.0	2-6 min	~\$2500	None
	Scientific Industries	60	0-0.5, 2.0	30 sec	\$2575	None
	Scientific Industries	67	0-0.1, 2.0	20 sec	\$1500	None
	Scott Aviation	11-7010	0-1.0, 5.0	13-90 sec	\$2250	None
<u>Colorimetric</u>	Atlas	Colorimetric	0-0.25, 10	1-6 min	\$1950	Aldehydes
	Houston Atlas	875	0-0.5, 100%	2 min	\$4420	Total sulfur, H <sub>2</sub> S
	Litton	411	0-0.5, 2.0	<10 min	\$2950	NO <sub>2</sub>
	Monitor Labs	8101	0-0.2, 2.5	5 min	\$2000	NO, NO <sub>2</sub> , NO <sub>x</sub>
	Pollution Monitors/CEA	PM 101/121	0-0.25, 4.0	8 min	\$2090	NO <sub>2</sub>
	Pollution Monitors/CEA	PM 111	0-0.25, 4.0	8 min	\$1895	NO <sub>2</sub>
	Technicon	Monitor IV	0-0.1, 1.0	14.5 min	\$5535	NO <sub>2</sub> , NO <sub>x</sub> , H <sub>2</sub> S, etc.
	Wilkens-Anderson	WACO	0-0.5, 8.0	5 min	\$2805	NO, NO <sub>2</sub> , NO <sub>x</sub>
<u>Amperometric (Coulometric)</u>	Atlas	Iodometric	0-0.1, 10	<2 min	\$1775	O <sub>3</sub>
	Barton	286	0-1.0, 1000	~5 min	\$4150	H <sub>2</sub> S, mercaptans
	Beckman	906A	0-0.5, 4.0	4 min	\$2760	None
	Philips	PW 9700	0-0.115, 3.83	5 min	\$5290	H <sub>2</sub> S, mercaptans
	Process Analyzers	Titri-log II	0-1.0, 3	2 min	\$4000	H <sub>2</sub> S, mercaptans, etc.

000003807132

\* The minimum and maximum ranges

TABLE OF SO<sub>2</sub> INSTRUMENTSAMBIENT AIR MONITORS

<u>Principle of Operation</u>	<u>Manufacturer</u>	<u>Model</u>	<u>Ranges* (ppm)</u>	<u>Response Time</u>	<u>Cost</u>	<u>Multi-Parameter Capability</u>
<u>Electrochemical Transducer</u>	Dynasciences	SS-310	0-1.0, 10	3 min	\$2250	NO <sub>x</sub> , NO <sub>2</sub> , CO, CH <sub>2</sub> O
	Envirometrics	NS-200	0.01-100, 20,000	5-10 sec	\$1750	NO <sub>x</sub> , NO <sub>2</sub> , H <sub>2</sub> S, CO
	Ericson	ARS-01/S2			\$ 700	
	Mast	812-1	0-0.2, 5.0	2-3 min	\$ 950	
	Theta Sensors	LS-400	0-1.0	23 sec	\$1950	
	<u>Flame Photometric Detector</u>	Bendix	8300	0-1.0	30 sec	\$3950
Meloy		SA-120	0.01 - 10	28 sec	\$3250	Total Sulfur and Phosphorus
Meloy		SA-160	0.01 - 10		\$3995	Total Sulfur and Phosphorus
Meloy		SA-165	0.01 - 1.0	12 sec	\$4750	Total Sulfur and Phosphorus
Meloy		SA-185R	0.01 - 1.0	28 sec	\$4225	Total Sulfur and Phosphorus
Meloy		SH-202	0.01 - 10	28 sec	\$5270	Total Sulfur, Phosphorus, & Hydrocarbons
<u>Gas Chromatography-Flame Photometric Detector</u>		Analytic Instrument (AID)	513			\$5950
	Bendix	8700	0-1.0	5 min	\$7200	Sulfur compounds
	Tracor	250 H	0-2.0	~3 min	\$5275	Sulfur & phosphorus compounds

\* The minimum and maximum **ranges**



TABLE OF SO<sub>2</sub> INSTRUMENTS  
STATIONARY SOURCE MONITORS

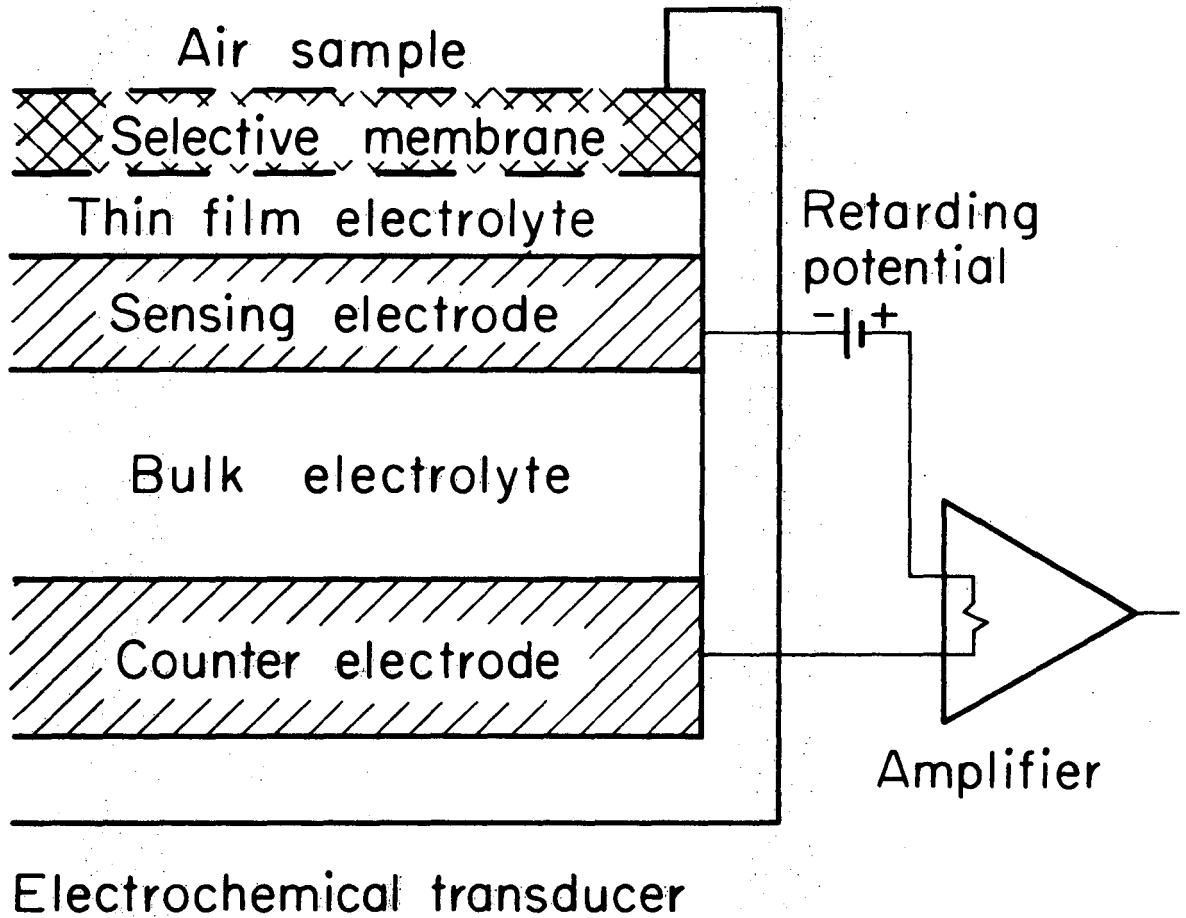
<u>Principle of Operation</u>	<u>Manufacturer</u>	<u>Model</u>	<u>Ranges* (ppm)</u>	<u>Response Time</u>	<u>Cost</u>	<u>Multi-Parameter Capability</u>
<u>Conductimetric</u>	Calibrated Instruments	Mikrogas MSK	0-500, 8000	2 min	\$5615	CO <sub>2</sub>
<u>Colorimetric</u>	Houston Atlas	875	0-0.5, 100%	2 min	\$4420	Total sulfur, H <sub>2</sub> S
<u>Coulometric</u>	Barton	286	0-1.0, 1000	5 min	\$4150	H <sub>2</sub> S, mercaptans
	Barton	400	0-1000		\$5425	H <sub>2</sub> S, mercaptans
<u>Electrochemical Transducer</u>	Dynasciences	SS-330	0-500, 5000	90 sec-3 min	\$2000	NO <sub>x</sub> , NO <sub>2</sub> , CO, CH <sub>2</sub> O
	Envirometrics	NS-200	0.01-100, 20,000	5-10 sec	\$1750	NO <sub>x</sub> , NO <sub>2</sub> , H <sub>2</sub> S, CO
	Theta Sensors	US-5000	0-500, 5000	20 sec	\$3500	NO <sub>x</sub>
	Theta Sensors	LS-800	0-500, 5000	13-20 sec	\$1150	NO <sub>x</sub>
<u>Flame Photometric Detector</u>	Meloy	FSA 190	25-2500, 10,000	12 sec	\$8500	Total Sulfur and Phosphorus
<u>Nondispersive Absorption Spectroscopy</u>	Beckman (IR)	IR-315 B		0.5 sec	~\$2900	CO, NO, NO <sub>2</sub> , etc.
	Bendix (IR)	UNOR 2	0-200, 50%	3 sec	\$3403	CO, NO, NO <sub>2</sub> , etc.
	Bendix (IR)	UNOR 6	0-2000	4 sec	\$2680	CO, NO, NO <sub>2</sub> , etc.
	Calibrated Instruments (IR)	SC/LC	0-500, 50%	~15 sec	\$2995	CO, NO, NO <sub>2</sub> , etc.

\* The minimum and maximum ranges

TABLE OF SO<sub>2</sub> INSTRUMENTS  
STATIONARY SOURCE MONITORS

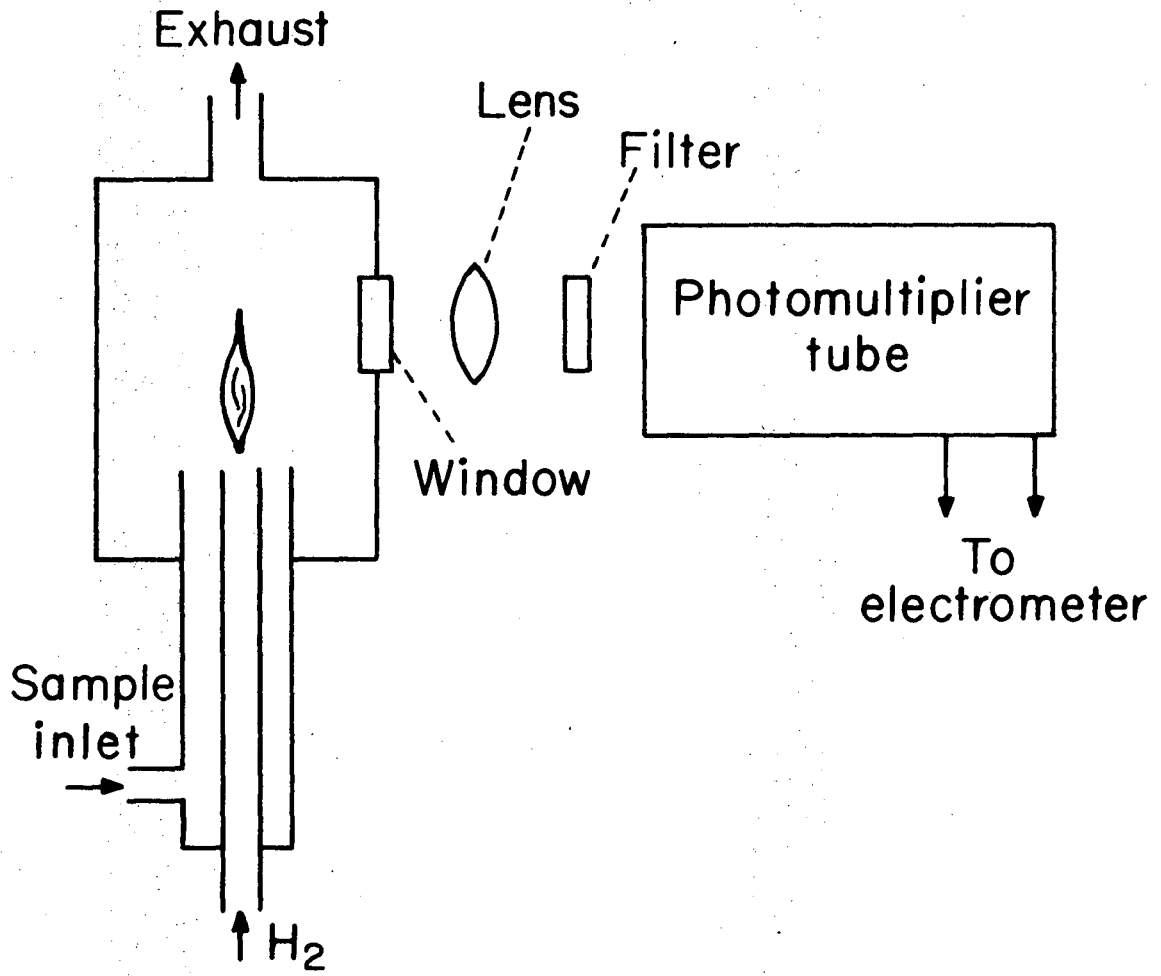
<u>Principle of Operation</u>	<u>Manufacturer</u>	<u>Model</u>	<u>Ranges* (ppm)</u>	<u>Response Time</u>	<u>Cost</u>	<u>Multi-Parameter Capability</u>
<u>Nondispersive Absorption Spectroscopy (cont)</u>	DuPont (UV)	460	0-200, 5000	15 sec	\$8175	NO <sub>2</sub> , NO <sub>x</sub> , Hg, etc.
	Intertech (IR)	Uras 2	0-200, 100%	0.5 sec	\$3280	CO, NO, NO <sub>2</sub> , etc.
	Mine Safety Appliances (IR)	LIRA 200	0-100, 100%	5 sec	\$3570	CO, NO, NO <sub>2</sub> , etc.
	Mine Safety Appliances (IR)	LIRA 300	0-5000, 20%	5 sec	\$1795	CO, NO, NO <sub>2</sub> , etc.
	Monitor Labs (IR emission)	8200				CO, NO, NO <sub>2</sub> , etc.
	Peerless (IR/UV)	209	0-50, 5%	<5 sec	\$2800- \$3800	CO, NO <sub>2</sub> , O <sub>3</sub> , etc.
<u>Dispersive Absorption Spectroscopy</u>	Environmental Data	Diga-Series				NO, CO, CO <sub>2</sub>
	Wilks (IR)	Miran 5630	0-3000	30 sec	\$3950	CO, NO, NO <sub>2</sub> , etc.
<u>Correlation Spectroscopy</u>	Combustion Equipment (CEA)	Mark IV	0-200, 5000	20 sec	\$7800	None
<u>Second Derivative Spectroscopy</u>	Spectrometrics	IV d <sup>2</sup>	0.1 - 100%		\$9000	NO, NO <sub>2</sub> , O <sub>3</sub> , NH <sub>3</sub> , etc.

\* The minimum and maximum ranges



XBL726-3102

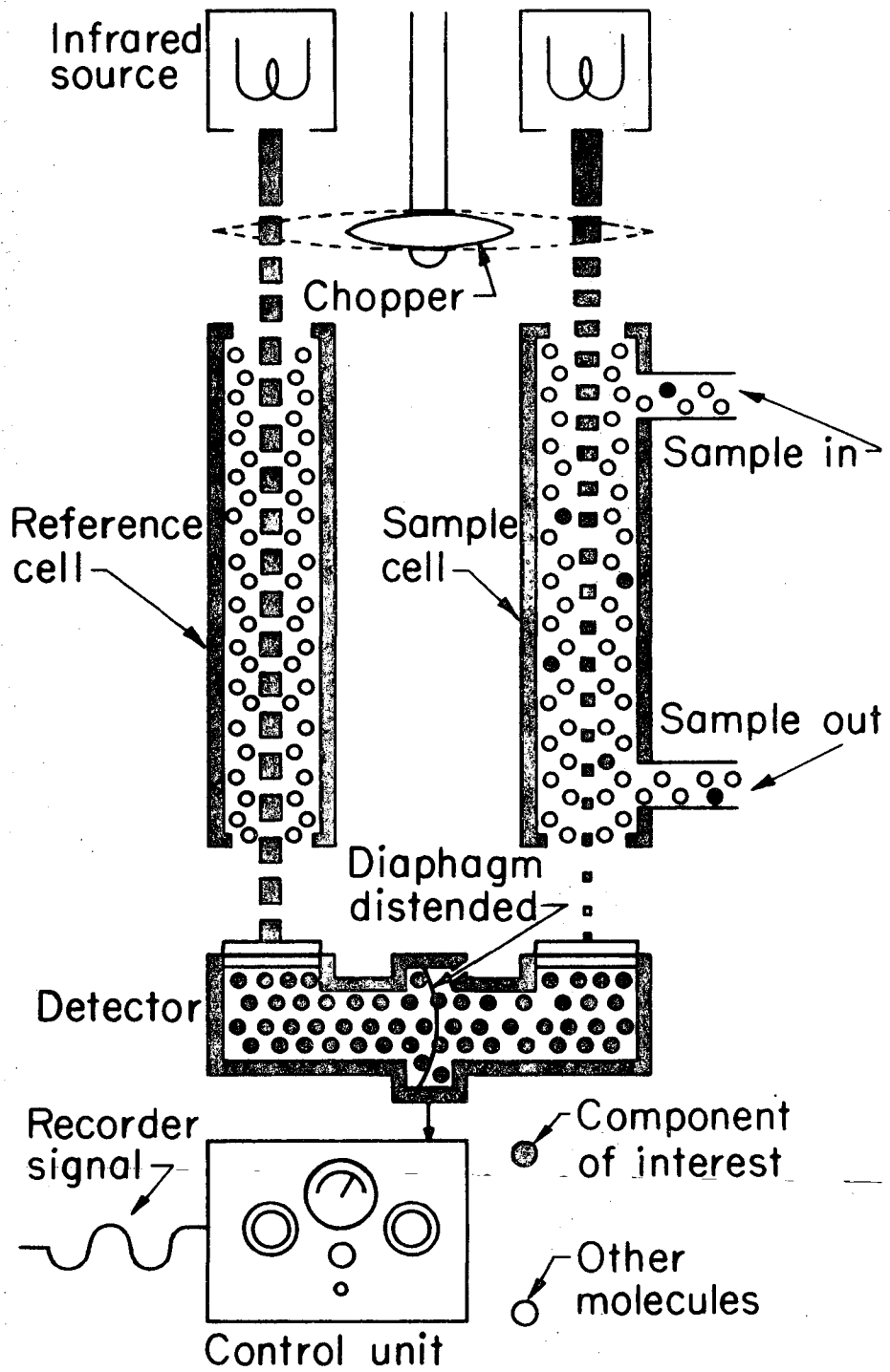
Figure 1  
Electrochemical Transducer Analyzer



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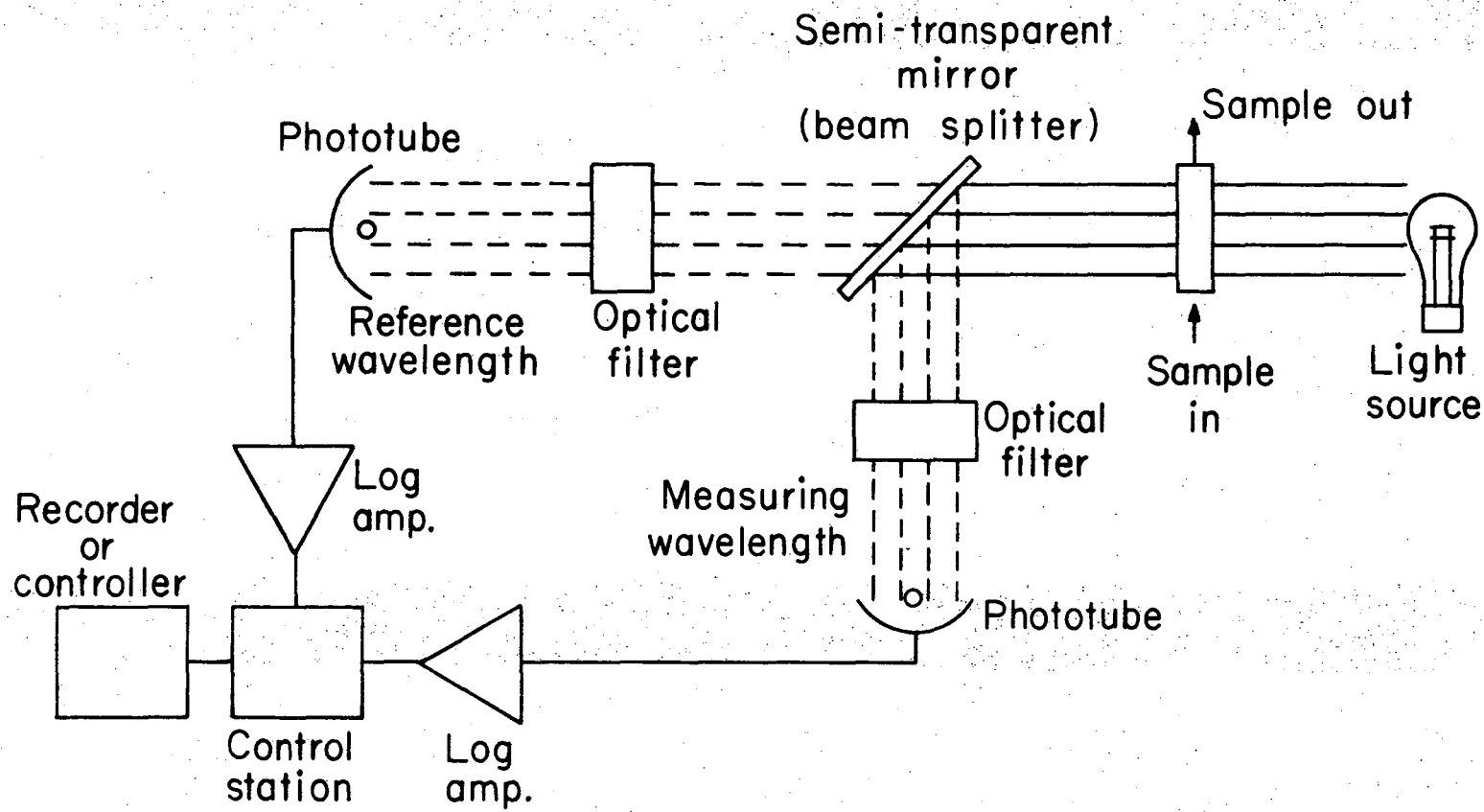
Figure 2  
Flame Photometric Detector





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Figure 3  
Nondispersive Infrared Analyzer



XBL726-3105

Figure 4  
Nondispersive Ultraviolet Analyzer

0 0 0 0 3 8 0 2 1 3 6

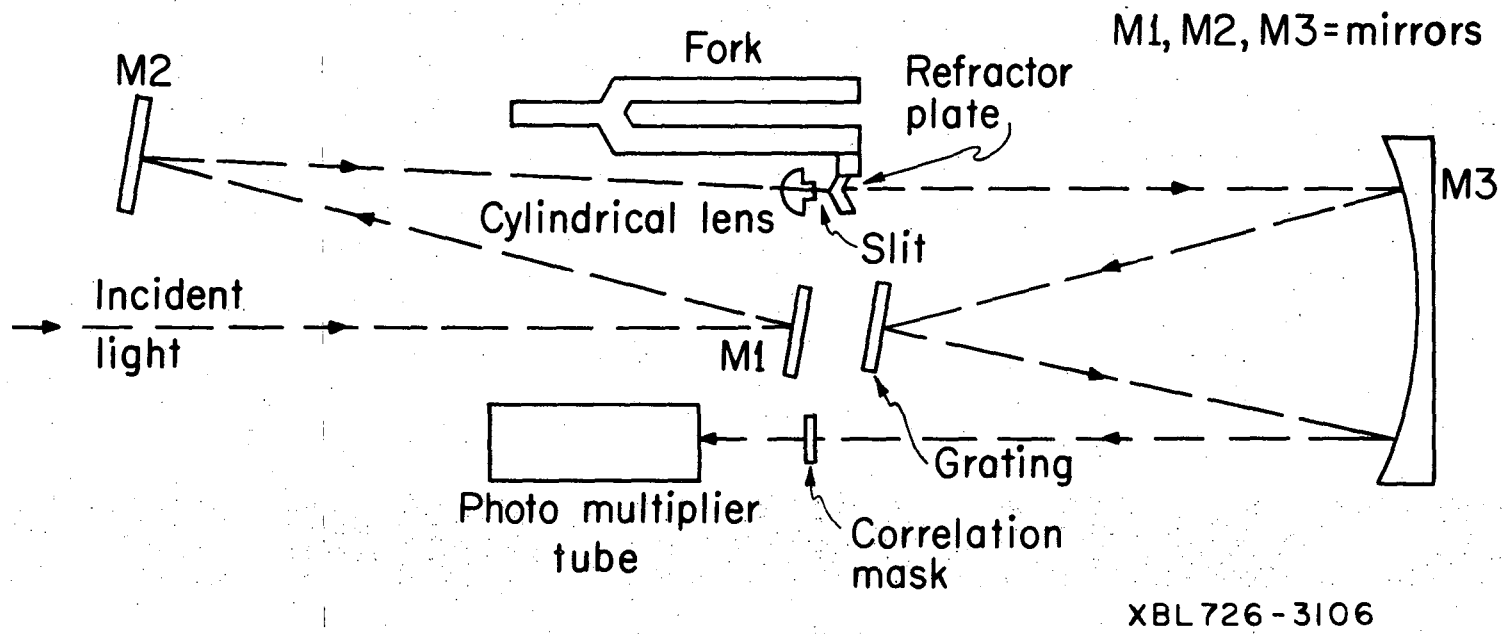
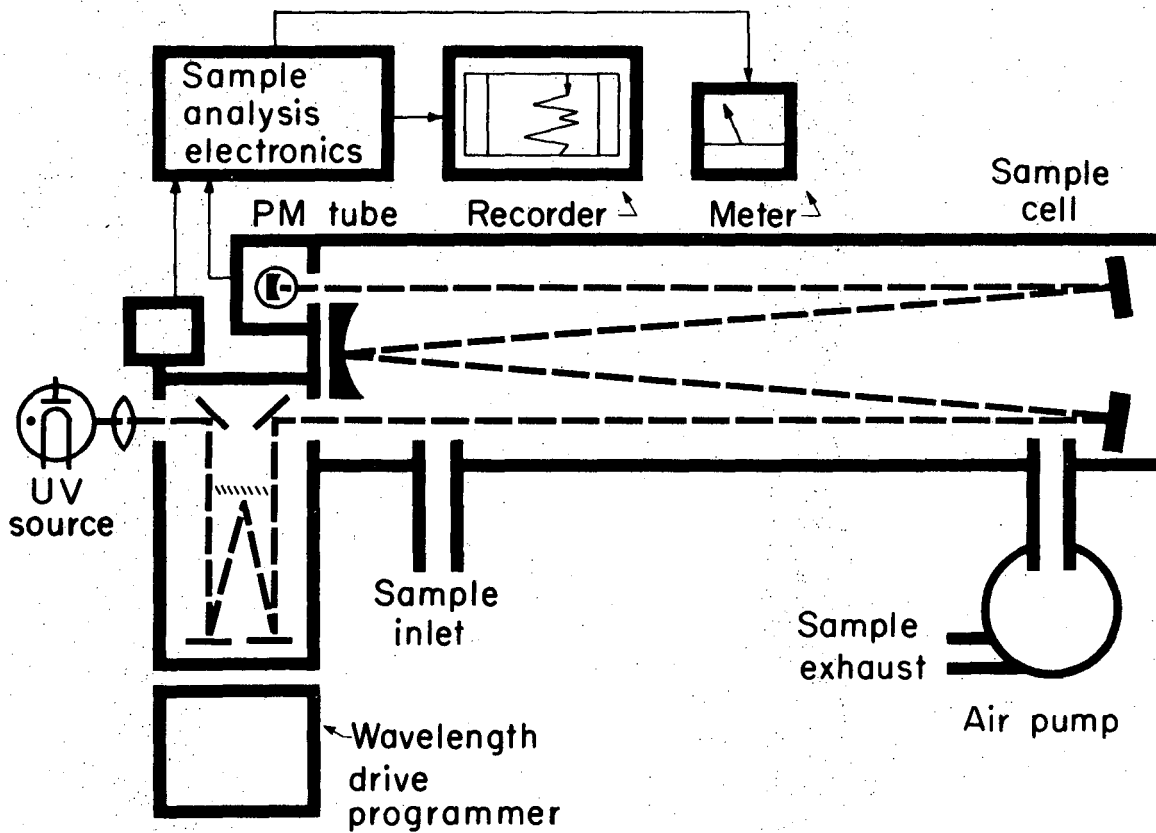


Figure 5  
Correlation Spectrometer for Remote Monitoring



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Figure 6  
Second Derivative Spectrometer

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