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Optical and Geometrical construction of Double-Beam Spectrophotometers

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ABSTRACT

Spectrophotometers measure the wavelength distribution of light. Double beam spectrophotometers allow real-time referencing using a separate reference position in the spectrophotometer. Small signal level differences at detector switching for highly accurate measurements even when the wavelength of detector is being switched : Multiple detectors are installed in the integrating sphere to perform measurement over a wide range of wavelengths, from ultraviolet to visible to near infrared regions. The split beam spectrophotometer is similar to the double beam, but it uses a beam splitter instead of a chopper to send light along the blank and sample paths simultaneously to two separate, identical detectors. A new double beam infra-red spectrometer recording directly in percent transmission vs. wave-length has been built on the principles described by Wright. The spectrometer and recorder are a single unit (40″ long, 22″ high, 20″ wide) with external amplifier and power supplies. Thus blank and sample measurements can be made at the same time. Spectra are measured in the same way for both instruments. Applications that require high speed, stability, and flexibility are better suited for the dual or split beam configuration. Measurements tend to be more reproducible, making them an appreciated instruments in industrial and quality control laboratories. Look for features such as long lamp life, on-board software, method storage, self-test diagnostics for GLP instrument performance validation, sample changers, extended warranties and service contracts. Optional accessories are available for specific application needs such as temperature control, tube adapters and automatic sippers.

Keywords:- Double beam spectrophotometers, optics, spectrophotometer

I. INTRODUCTION

In double beam design, the energy of the light source is divided into two with a half mirror so that one passes through the reference side, and the other through the sample side, which is unavailable with the single beam design[1]. Since the reference-side energy is also incident on a detector, photometry is carried out on the basis of this signal. Therefore, an energy change in the light source can be compensated to ensure stable measurement for a long time. The changes in photometric values at detector switching (from signal level differences) are minimized due to a design utilizing Hitachi's expertise in integrating sphere construction, signal processing technologies, etc. Spectrometers are used to measure the properties of light for a variety of applications including environmental or chemical analysis, fluorescence, or Raman as shown in fig.1. Spectrometers are optical instruments that can detect spectral lines and measure their wavelength or intensity. Additionally, fluorescence Spectrometers feature broadband spectral response ranges for detecting wide wavelength bands along with a wide slit width for increased throughput[2].

A spectrometer is an instrument for making relative measurements in the optical spectral region, using light that is spectrally dispersed by means of a dispersing element.

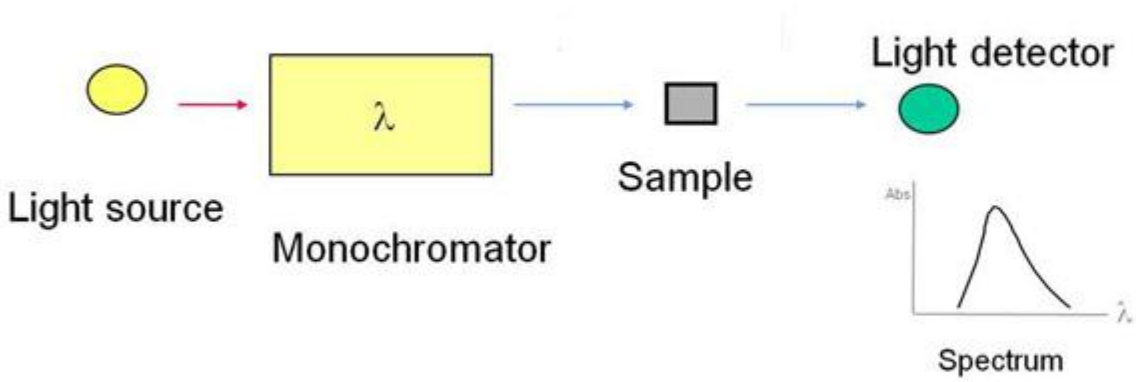

Fig.1.Block diagram of spectrum generation

Spectrophotometers, like all spectrometers, are devices used to discover the components which make up a material. All of this analysis and spectrophotometry is carried out using a complex system of components working together to analyze the material[3]. Essentially, a light source is fired on to a monochrometer, then the sample being studied before hitting a detector. This is done by measuring the radiant energy, also known as electromagnetic radiation, or light that is either transmitted through the material or reflected by the material.

We direct the light onto the sample. We know the intensity and wavelength of that light. Then we use a detector of some sort to measure what comes out the other side. What we will see is a spectrum. We see a change in the absorbance or intensity of that light as we move across the spectrum and change the wavelength. Based on these fundamentals, we have a range of different spectroscopic techniques available to us as scientists and engineers.

II. OPTICAL SPECTRUM ANALYSIS

Optical spectrum analysis is the measurement of optical power as a function of wavelength. Applications include testing laser and LED light sources for spectral purity and power distribution, as well as testing transmission characteristics of optical devices. Spectroscopes are often used in astronomy and some branches of chemistry[4].

Early spectroscopes were simply prisms with graduations marking wavelengths of light. Modern spectroscopes generally use a diffraction grating, a movable slit, and some kind of photodetector[5], all automated and controlled by a computer. When a material is heated to incandescence it emits light that is characteristic of the atomic makeup of the material.

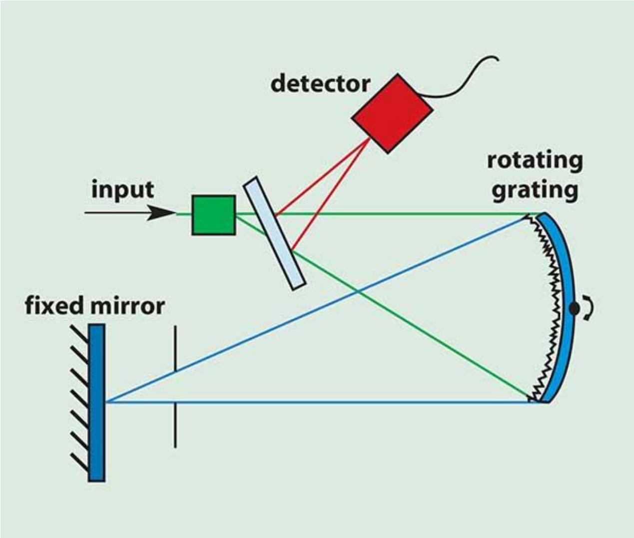

Fig.2. **Optical spectrum analysis**

An optical spectrometer (spectrophotometer, spectrograph or s pectroscope) is an instrument used to measure properties of light over a specific portion of the electromagnetic spectrum, typically used in spectroscopic analysis to identify materials[6].

Spectrometers are ideal for determining compositional makeup for detecting weak light signals. Spectrometers can also be used to test the efficiency of an optical filter in order to determine whether a filter has properly blocked or transmitted specific wavelengths as shown in fig.2.

Particular light frequencies give rise to sharply defined bands on the scale which can be thought of as fingerprints. For example, the element sodium has a very characteristic double yellow band known as the Sodium D-lines at 588.9950 and 589.5924 nanometers, the color of which will be familiar to anyone who has seen a low pressure sodium vapor lamp.

III. GEOMETRICAL ARRANGEMENT OF OPTICS

The Fluorescence Spectrometers are ideal for use in low light fluorescence applications where the ability to detect weak signals is crucial for proper measurement[7]. Optical spectrum analyzers can be divided into three categories: diffraction-grating-based and two interferometer-based architectures, the Fabry-Perot and Michelson interferometer-based optical spectrum analyzers[8]. Diffraction-grating-based optical spectrum analyzers are capable of measuring spectra of lasers and LEDs. The resolution of these instruments is variable, typically ranging from 0.1 nm to 5 or 10 nm. Fabry-Perot-interferometer-based optical spectrum analyzers have a fixed, narrow resolution, typically specified in frequency, between 100 MHz and 10 GHz. This narrow resolution allows them to be used for measuring laser chirp, but can limit their measurement spans much more than the diffraction-grating-based optical spectrum analyzers[9].

Geometrical optics in fig.3. or ray optics, describes light propagation in terms of rays. The ray in geometric optics is an abstraction useful for approximating the paths along which light propagates under certain circumstances.

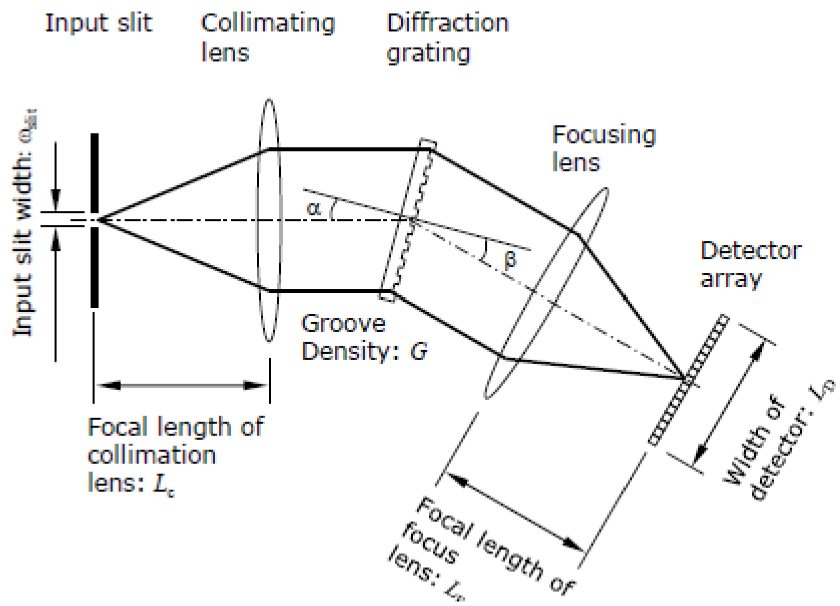

Fig. 3. Gometric optics arrangement

Input parameters:
Wavelength range: $\lambda_2 - \lambda_1$; $\lambda_c = (\lambda_2 + \lambda_1)/2$
Optical resolution : $\Delta\lambda$

Choose a geometry : Φ

Choose a grating: G

Calculate α and β as

$$\alpha = \sin^{-1}\left(\frac{\lambda_c G}{2\cos(\Phi/2)}\right) - \frac{\Phi}{2}$$

$$\beta = \Phi - \alpha$$

Choose a detector: L_D

Calculate focal length of focus lens/mirror: L_F

$$L_F = \frac{L_D \cos(\beta)}{G(\lambda_2 - \lambda_1)}$$

Choose magnification: M

Calculate focal length of collimation lens/mirror: L_C

$$L_c = L_F \frac{\cos(\alpha)}{M\cos(\beta)}$$

Calculate input slit width: w_{slit}

$$w_{slit} = \frac{G\,\Delta\lambda\,L_c}{\cos(\alpha)}$$

The simplifying assumptions of geometrical optics include that light rays:

- propagate in straight-line paths as they travel in a homogeneous medium
- bend, and in particular circumstances may split in two, at the interface between two dissimilar media[10,11].
- follow curved paths in a medium in which the refractive index changes
- may be absorbed or reflected.

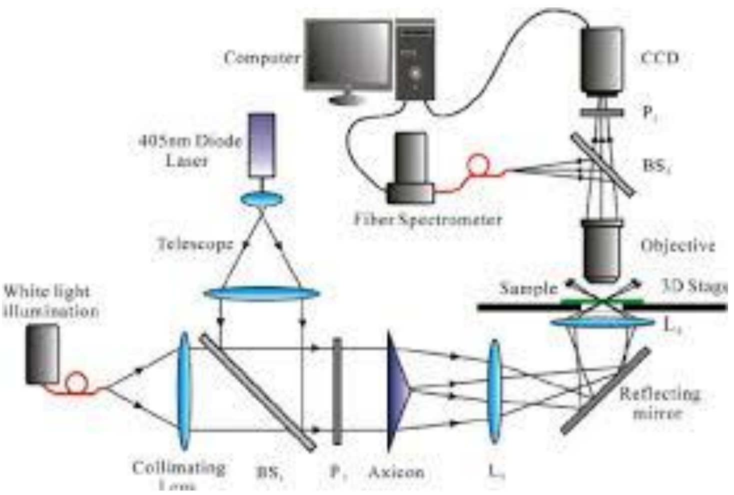

Fig. 4. Geometrical arrangement of optics

Geometrical optics does not account for certain optical effects such as diffraction and interference. This simplification is useful in practice; it is an excellent approximation when the wavelength is small compared to the size of structures with which the light interacts. The techniques are particularly useful in describing geometrical aspects of imaging, including optical aberrations[12].

Michelson interferometer-based optical spectrum analyzers, used for direct coherence-length measurements, display the spectrum by calculating the Fourier transform of a measured interference pattern as shown in fig.4. The optics of this instrument adopts the Seya-Namioka monochromator widespread as a representative concave diffraction grating monochromator.

Because a concave diffraction grating has both beam condensing and dispersing functions, an optical system canbe configured with fewer mirrors. In a spectrophotometer, use of fewer mirrors signifies a shorter optical path, thus giving rise to an aberration-free bright optics.

For elimination of the aberrations which were essentially unavoidable in the past, a stigmatic concave diffraction grating has been developed by applying Hitachi's original technology. As a result, a higher resolution has been realized. A higher resolution has been achieved by eliminating coma from the Seya- Namioka monochromator which is the most popular concave diffraction grating monochromato[13]r. Its grooving is supported by the only ruling engine in Japan. The diffraction gratings of Model U-2900/2910 have also been made with this machine.

IV. RESULTS AND DISCUSSION

A spectrometer is used in spectroscopy for producing spectral lines and measuring their wavelengths and intensities. Multi functions operated directly on the spectrophotometer and display the test results' curve and data: wavelength scanning, standard curve, kinetics, multi wavelength scanning, DNA/protein test. Spectrometers may also operate over a wide range of non-optical wavelengths, from gamma raysand X-rays into the far infrared[14]. Spectrometers measure which wavelengths a material absorbs and which wavelengths it reflects, whilst a spectrophotometer measures the amount of light or the intensity of light a material absorbs or reflects at a specific wavelength. As a result, spectrophotometers can provide more information about the material being studied than a spectrometer.

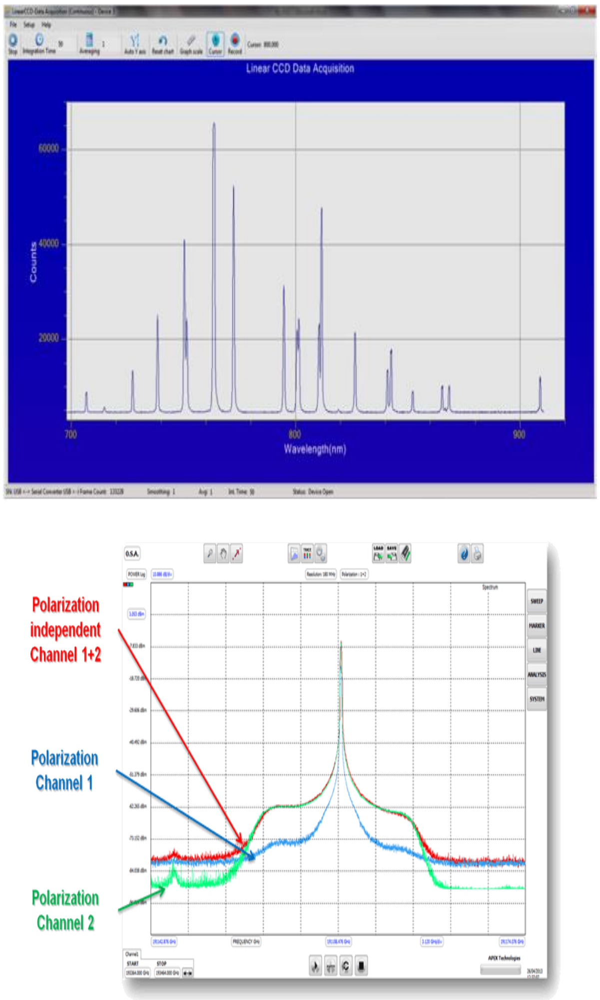

Fig.5. High resolution optical spectrum analysis

If the instrument is designed to measure the spectrum in absolute units rather than relative units, then it is typically called a spectrophotometer. The majority of spectrophotometers are used in spectral regions near the visible spectrum.

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