Optical density\turbidity meter report

TEAM 7

Basmalah tarek - Lama Zakaria Hassan

Lamees Mohamed Mohee Eldeen - Manar Ashraf

Nouran Mahmoud Mahmoud - Yasmeen Tarek

1. Description of the project

This project aims to create a low-cost gauge that can be used as an optical density meter or a turbidity meter using an LDR as a light sensor, magnifying lenses and the glass container that acts like a cylinder\spherical lens

Optical density (OD), also referred to as absorbance, is a property that describes a material's ability to absorb the power of a given light (called "radiant power") that is passed through that material. It is defined as a ratio between the incident radiant power (the power of the light as it hits the material) and the transmitted radiant power (the power of the light as it exits the material). In other words, optical density is the ability of a material to block a particular light. 1

The optical density or absorbance of a material is a logarithmic intensity ratio of the light falling upon the material, to the light transmitted through the material. Density measurement is widely used in research and clinical labs as it provides a rapid and inexpensive method of adjusting microbial suspensions to set concentrations. The technique is particularly powerful when used in conjunction with cell counting methods, allowing researchers to rapidly dilute suspensions to an estimated concentration using optical density and then confirm the estimate was correct using cell concentration counting. 2

An optical density meter is an instrument used to measure optical density, absorbance or transmittance, the flipside of absorbance, based on the Beer-Lambert Law:

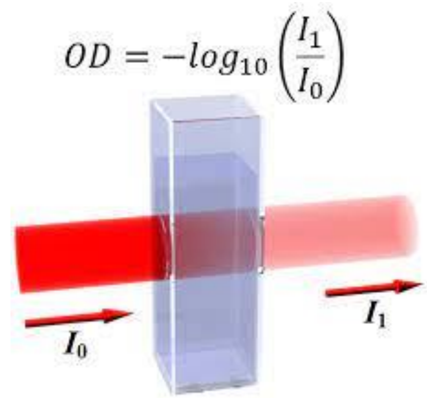
A = log10 (1/T) = log10 (Io/I)

A : Absorbance.

T: Transmittance.

Io: Incident light intensity.

I: Transmitted light intensity.



Noticing that optical density measurement takes both, the absorption and scattering of light, into consideration.3

Turbidity is the measure of the relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material in the water when a light is shined through the water sample. The higher the intensity of scattered light, the higher the turbidity. 4

Turbidimetry is a method for determining the concentration of a substance in a solution by measuring the loss in intensity of a light beam through a solution that contains suspended particulate matter. 5

A turbidity meter is a testing device designed to measure the haziness, or cloudiness of a liquid sample by determining how much light can pass through it based on turbidimetry or nephelometry. A turbidity probe works by sending a light beam into the water to be tested. This light will then be scattered by any suspended particles. A light detector is placed at a 90-degree angle in case of nephelometry and a 180-degree angle in case of turbidimetry to the light source and detects the amount of light that is reflected back at it. 6

Applications of optical density:

- Optical density (OD) is used as a rapid proxy measurement of suspended biomass concentration.
- Optical density measurements are most commonly used in microbiology laboratories to assess the growth of microbes in terms of OD.
- Optical density is used both qualitatively as the turbidity of culture and quantitatively as a measure of the intensity of light transmitted along a path through the culture of known path length.
- OD can also be used to estimate levels of pigments within cells when the chosen wavelength corresponds to the chromophore absorption. 7
- For materials such as black film, X-ray film, aluminized film and ink on cell phone lenses that we can see in our daily life are all required to test optical density in the industry. For these materials with very low light transmittance, it is difficult to compare the difference between the materials with the light transmittance value. But if converted into the optical density value, the data will be more intuitive. 8

Applications of turbidimetry:

- Find the number of cells in a solution. 9
- Check the purity of water.
- Determine air and water pollution.
- Determine densities of microbes. 10
- Used in turbidimetric titration.
- Determine the concentration of protein molecules in biological fluids such as urine and CSF.
- Determine the molecular weight of high polymers. 11

2. Light signal and its parameters

Visible light is a form of electromagnetic (EM) radiation, as are radio waves, infrared radiation, ultraviolet radiation, X-rays and microwaves.

Generally, visible light is defined as the wavelengths that are visible to most humans. We are using a torch / mobile flash to emit the light in our project.

The primary properties of light are intensity, propagation direction, frequency, wavelength spectrum and polarization.

Its speed in the vacuum is 3×10^8 m/s.

Visible light is usually defined as having wavelengths in the range of 400–700 nanometers (nm), corresponding to frequencies of 750-420 THz, THz is a Terahertz the infrared (with longer wavelengths) and the ultraviolet (with shorter wavelengths

For this law V= f×h

There is an inversely proportional relationship between the frequency (f) and wavelength (h).12

There's also illumination which is measured in (lux) - as known - it depends on the distance from the light source and inversely proportional with the square of the distance, we can measure the luminous intensity of the source (the torch in our case).13

Knowing that I in watt per meter square is directly proportional to I in lux.22

So the power P in watts (W) is equal to the illuminance E_v in lux (lx) times the surface area A in square meters (m^2), divided by the luminous efficacy η in lumens per watt (lm/W):

$$P_{(W)} = E_{v(lx)} \times A_{(m^2)} / \eta_{(lm/W)}$$

So

watts = lux × (square meters) / (lumens per watt)

or

$W = lx \times m^2 / (lm/W)$

And knowing that OD depends on dividing I and I0, so using either unit is fine

The particle properties of light appears clearly in the LDR working principle as when the photons hit the locked electrons in the semiconductor they absorb energy and move away from the crystal lattice so that they can conduct electricity.14

3. **Material properties and type of material-light interaction**

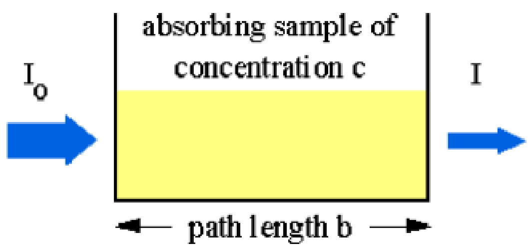
If a beam of light is passed through a cloudy sample or a culture its intensity is reduced by scattering, absorption. The amount of light scattered depends on the concentration, distribution, type and shape of the particles

A water sample colored by dissolved substances (solution) is a homogeneous system that only attenuates the radiation that goes through it while a water sample that contains undissolved particles attenuates the incident light and, in addition, the particles scatter the light unequally in all directions (colloid). The scattering of the radiation towards the front generated by the particles, changes the attenuation in such way that the relative spectral attenuation coefficient $\mu(\lambda)$ is the sum of the spectral diffusion coefficients $s(\lambda)$ and the spectral absorption coefficient $\alpha(\lambda)$.15

$\mu(\lambda) = s(\lambda) + \alpha(\lambda)$

Firstly, absorption

Absorption occurs when the photon frequency matches the frequency associated with the molecules energy transition, knowing lambert-beer law



$$I = I_o e^{-\mu_a \cdot b}$$

$$\mu_a = N_a \cdot \sigma_a$$

The intensity of transmitted light is inversely proportional to the number of molecules per unit volume (concentration),

So when the concentration of the dissolved substances in the liquid increases that leads to decreasing the light level read by the LDR.

If the solution is colored, the molecules absorb all the other colors in the light and reflects that color only.

Absorption affects scattering too as will be shown

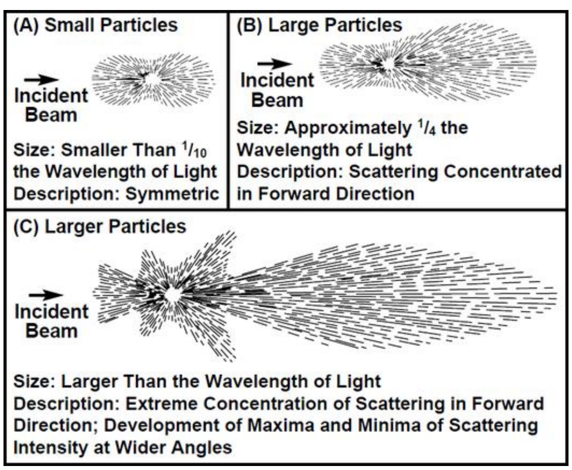
As for scattering, Particles interact with incident light absorbing it and scattering it in all directions. The spatial distribution of scattered light depends on many factors:

1. Particle color-This determines the ability to absorb or reflect the incident light beam. For example the sand absorbance of light is not as coal powder.

2. Particle shape-This determines the ability of the suspended solids to provide a constant spatial distribution pattern. A smooth, spherical-shaped particle is not as irregularly-shaped particles

3. A difference between the refractive indexes of the particle and the sample fluid, the intensity of the scattered light increases as the difference increases.16

And most importantly: the ratio of particle size to wavelength of incident light according to this figure.15



It should be notices that the amount of scattered light is proportional to the concentration but till certain limit.16

- **Scattering Coefficient, μ_s [1/m]**
  - $\mu_s = N_s \sigma_s$,
    - N_s = the number density of scatterers
    - σ_s = scattering efficiency
  - Cross-sectional area for scattering per unit volume of medium

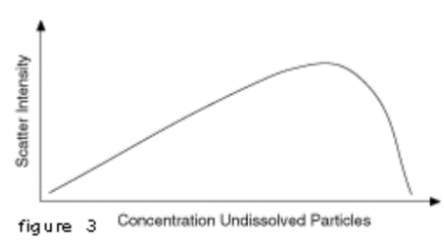
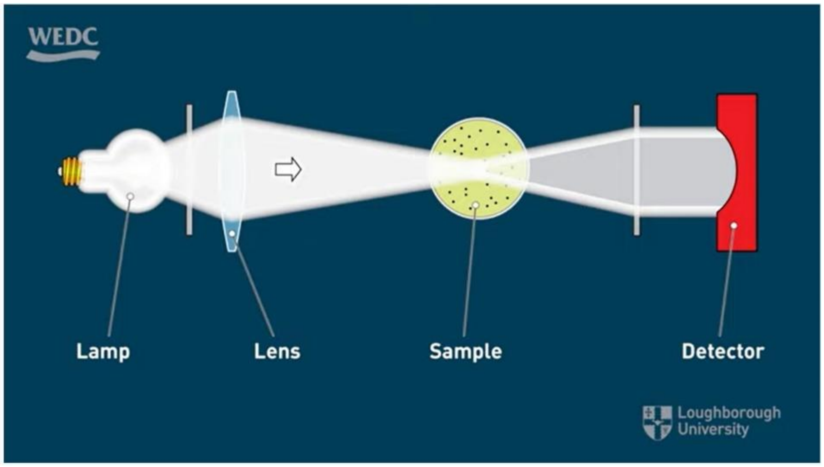


figure 3

Optics part

As explained briefly before we’re using a convex lens and a cylinder\spherical lens with some aberration.



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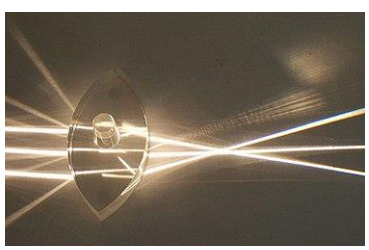
Firstly: The Convex lens:

The convex lens is a lens that converges rays of light that convey parallel to its principal axis which is relatively thick across the middle and thin at the lower and upper edges. The edges are curved outward rather than inward.

Generally, a convex lens can converge a beam of parallel rays to a point on the other side of the lens. This point is called a focus of the lens and its distance from the Optical Center of the beam is called the focal length.

Formula:

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$



Where, f is focal length,

v is denoted as the distance of the image from the optical center,

u is denoted as the distance of the object from the optical center.

In convex lenses, the focal length is positive.

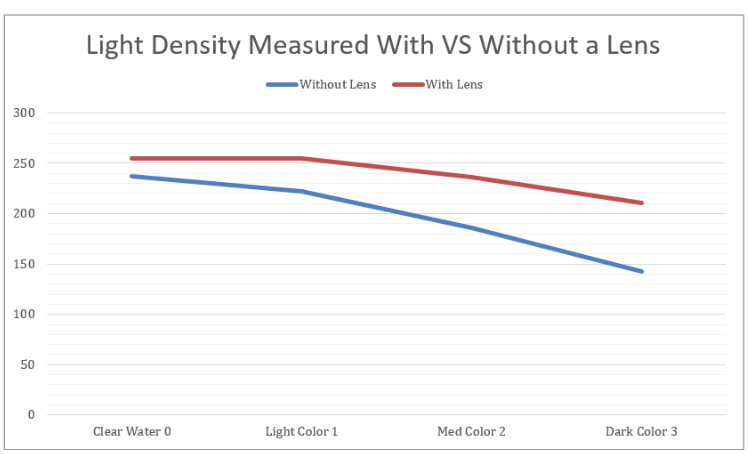
We will use a Double Convex Lens (The magnifying lens) -that is curved outwards from both sides- before the sample whose absorbance to be measured, it is used to concentrate the light incident on the sample and thus help both use a low-power light source and focus the light on the sample. It has a shorter focal length than Plano-convex lenses of equal diameter and surface radius. The double convex lens is used in general as objectives or magnifiers, it produced the virtual image for the human eye and the real image for photography and as an optical sensor and used in burning glass.18

Real Image and Virtual Image for Convex Lens

Real Image: A convex lens can be used to produce a real image, and this occurs if the object is located at a position of more than one focal length from the lens. It is projected in front of the lens and can be captured on a screen. It is used in movie theaters, projector etc.

Virtual Image: A convex lens will produce a virtual image if the object is located in front of the focal point. It is used in eyeglasses to give clear images.

We've tried to check the effect of using the convex lens, we firstly recorded the reading without using any lenses and then we increased the concentration of the substance gradually and noticed that on using lenses the intensity read is higher than the intensity read without using lenses as shown in the graph



As for the glass container we noticed that it acts like a cylinder\spherical lenses that are used to gather the light similarly to the convex lens, which means that we don't need another magnifying lens.

Cylinder Lenses are typically used to focus incoming light to a line, or to change the aspect ratio of an image. Cylindrical Lenses have a single cylindrical surface that causes incoming light to be focused in only a single dimension, stretching the image. Cylinder Lenses are available with positive or negative focal lengths, ideal for laser line generation or anamorphic beam shaping to circularize laser outputs (noticing that the LDR shape is a circle).19

And they have pretty special way to express their effective focal length.20

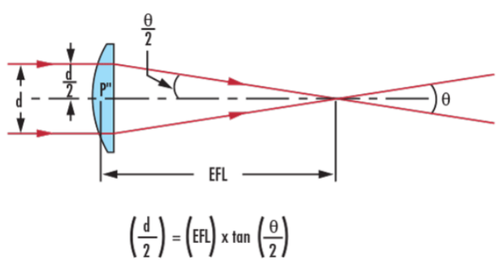
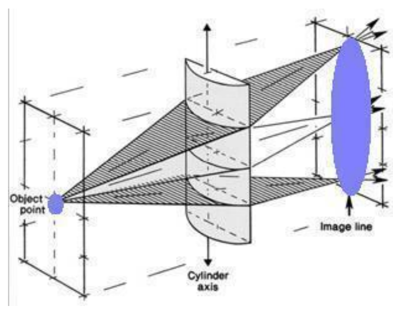


Figure 5: Visual Illustration of Equation 3 for Calculating Effective Focal Length



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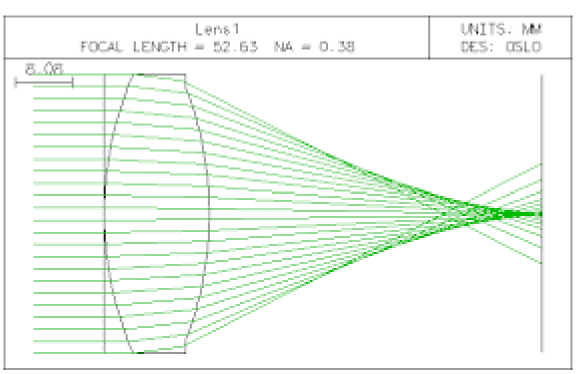
We also noticed that there's some aberration in the beams but that doesn't influence the effect of changing concentration on the light level read by the LDR



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