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Determination of the Optical Properties of Cobalt Oxide Using Ultraviolet Visible Spectroscopy

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ABSTRACT

This study explores the optical properties of cobalt oxide using ultraviolet-visible spectroscopy, crucial for applications in optical reagents, solar cells, and related technologies. Five samples with varying molarities (0.1, 0.3, 0.5, 0.7, and 0.9 M) of cobalt oxide were prepared via the Sol-Gel technique. Optical characteristics including absorption, reflection, refraction, transmission, absorption coefficient, and energy gap were analyzed using a Shimadzu 1240 scanning spectrophotometer at room temperature over a wavelength range of 273 to 585 nm. Key findings include a maximum absorbance of 1.02 within 273 to 351 nm, transmission value of 28% at 312 nm, and reflection value of 0.113 from 272 to 351 nm. The absorption coefficient peaked at 4.52×10^3 within 273 to 351 nm, and the energy gap was determined as 3.782 eV at 368 nm, consistent with the expected range for conductor oxides (3.0 - 4.0 eV) within the wavelength range of 300 to 400 nm. The study reveals that increasing cobalt oxide concentrations, increases absorption and absorption coefficient and decreases reducing reflectance and energy gap. This research recommends further investigation using different concentrations of cobalt oxide and suggests employing alternative methods and devices for validating these optical property determinations on the same samples.

Keywords: Optical Properties, Cobalt Oxide, and Ultraviolet Visible Spectroscopy

INTRODUCTION

The exploration of semiconductor materials, which possess electrical conductivity values between those of metals and insulators, began in the 19th century (Hamza, 2019). Semiconductors are characterized by their intermediate electrical properties relative to insulators and conductors. Magnetic semiconductors are a subclass that includes metal oxides combined with ferric oxides, exhibiting a range of electrical and magnetic properties relevant to various applications in the electronics industry (Łukasiak and Jakubowski, 2010).

Semiconductors feature an energy gap between their valence and conduction bands. To enable electrical conduction, electrons must acquire sufficient energy to transition from the valence band to the conduction band (Yu and Cardona, 2010).

The optical properties of materials describe their interactions with electromagnetic radiation. This spectrum includes x-rays, ultraviolet (UV), visible light, infrared, and radio waves. Key optical properties include energy gap, absorption coefficient, reflection, transmission, and absorbance (Kailas, 2003). Optical interactions occur when photons interact with a material's electronic or crystal structure, leading to phenomena such as absorption (energy uptake), reflection (re-emission of photons), transmission (passage through the material), and refraction (change in photon velocity). The total incident light intensity equals the sum of absorbed, reflected, and transmitted intensities, highlighting the significance of all optical phenomena (Swati et al., 2015).

Cobalt (Co), a transition metal in the d-block, is a bluish-white element located between iron and nickel in the periodic table. It shares many properties with these elements, including an electronegativity of 1.88 on the Pauling scale and a first ionization potential of 7.88 eV (Faucon and Pourret, 2016). Cobalt oxide, a stable compound, exhibits notable electronic and magnetic properties, making it an efficient catalyst in various reactions and a promising material for scientific and technological applications (Danick, 2006).

The UV-visible range constitutes a small segment of the electromagnetic spectrum, extending from approximately 190 nm at the high-energy UV end to about 750 nm at the low-energy red end. Light outside this range generally induces different types of transitions, often not energetic enough for electronic transitions but sufficient to excite molecular vibrations (Meier, 2005).

Ultraviolet-visible (UV-Vis) spectroscopy, one of the oldest instrumental techniques, is crucial for analyzing micro and semi-micro quantities in samples. It involves measuring the effects of UV and visible radiation on absorbing species, such as atoms, molecules, or ions (Alaa, 2019).

Chen et al. (2011) investigated the electronic structure and bonding properties of cobalt oxide in the spinel structure. Their study utilized Density Functional Theory with GGA+U calculations, employing a plane wave pseudo potential scheme within the Quantum ESPRESSO package. The study provided detailed insights into the lattice constants, bond distances, and electronic properties, including band structures and energy gaps.

Emily et al. (2020) focused on the chemical exfoliation of cobalt oxide using UV-Vis spectroscopy to analyze the concentration of 2D cobalt oxide nanostructures under various reaction conditions. The study involved a two-step wet chemical method, which revealed significant morphological changes in the exfoliated material, particularly under the influence of tetraethyl ammonium hydroxide (TMAOH).

Ahmed (2004) investigated the magnetic properties and morphology of block cobalt oxide nanocomposites using a HTACH H600 transmission electron microscope (TEM) and UV-Vis spectrophotometer. The study reported that the polymer-cobalt oxide nanocomposites exhibited an absorption edge at 300 nm and were transparent in the visible range. However, the materials were highly susceptible to electron beam damage, complicating the analysis of their crystal structure using electron diffraction.

The optical properties of cobalt oxide are complex and require both modern and classical methods to accurately determine. This research aims to further explore and characterize these properties. The specific objectives of the present research are to:

i. study optical properties of cobalt oxide,
ii. prepare the cobalt oxide with different concentrations using the sol-gal method,
iii. determine the optical properties of cobalt oxide such as energy gap, Absorbance, Absorption coefficient, Reflection, Refraction, Transmission.

MATERIALS AND METHODS

Preparation of Cobalt Oxide

Five samples of cobalt oxide with different concentration (0.1, 0.3, 0.5, 0.7,and 0.9 M) was prepared by the sol-gel method, the uv spectrophotometer was used to analysis cobalt oxide, A glass cup, nitric acid, filtered water, a sensitive weighing scale, and an ultraviolet

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spectrophotometer were used in the experiment.

Method of Deposition of Metallic Oxide

Translucent carrier oxide or metal oxides can be deposited via two methods namely: physical methods and chemical methods. Of interest to this work is chemical (sol-gel) method.

Sample Preparation

In this research, samples with different concentrations of cobalt oxide were prepared (0.1, 0.3, 0.5, 0.7, 0.9M) using the sol-gel method. Three samples of cobalt oxide with varying concentrations were prepared. First, cobalt hydroxide $Co(OH)_2$ was weighed using a sensitive balance. The weighed cobalt hydroxide was then dissolved in an appropriate amount of filtered water in a graduated glass beaker. The beaker was placed on a magnetic stirrer, and the solution was stirred to ensure uniform mixing.

Next, a few drops of concentrated nitric acid were gradually added to the solution using a pipette. The addition of nitric acid was continued until the solution became homogeneous. The following chemical equations illustrate the reactions involved:

$$Co(OH)_2 + 2HNO_3 \rightarrow Co(NO_3)_2 + 2H_2O$$

After stirring the mixture for half an hour, until it becomes homogeneous, the solution is placed in an oven for drying. Once dried, the sample is transferred into a quartz cuvette and left at room temperature for 24 hours. Finally, the sample is analyzed using a UV spectrophotometer.

RESULTS AND DISCUSSION

The optical properties of CoO_2 samples were studied using a Shimadzu UV-2600 UV-Vis spectrophotometer. The results are discussed below based on the relationships between absorbance, transmission, reflection, absorption coefficient, and energy gap.

Absorbance vs. Wavelength

The absorbance spectra of CoO_2 samples show that the maximum absorbance value is 102, while the minimum is 59, within the wavelength range of 273 to 351 nm (Figure 1). Higher concentrations of cobalt oxide result in increased absorbance values. This suggests that as the concentration of cobalt oxide increases, the material exhibits greater light absorption.

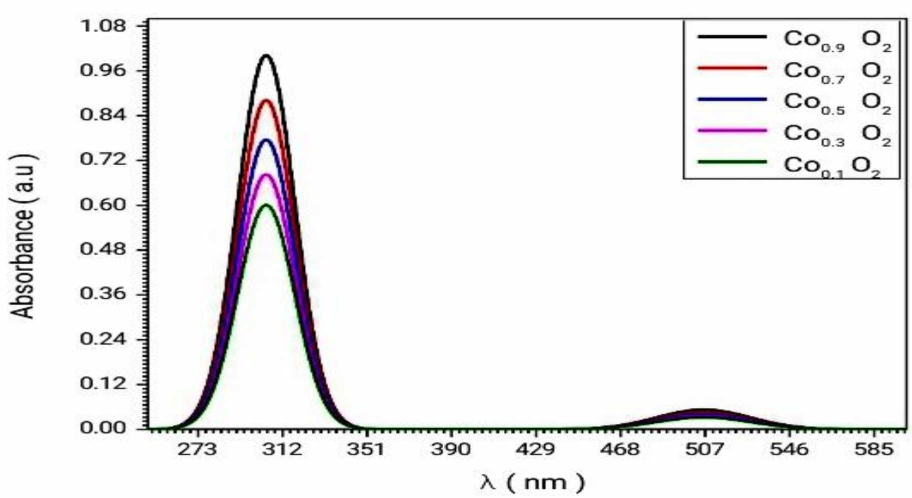

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Figure 1: The relationship between absorbance and wavelength of the cobalt oxide samples was acquired using a Shimadzu UV-2600 UV-Vis spectrophotometer.

Transmission vs. Wavelength

The transmission spectra indicate that the maximum transmission value is 28 and the minimum is 10, observed at a wavelength of 312 nm (Figure 2). Lower concentrations of cobalt oxide lead to higher transmission values. This implies that samples with lower cobalt oxide concentrations allow more light to pass through.

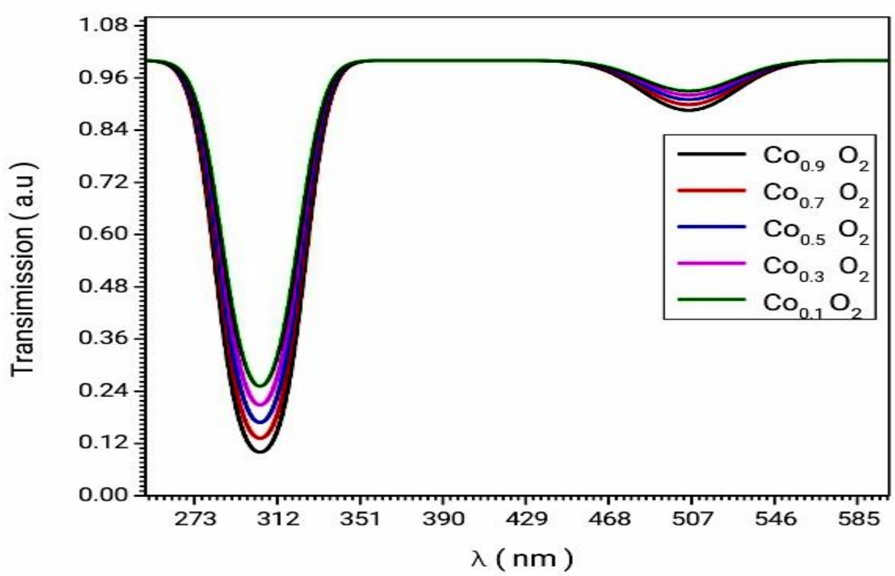

Figure 2: Relationship between transmission (a.u.) and wavelength (λ) of the CoO_2 sample, measured using a Shimadzu UV-2600 UV-Vis spectrophotometer.

Reflection vs. Wavelength

In the wavelength range of 273 to 351 nm, the maximum reflection value is 0.113, and the minimum is zero. Higher concentrations of cobalt oxide result in reduced reflection. Conversely, in the range of 429 to 585 nm, the maximum reflection value is 0.084 and the minimum is 0.053 (Figure 3). Lower concentrations of cobalt oxide result in higher reflection values. This indicates that cobalt oxide concentration affects the material's reflective properties across different wavelength ranges.

Absorption Coefficient vs. Wavelength

The absorption coefficient values range from a maximum of 4.52×10^3 to a minimum of 2.79×10^3, within the wavelength range of 272 to 351 nm (Figure 4). Higher concentrations of cobalt oxide result in increased absorption coefficients. This demonstrates that the material's ability to absorb light intensifies with greater cobalt oxide concentration.

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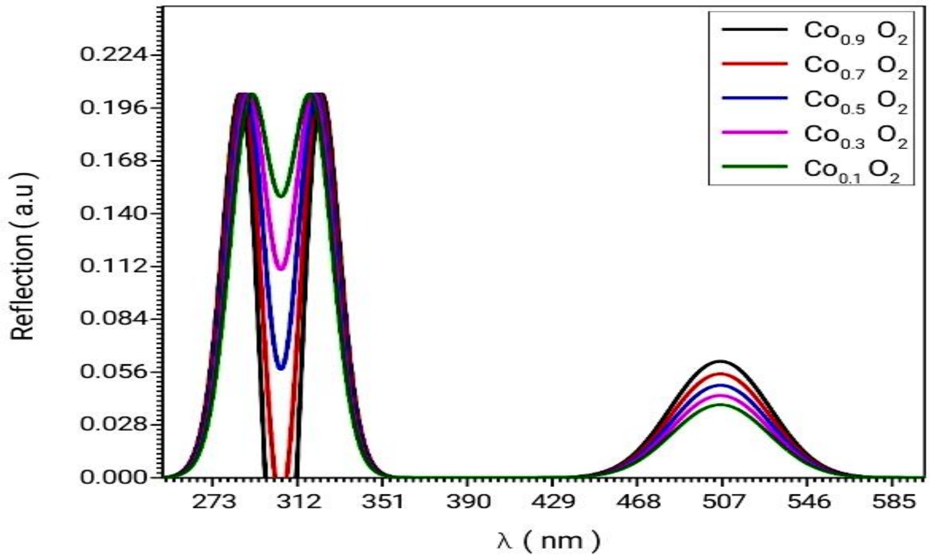

Figure 3: Relationship between reflection (a.u.) and wavelength (λ) of the CoO_2 sample, measured using a Shimadzu UV-2600 UV-Vis spectrophotometer.

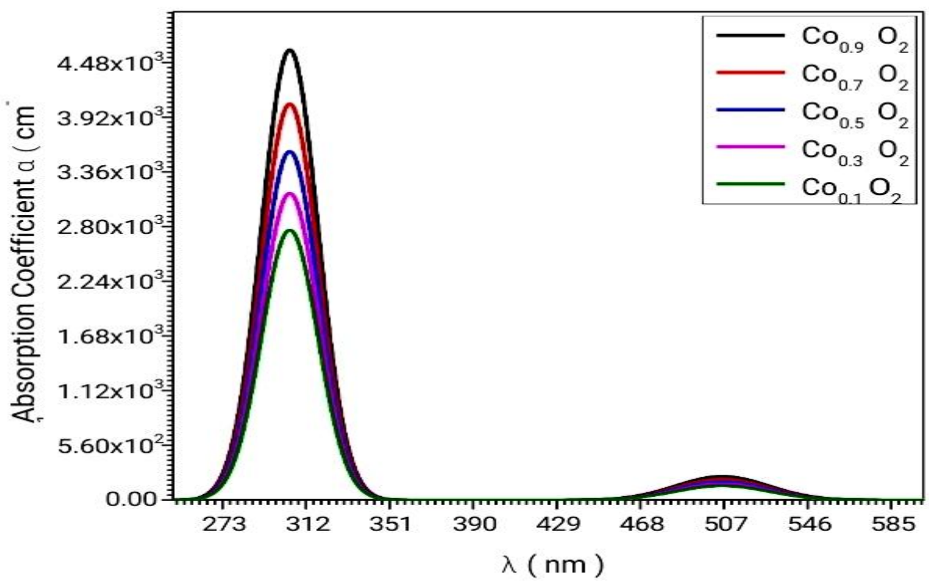

Figure 4: Relationship between the absorption coefficient (α\alphaα in cm−1^{-1}−1) and wavelength (λ\lambdaλ) of CoO_2 samples, measured using a Shimadzu UV-2600 UV-Vis spectrophotometer.

Energy vs. Energy Gap

The energy gap values range from a maximum of 3.783 eV to a minimum of 3.744 eV, observed at a wavelength of 3.68 eV (Figure 5). Lower cobalt oxide concentrations lead to larger energy gaps. This suggests that the band gap of cobalt oxide changes with varying concentrations, affecting the material's electronic properties.

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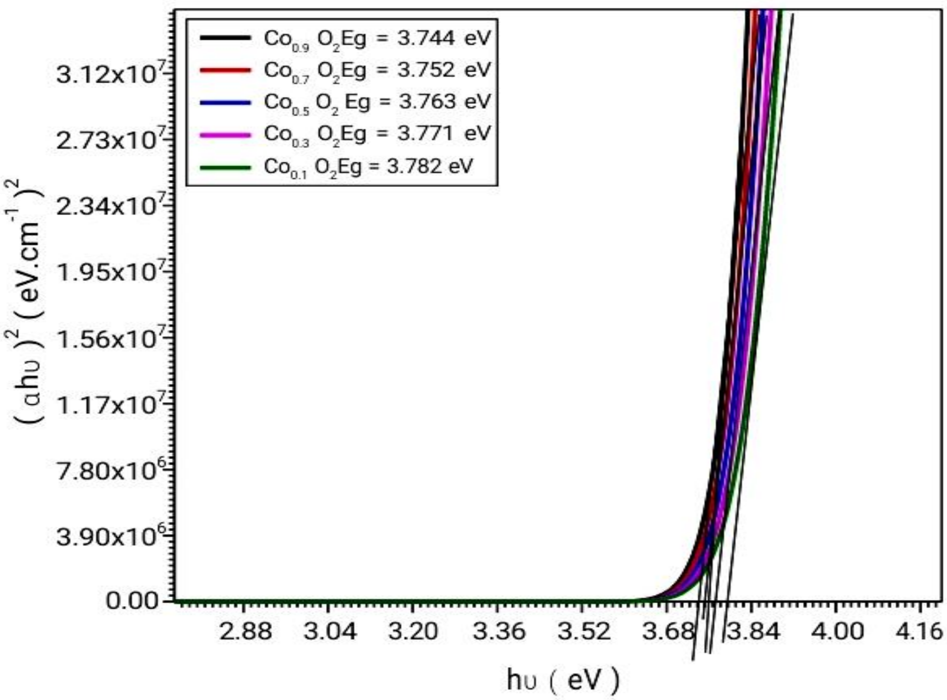

Figure 5: Relationship between energy (E) and the energy gap of CoO_2 samples, measured using a Shimadzu UV-2600 UV-Vis spectrophotometer.

CONCLUSION

This study provides a comprehensive analysis of the optical properties of CoO_2 samples using ultraviolet-visible spectroscopy. The investigation revealed that varying concentrations of cobalt oxide significantly impact absorbance, transmission, reflection, absorption coefficient, and energy gap. Higher concentrations of CoO_2 result in increased absorbance and absorption coefficient while decreasing transmission and reflection. This trend indicates that cobalt oxide concentration enhances the material's light absorption capabilities while reducing its transparency and reflective properties. Conversely, lower concentrations lead to improved transmission and reflection, as well as a larger energy gap. These findings offer valuable insights into the optical behavior of CoO_2, which could be beneficial for applications requiring precise control of light absorption and transmission properties. Overall, this research contributes to a deeper understanding of the material's optical characteristics and opens avenues for further studies in optical and electronic applications of cobalt oxide.

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