Sudan University of Science and Technology

Postgraduate Studies College

Calculation of the Energy Band Gap and some Optical Properties of Single Wall Carbon Nanotube

حساب فجوة حزمة الطاقة وبعض الخصائص البصرية لأنابيب الكربون النانوية أحادية الجدار

A Thesis submitted in partial for requirement of the Degree of Master in physics

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الآيـــــــة

قال تعالى:

بسم الله الرحمن الرحيم

إقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ (1)خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ (2)اقْرَأْ وَرَبُّكَ الْأَكْرَمُ
(3)الَّذِي عَلَّمَ بِالْقَلَمِ (4)عَلَّمَ الْإِنْسَانَ مَا لَمْ يَعْلَمْ (5)

صدق الله العظيم

سورة العلق

Dedication

To the parents........ Without them, I would not have existed in this life, and from them I learned to be steadfast, regardless of the difficulties.To my esteemed teachers........ From them I drew letters and learned how to pronounce words, formulate phrases, and refer to the rules in the field of. To colleagues, who have spared no effort in providing information and data I dedicate a master's thesis to you

Acknowledgements

Thanks be to God Almighty, then my parents for all their efforts from my birth to these moments, you are everything that God loves you most in love. I am pleased to extend my thanks to everyone who advised me, guided me, directed me, or contributed with me in preparing this research by sending me to the references and resources required at any stage of its stages, and I especially thank my distinguished professor, the Dr. Rawia Abdelgani for my support and guidance for advice, correction, and for choosing the title and topic, my thanks go to the administration of the College of Science - Department of Physics at the Sudan University of Science and Technology.

Abstract

Carbon Nanotube (CNT) is tubular form carbon with diameter as small as 1nm and length of few nanometers to microns. CNT is configurationally equivalent to a two dimensional graphene sheet rolled into a tube. The aim of research was manufacturing single walled carbon nanotube and calculation its absorbance, transmission and energy gap. In this research the optical properties investigated. Three different types of single walled carbon nanotube (lampblack, kohl and frankincense) weighted by using electric balance and dissolved in four hydrocarbon solutions benzene, acetone, methanol and ethanol in order to obtain 12 samples of single walled carbon nanotube to study their optical properties such as absorption and transmission. The absorbed spectrum and energy gap were studied using USB Spectrophotometer which gives higher absorptivity wavelength for lampblack at 477 nm in methanol solution, and higher absorbance for kohl in benzene solution and equal 1.20 au and higher transmission for frankincense in acetone solution equal 29.4 %, higher energy gab of lampblack, kohl and frankincense in methanol solution and equal 2.53 eV.

المستخلص

الانابيب النانوية الكربونية (CNT) هو شكل أنبوبي من الكربون بقطر صغير يصل إلى 1 نانومتر وطوله بضعة نانومترات إلى ميكرونات . (CNT) مكافئ شكليًا لصفيحة جرافين ثنائية الأبعاد ملفوفة في شكل أنبوب. هدف البحث هو تصنيع أنابيب كربونية نانوية أحادية الجدار وحساب امتصاصيتها ونفاذيتها وفجوة طاقتها .وتم الحصول على ثلاثة أنواع مختلفة من انابيب الكربون اوحادية الجدار وهي (السناج و الكُحل و اللبان)، تم وزنها باستخدام الميزان الكهربائي ثم أذيبت في اربعة محاليل هيدروكربونية وهي البنزين والأسيتون والايثانول والميثانول للحصول على عدد 12 عينة من أنبوب الكربون أحادي الطبقة ودرست الخصائص البصرية مثل الامتصاصية والنفاذية .تم دراسة الطيف الممتص وفجوة الطاقة باستخدام مقياس الطيف الضوئي USB الذي اعطي اعلى طول موجة امتصاصية للسناج في محلول الميثانول وكانت 477 نانومتر، وكانت اعلى امتصاصية للكحل في محلول البنزين وتساوي 1.2 au واعلى نفاذية للبان في محلول الاسيتون وتساوي % 29.4 واعلى فجوة طاقة لكل من السناج والكحل واللبان في محلول الميثانول وتساوي 2.53 الكترون فولت.

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CHAPTER ONE

CHAPTER ONE
INTRODUCTION

1.1 Background

Nano is a short word consisting of four letters, the world's passion for it has increased in recent times after it shown in the skies of our daily life since the beginning of this century. A kind of imagination or just a dream that flicked the imaginations of scientists and moved the pens of the authors of science fiction films stories.

1.2 Problem of Research

The research problem is to produce carbon nanotubes and learn how to manufacture them with local capabilities to introduce nanotechnology for our country, there are new features that make it useful in many applications such as electronics, optics, in addition to many other fields where it shows exceptional strength, unique electrical properties and it is also good conductors of heat.

1.3 Aims of the Research

Manufacturing single walled carbon nanotube and calculation its absorbance, transmission and its energy gap.

1.4 Literature Review

- ✓ In 2007 Seok Ho Jeong provided A simple method of determining concentration of carbon nanotubes in solution by using optical absorption spectroscopy and they demonstrates the concentration of unknown carbon nanotubes dispersed in aqueous solution can be easily determined by simply measuring absorbance, once the extinction coefficient of the material is determined in advance.
- ✓ In 2006 Á. Pekker, using optical absorption spectra for characterizing carbon nanotubes they found the far-infrared spectral region creates a

unique possibility for estimating the amount of metallic tubes in different nanotube networks.

- ✓ In 2001 Min Ouyang, Jin-Lin Huang used low-temperature atomically resolved scanning tunneling microscopy to investigate zigzag and armchair nanotubes, both thought to be metallic. “Metallic” zigzag nanotubes they found energy gaps with magnitudes depend inversely on the square of the tube radius, whereas isolated armchair tubes do not have energy gaps. Additionally, armchair nanotubes packed in bundles have pseudo gaps, which exhibit an inverse dependence on tube radius. They observed energy gaps suggest that most “metallic” single-walled nanotubes are not true metals.
- ✓ In 2010 J. Phys provided an effective means for quantifying the diameter distribution of SWNTs using optical absorption spectroscopy without a prior assumption on the form of the diameter distribution. They found the good agreement among different techniques indicates that this approach enables accurate and rapid assessment of diameter distribution and can be extended to bulk SWNT samples with various diameter distributions.

1.5 Thesis Layout

This research contains five chapters, chapter one include the introduction and the Literature Review, chapter two contains the definition of nanotechnology, types of carbon nanotubes and its properties, chapter three consist of interaction between light and matter, beer’s lambert low and energy gab. Chapter four consists of materials and method, chapter five consists of results, Discussion, Conclusion, Recommendations and References.

CHAPTER TWO

CHAPTER TWO

NANOTECHNOLOGY AND CARBON NANOTUBES

2.1 Introduction

Nano is the prefix derived from the Greek "Nanos", meaning "dwarf". Now, "Nano" is used as a prefix that means "billionth" or a factor of 10^{-9} [1], it means very small scale about the size of a molecule such as benzene, to imagine the size of nanoscale, the thickness of a human hair about 50000 nanometer and the smallest thing that human can see at the range 10000 nanometer. Coupling the word "Nano" with the unit "meter" brings the term "nanometer", which indicates a unit of spatial measurement that is one billionth of a meter. With this in mind, nanotechnology shall be defined as the science, engineering, and technology conducted at the scale that range between 1 to 100 nanometers.

2.2 Nanotechnology

The thinking about the nanotechnology is beginning after a talk entitled "There's Plenty of Room at the Bottom" by the physicist Richard Feynman at the American Physical Society meeting at the California Institute of Technology (CalTech) in 1959. In his talk, Feynman described a process make scientists would be able to manipulate and control individual atoms and molecules [2], he open door for them. After two decades professor Norio Taniguchi coined the term nanotechnology, during his examinations of ultra-precise machining processes. But the modern era of nanotechnology started only in 1981, when the scanning tunneling microscope that could "see" individual atoms was developed and used.

2.3 Carbon Nanotubes

Carbon Nanotube (CNT) is tubular form of carbon with diameter as small as 1nm and length of few nanometers to microns.

CNT is configurationally equivalent to a two dimensional graphene sheet rolled into a tube. Its Young’s modulus is over 1 TPa and the tensile strength is an estimated 200 GPa. Depending on the atomic arrangement of the carbon atoms making up the nanotube (chirality), the electronic properties can be metallic or semiconducting in nature, making them widely used in several applications due to their unique electrical, mechanical, optical, thermal and other properties. The application of CNTs is usually depends on the CNTs structure [3].

2.4 Single Walled Carbon Nanotube

Single walled carbon nanotube is with a wall in one atomic layer. The diameter of the single-layer tube is 0.6 - 1.8nm (typical 1.4nm).The carbon nanotube structure is consisting by a layer of carbon atoms that are bonded together in a hexagonal. This one-atom thick layer of carbon is called graphene, and it is coiled in the shape of a cylinder and bonded together to form a single wall carbon nanotube. Nanotubes can have a single wall of carbon, or they can be made of multiple walls (cylinders inside other cylinders of carbon). Carbon nanotubes have a range of electric, thermal, and structural properties that can change based on the physical design of the nanotube. Single-walled carbon nanotubes can be formed in three different designs: Armchair, Chiral, and Zigzag. The design depends on the way the graphene is wrapped into a cylinder. For example, imagine rolling a sheet of paper from its corner, which can be considered one design, and a different design can be formed by rolling the paper from its edge [4].

Figure 2.1: Explain Single walled carbon nanotube

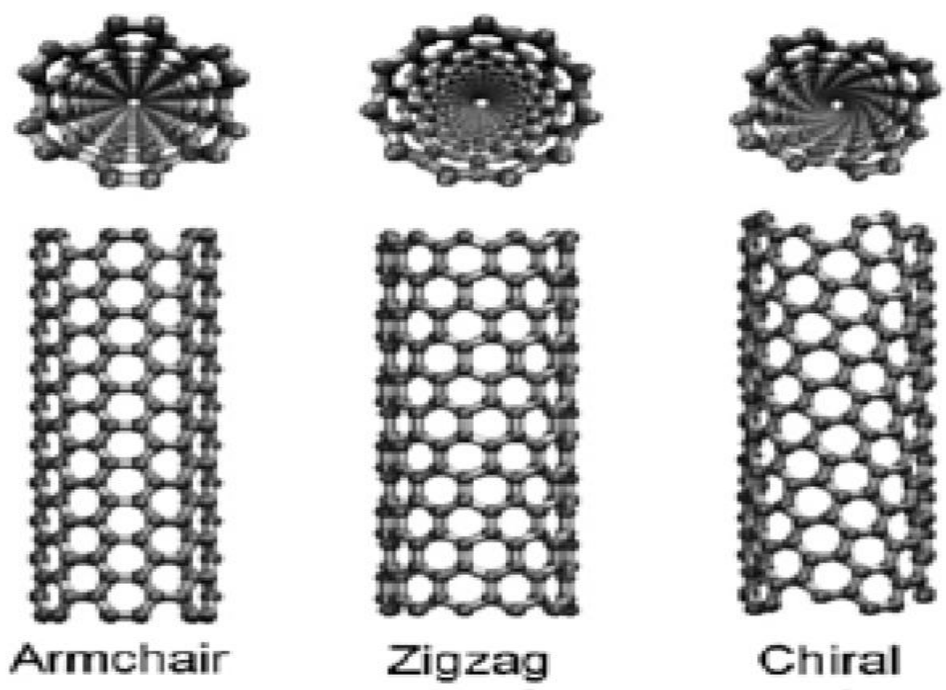

Figure 2.2: explain the three different design of single walled carbon nanotubes

2.5 Multiple Walled Carbon Nanotube

Multiple walled carbon nanotubes (MWCNTs) are elongated cylindrical Nano objects made of sp^2 carbon. Their diameter is 2–20 nm and they can grow several micrometers long [5], thus their aspect ratio can vary between 10 and ten million. There are two structural models of multiple walled carbon nanotubes. In the Russian Doll model, a carbon nanotube contains another nanotube inside it (the inner nanotube has a smaller diameter than the outer nanotube). In the Parchment model, a single graphene sheet is rolled around itself multiple times, resembling a rolled up scroll of paper [6]. Multiple walled carbon nanotubes have similar properties to single walled carbon nanotubes, yet the outer walls on multiple walled carbon nanotubes can protect the inner carbon nanotubes from chemical interactions with outside materials. Multiple walled carbon nanotubes also have a higher tensile strength than single walled carbon nanotubes.

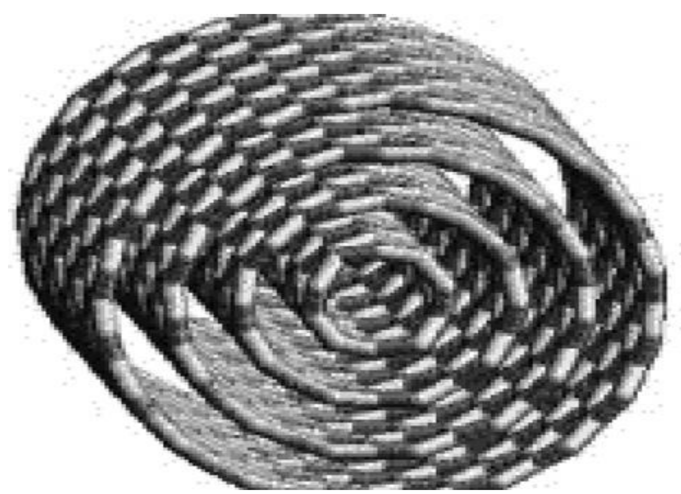

Figure 2.3: explain multiple walled carbon nanotube

2.6 Carbon Nanotube Growth Method

There are various techniques used for growth of CNTs. Three popular methods are arc discharge, laser ablation and chemical vapor deposition (CVD). The common characteristic of these techniques is to provide energy to a carbon source for the creation of Carbon atoms that generate CNTs. The energy source is current in an arc discharge, the high-intensity light from a laser in the laser ablation & heat from a furnace in CVD [6].

2.7 Properties of Carbon Nanotubes

Carbon nanotubes have a range of electric, thermal, and structural properties that can change based on the physical design of the nanotube.

2.7.1 Strength

Carbon nanotubes have a higher tensile strength than steel. [4] Their strength comes from the sp^2 bonds between the individual carbon atoms. This bond is even stronger than the sp^3 bond found in diamond. Under high pressure, individual nanotubes can bond together, trading some sp^2 bonds for sp^3 bonds. This gives the possibility of producing long nanotube wires. Carbon nanotubes are not only strong, they are also elastic. You can press on the tip of a nanotube and cause it to bend without damaging to the nanotube, and the nanotube will return to its original shape when the force is removed. A nanotube's elasticity does have a limit, and under very strong forces, it is possible to permanently deform to shape of a nanotube.

2.7.2 Electrical Properties

Because of the symmetry and unique electronic structure of graphene, Endo M. et al. (2001) find that the structure of a carbon nanotube strongly affects its electrical properties it can act as a metal as well as semiconductor. Metallic nanotubes can have an electrical current density more than 1,000 times greater than metals such as silver and copper [3].

2.7.3 Thermal Properties

The strength of the atomic bonds in carbon nanotubes allows them to withstand high temperatures. Because of this, carbon nanotubes have been shown to be very good thermal conductors. When compared to copper wires, which are commonly used as thermal conductors, the carbon nanotubes can transmit over 15 times the amount of watts per meter per Kelvin. The thermal conductivity of carbon nanotubes is dependent on the temperature of the tubes and the outside environment.

CHAPTER THREE

CHAPTER THREE

INTERACTION BETWEEN LIGHT AND MATTER

3.1 Introduction

When light interacts with matter it can do one of several things, depending on its wavelength and what kind of matter it encounters: it can be transmitted, reflected or adsorbed.

3.2 Transmission

Which occurs when light passes through the matter without interacting. Light coming through window is a simple example of transmission.

3.3 Reflection

Reflection occurs when a light hits the interface between two dissimilar media, so that all of or at least part of the light front returns into the medium from which it originated. Reflection of light may be specular or diffuse. The first occurs on a blank mirroring surface that retains the geometry of the beams of light. The second occurs on a rougher surface, not retaining the imaging geometry, only the energy.

3.4 Absorption

Occurs when the incoming light hits an object and causes its atoms to vibrate, converting the energy into heat which is radiated. Anyone with a dark-colored car on a hot day will experience the effects of adsorption.

3.5 Beer's-Lambert law

The Beer-Lambert law states that the quantity of light absorbed by a substance dissolved in a fully transmitting solvent is directly proportional to the concentration of the substance and the path length of the light through the solution.

3.5.1 Beer's Law

Beer law states that concentration and absorbance are directly proportional to each other and it was stated by August Beer.

3.5.2 Lambert Law

Lambert law states that absorbance and path length are directly proportional and it was stated by Johann Heinrich Lambert.

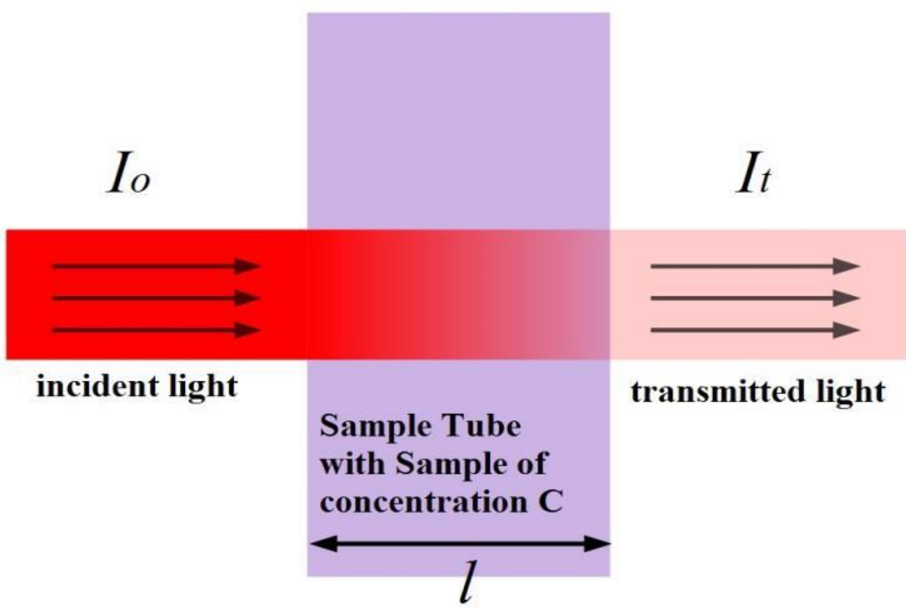

Figure 3.1: explain how the incident light transmitted the sample

The law states that:

$$A(\lambda) = \varepsilon(\lambda)\iota\, c. \tag{3.1}$$

$A(\lambda)$ is called the absorptivity of the substance at the wavelength λ.

$\varepsilon(\lambda)$ Is called the molar absorptivity if the concentration is measured in moles/liter.

ι is called the path length.

c is called the concentration.

The absorbance is inversely proportional to the transmittance of the solution.

$$T = \frac{I_t}{I_0} \tag{3.2}$$

Where:

T is transmittance.

I_t is intensity of the exiting light.

I_0 is intensity of the entering light.

Transmittance: %T = %100 T

$$A = \log_{10} (I_0/I_t) \tag{3.3}$$

$$A = \log_{10} (1/T) = -\log (T) \tag{3.4}$$

$$A = \log_{10} (100/\%T) \tag{3.5}$$

$$A = 2 - \log_{10} (\%T) \tag{3.6}$$

Where:

A is absorbance [7].

3.5.3 Limitations of the Beer-Lambert Law

deviations in absorptivity coefficients at high concentrations (>0.01M) due to electrostatic interactions between molecules in close proximity, scattering of light due to particulates in the sample, fluorescence or phosphorescence of the sample, changes in refractive index at high analyte concentration, shifts in chemical equilibria as a function of concentration, non-monochromatic radiation, deviations can be minimized by using a relatively flat part of the absorption spectrum such as the maximum of an absorption band, stray light.

3.6 Energy Band Gap

It is a region in solids where no electron states can exist its location between valance and conduction band. The band gap is the energy needed to promote an electron from the lower energy valence band into the higher energy conduction band and expressed by electron volt. Band gap occurs in insulators and semiconductors and its value determines a lot of the optical and electrical properties of an object. The band gap is the energy needed to promote an electron from the lower energy valence band into the higher energy conduction band. The band gap in conductors is very small. Ordinary thermal energy promotes the valence electrons to the conduction band where they move freely about the metal. In isolators the band gap is very large and electrons seldom have enough energy to cross from the valence level to the conduction band. In semiconductors, then band gap is moderately wide, so under certain conditions, electrons are promoted into the conduction band resulting in a current.

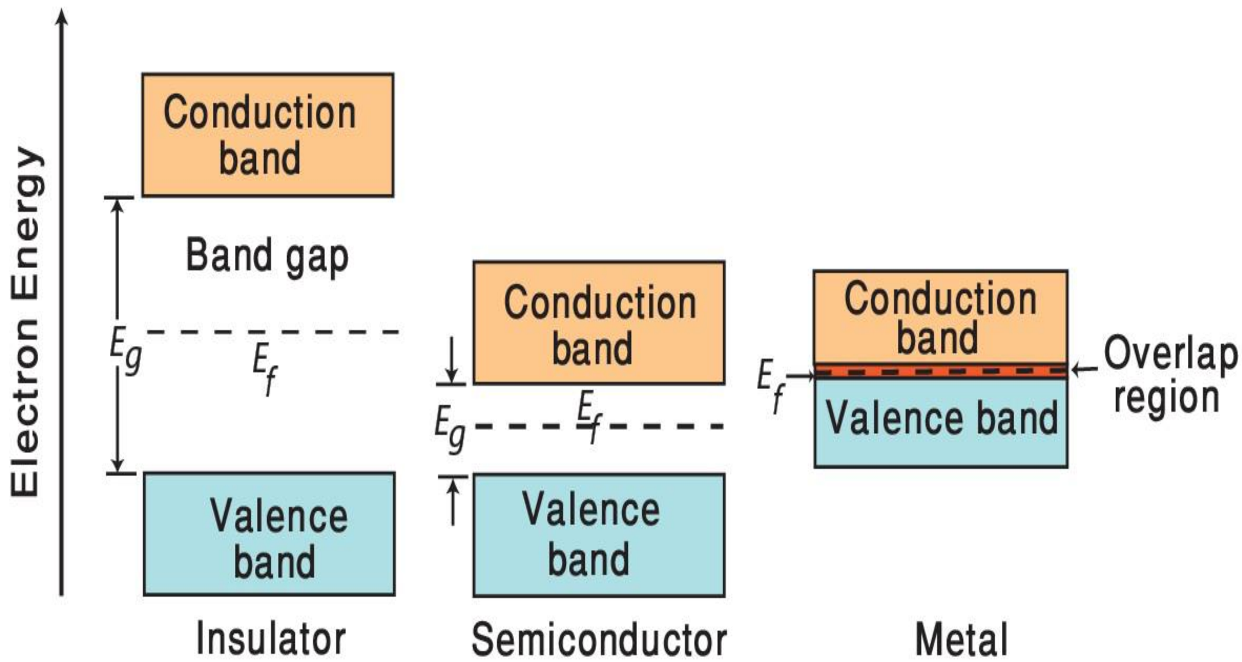

Figure 3.2: explain the energy band gab

CHAPTER FOUR

CHAPTER FOUR

MATERIALS AND METHODS

4.1 Introduction

This chapter show the materials used in the experiment its properties and structure.

4.2 Material

4.2.1 Carbon

Carbon, the 6th element in the periodic table is denoted by letter ‘C.’ Carbon is found almost everywhere, and it is one of the most abundant materials on earth. It is the 4th most common element in the universe and 15th most common on earth’s crust. The name carbon comes from a Latin word “carbo,” which means coal and charcoal; hence, it is also derived from the French word “charbon” which means charcoal [8]. Carbon is the most versatile element in the periodic table, owing to the type, strength, and number of bonds it can form with many different elements [9]. The carbon atom bears six electrons – two tightly bound, close to the nucleus, and the remaining four as valence electrons its make Covalent bonds. All the organic life on earth is made up of allotropes of carbon. All living organisms are composed of carbon, including human beings, animals, plants etc. In the human body, carbon is the second most abundant element by mass after oxygen. Carbon has basically 8 allotropes diamond, graphite, lonsdaliete, C_{60}, C_{540}, C_{70}, amorphous carbon and carbon nanotubes [8].

4.2.2 Ethanol

Chemical formula: C_2H_6O.

Ethanol is a clear, colorless liquid with a characteristic, agreeable odor. In dilute aqueous solution, it has a somewhat sweet flavor, but in more concentrated solutions it has a burning taste. Ethanol is an alcohol, a group of chemical compounds whose molecules contain a hydroxyl group, – OH, bonded to a carbon atom. Ethanol melts at –114.1°C, boils at 78.5°C, and has a density of 0.789 g/mL at 20°C. Its low freezing point has made it useful as the fluid in thermometers for temperatures below – 40°C.

4.2.3 Methanol

Chemical formula: CH_3OH.

Methanol is an alcohol, a group of chemical compounds whose molecules contain a hydroxyl group, –OH, also known as methyl alcohol or wood alcohol is a colorless, water-soluble liquid with mild alcoholic odour. It freezes at -97.6°C, boils at 64.6°C and a density of 791 kg/m^3 at 20°C. It is polar, acid-base neutral, and generally considered non-corrosive. It is miscible with most organic solvents and is capable of dissolving many inorganic salts.

4.2.4 Acetone

Chemical formula: C_3H_6O.

Acetone is a colorless liquid that is a very important solvent for some kinds of fibers and plastics. Acetone is one of the most vital materials due to its many different uses and purposes. Acetone is also used as a solvent in the pharmaceutical industry and in the production of synthetic fibers, in the application of biological research, in the cleaning residue from glass, laboratory tools, fibers and cleaning of various materials and surfaces, However, acetone is toxic and flammable, so it should be kept away from any source of fire or ignition due to its flammable chemical nature. It should be stored in a safe environment.

4.2.5 Benzene

Chemical formula: C_6H_6.

Benzene is a liquid natural constituent of petroleum products. Boils at 80°C and Freezes at 5.5°C. It was formerly used to decaffeinate coffee and component of many consumer products, such as rubber cements, and home dry-cleaning spot removers. A precursor in the production of plastics (such as Styrofoam and nylon), drugs, detergents, synthetic rubber, pesticides, and dyes. It is used as a solvent in cleaning and maintaining printing equipment and for adhesives, but because it is a known carcinogen, its use as an additive in gasoline is now limited.

4.3 Devices

- USB spectrometer 2000.
- Computer
- Origin 8.6 program

4.4 Method

Carbon nanotube samples was prepared as the following:

4.4.1 Lampblack Sample

It was produced by burning wood and depositing the carbon nanotube on an iron sheet.

4.4.2 Frankincense Sample

It was produced by burning glue at a low temperature and depositing the carbon nanotube on an ion sheet.

4.4.3 Kohl Sample

It was bought from the market.

The aforementioned samples dissolved in the solvents of acetone, methanol, ethanol and benzene. The method of experiment depends on the relationship between absorption and concentration of the substance, and then the absorption spectrum of the sample can be measured.

Weighed 0.18 g from each samples and dissolved in 50 mm of each solvents. We get twelve samples:

Table 4.1: the samples and solvents

Lampblack with	Frankincense With	Kohl with
Methanol	Methanol	Methanol
Ethanol	Ethanol	Ethanol
Acetone	Acetone	Acetone
Benzene	Benzene	Benzene

4.5 Calculation of the Absorption Spectrum

The USB device use this equation:

$$A = -\text{Log}(S - D)/(R - D) \qquad (4.1)$$

Where

A is absorbance.

R is the raw spectrum.

S is a reference.

D is a dark.

Figure 4.1: device of experiment

CHAPTER FIVE

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

In this chapter, the results obtained from the USB spectrometer for the absorbance and energy gap of all samples as figures.

5.2 Results

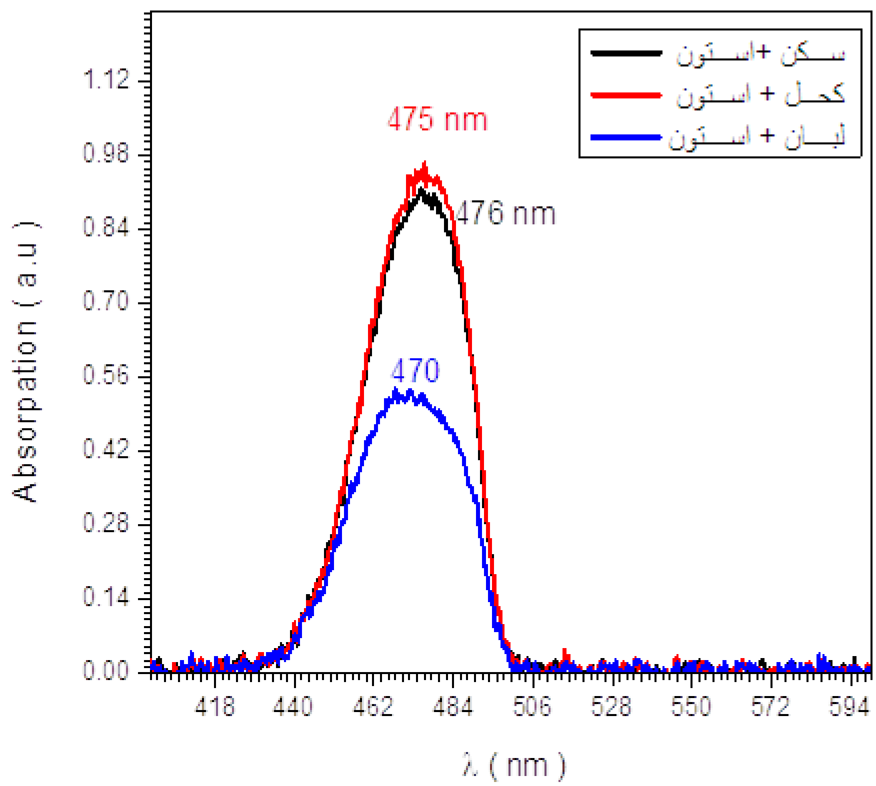

Figure 5.1: explain the absorbance of all carbon nanotubes samples in acetone

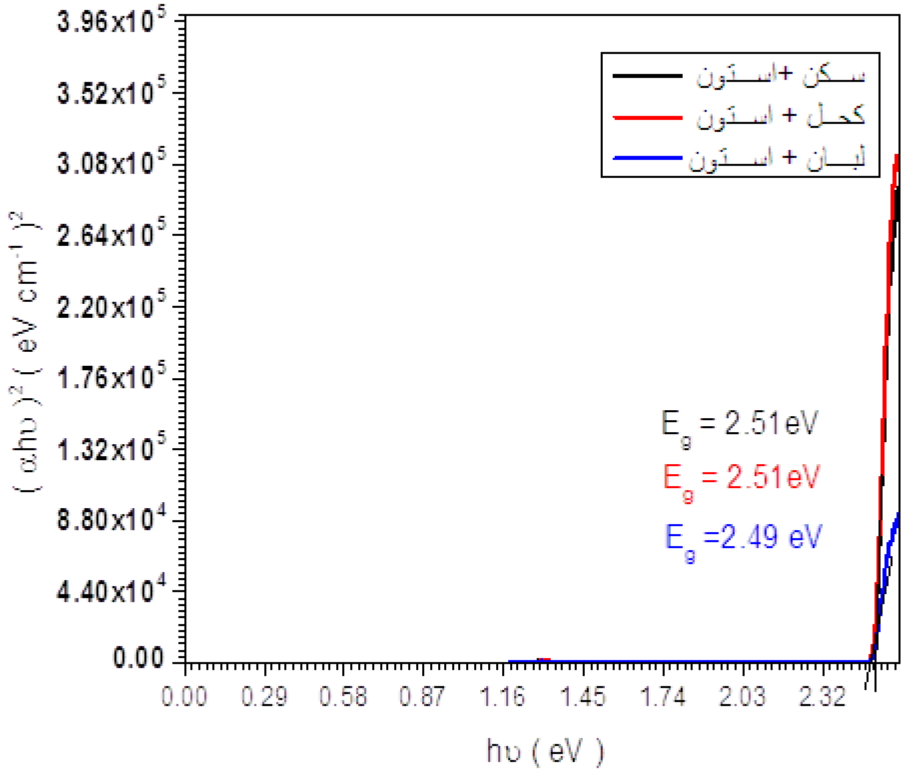

Figure 5.2: explain the relationship between photon energy and photon energy as Function in absorbance factor to calculate energy gap for all carbon nanotube samples dissolved in acetone solvent.

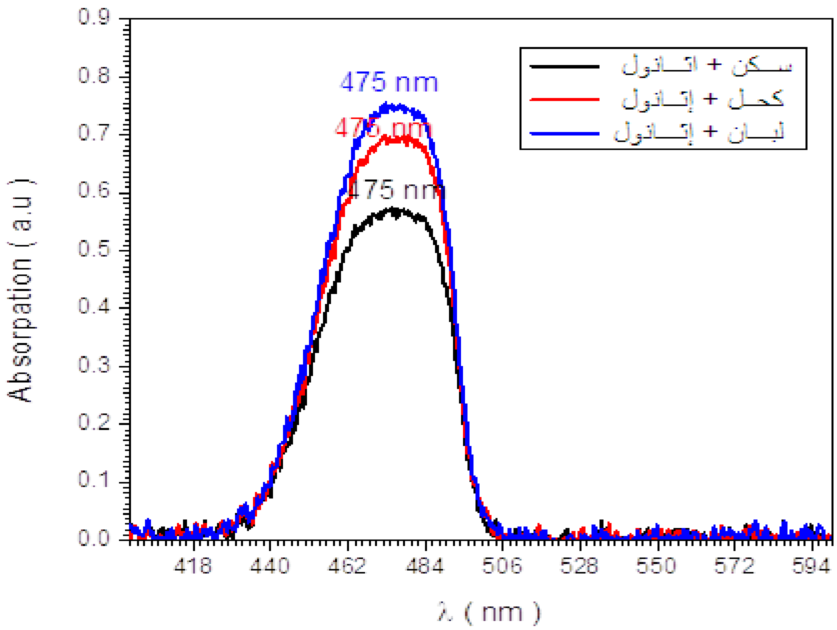

Figure 5.3: explain the absorbance of all carbon nanotubes samples in ethanol.

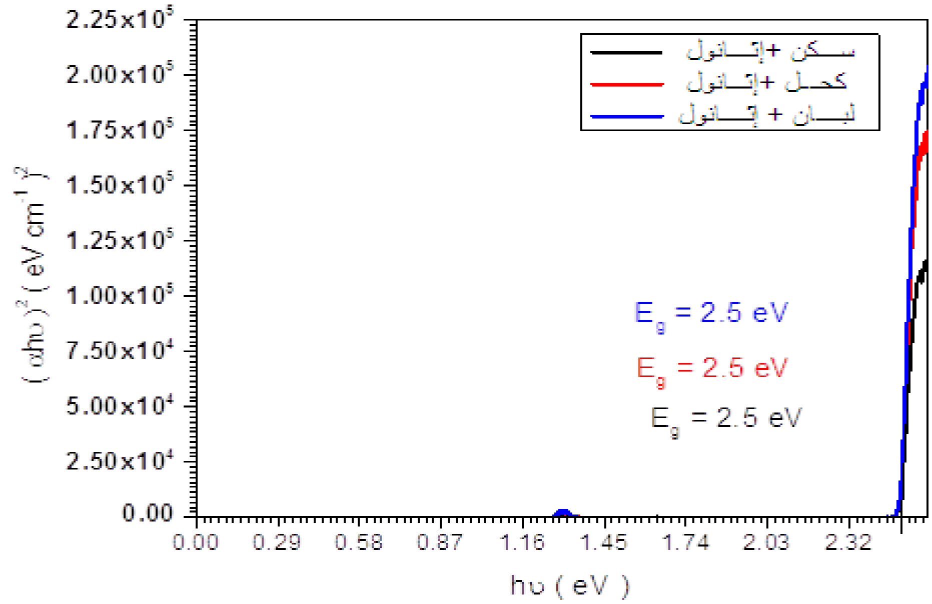

Figure 5.4: explain the relationship between photon energy and photon energy as Function in absorbance factor to calculate energy gap for all carbon nanotube samples dissolved in ethanol solvent.

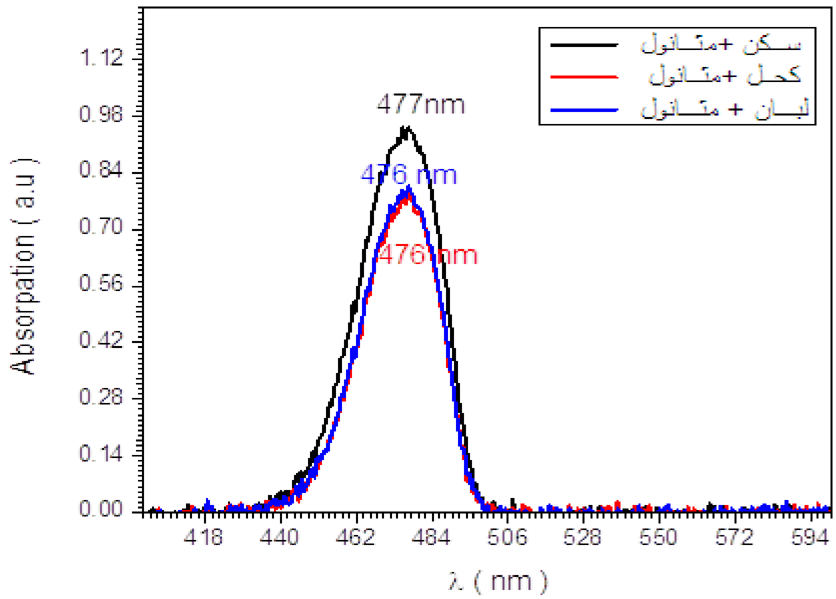

Figure 5.5: explain the absorbance of all carbon nanotubes samples in methanol.

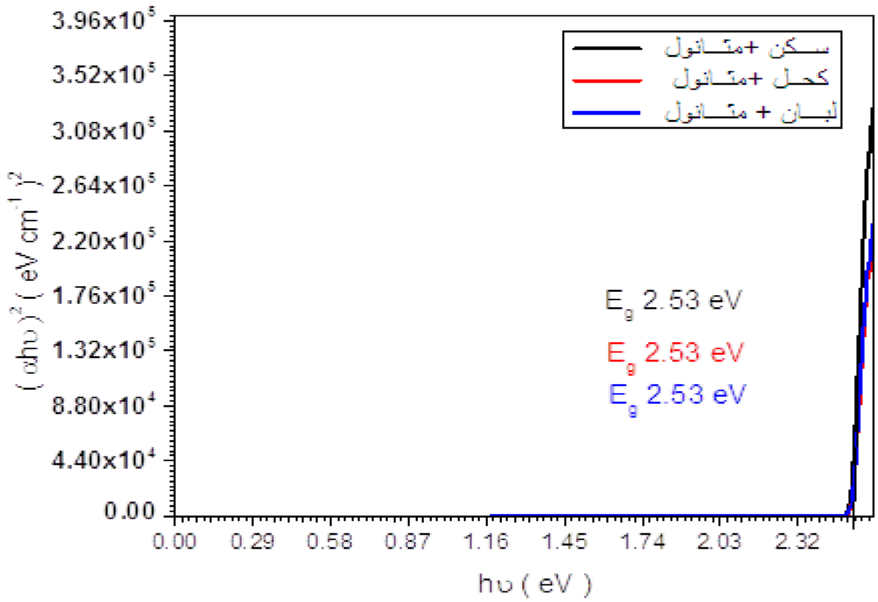

Figure 5.6: explain the relationship between photon energy and photon energy as Function in absorbance factor to calculate energy gap for all carbon nanotube samples dissolved in methanol solvent.

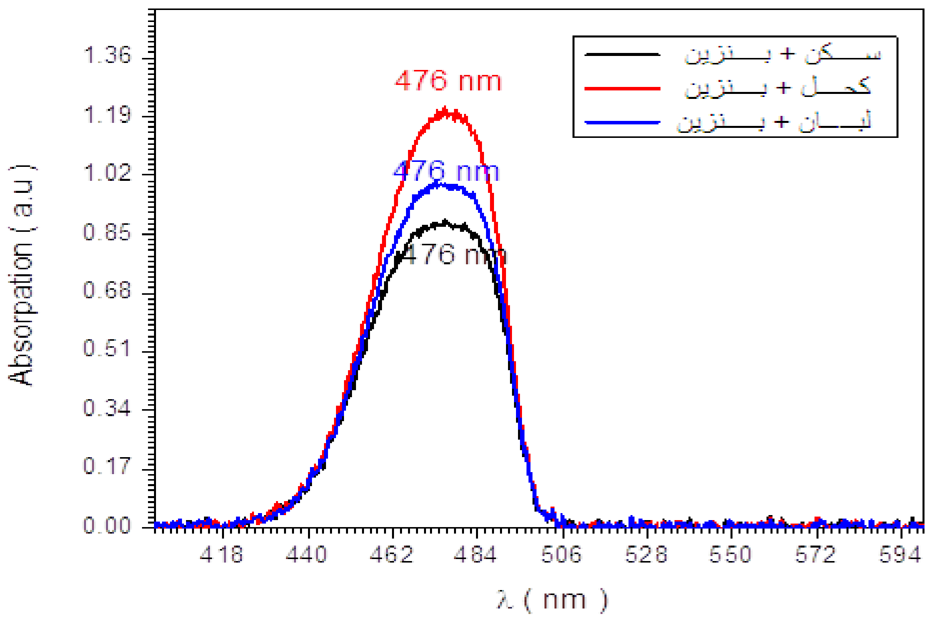

Figure 5.7: explain the absorbance of all carbon nanotubes samples in benzene.

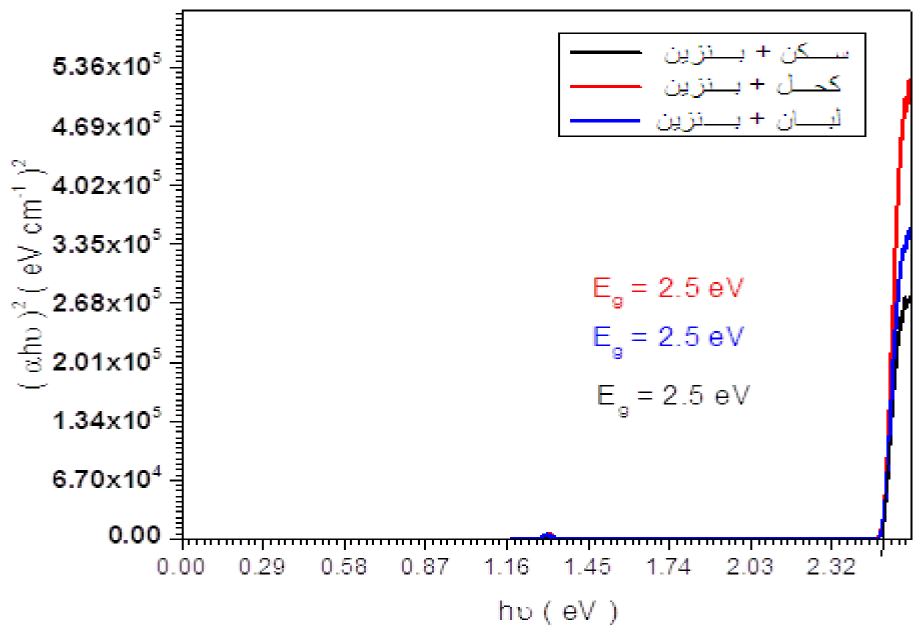

Figure 5.8: explain the relationship between photon energy and photon energy as Function in absorbance factor to calculate energy gap for all carbon nanotube samples dissolved in benzene solvent.

Tables explain the values of absorbance, transmission, energy gap and wave length of the solvents.

Table 5.1: explain the values in acetone solvent

Acetone with	Absorbance	Transmission	Energy gap	Wave length
Kohl	0.98	%10.5	2.51	475
Lampblack	0.91	%12.3	2.51	476
Frankincense	0.53	%29.4	2.49	470

Table 5.2: explain the values in ethanol solvent

Ethanol with	Absorbance	Transmission	Energy gap	Wave length
Kohl	0.70	%19.9	2.50	475
Lampblack	0.57	%26.9	2.50	475
Frankincense	0.74	%18.1	2.50	475

Table 5.3: explain the values in methanol solvent

Methanol with	Absorbance	Transmission	Energy gap	Wave length
Kohl	0.78	%16.6	2.53	476
Lampblack	0.95	%11.2	2.53	477
Frankincense	0.79	%16.2	2.53	476

Table 5.4: explain the values in benzene solvent

Benzene with	Absorbance	Transmission	Energy gap	Wave length
Kohl	1.20	%6.3	2.50	476
Lampblack	0.90	%12.6	2.50	476
Frankincense	0.99	%10.2	2.50	476

5.3 Discussion

- In figure (5.1) kohl have highest absorbance 0.98 Au with wave length 475nm it follows by soot with absorbance 0.91 Au and its wave length 476nm and finally the absorbance of glue is 0.53 Au with wave length 470nm.
- In figure (5.2) the energy gab of kohl and soot equal 2.51 eV and the energy gab of glue is 2.49 eV.
- In figure (5.3) glue have highest absorbance 0.74 au with wave length 475nm it follows by kohl its absorbance 0.70 au with wave length 475nm and the absorbance of soot is 0.57 au with wave length 475nm, all of them have the same wave length.
- In figure (5.4) the energy gab is the same for all samples and its equal 2.50 eV.
- In figure (5.5) the soot have highest absorbance 0.95 au with wave length 477nm it follows by kohl its absorbance 0.78 au with wave length 476 nm and the absorbance of glue is 0.79 with wave length476nm. The kohl and glue have the same wavelength.
- In figure (5.6) the energy gab is the same for all samples and its equal 2.53 eV.

- In figure (5.7) the kohl have highest absorbance 1.20 au with wavelength 476nm it follows by glue its absorbance 0.99 au with wavelength 476nm and the absorbance of soot is 0.90 with wavelength 476nm. All of them have the same wavelength.
- In figure (5.8) the energy gab is the same for all samples and its equal

5.4 Conclusion

Kohl has a highest absorbency 1.2 au and less transmission 6.3% in benzene solution, Glue has a less absorbency 0.53 au and highest transmission 29% in acetone solution. All samples solved in methanol solution has a highest energy gap and its equal 2.53au.

5.5 Recommendations

- In the future it is recommended to study anther optical properties of carbon nanotubes to such as decay coefficient (attenuation coefficient), refractive index, and the conductive properties.
- Can be used carbon nanotube in electronic and photoelectrical applications.
- Can be used electron microscope or XRD device to study crystal structure of carbon nanotubes.

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