Sudan University of Sciences & Technology

Faculty of Graduate Studies

A study of Human Skin Optical Properties Using a New Dispersion Law

دراسة الخصائص البصرية لطبقات جلد الإنسان باستخدام قانون تشتت جديد

A thesis submitted in partial fulfillment of the requirements for the degree of MSc. in laser applications

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بسم الله الرحمن الرحيم

استهلال

قال تعالى: ﴿ اللَّهُ نُورُ السَّمَاوَاتِ وَالْأَرْضِ مَثَلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ الْمِصْبَاحُ فِى زُجَاجَةٍ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّىٌّ يُوقَدُ مِنْ شَجَرَةٍ مُبَارَكَةٍ زَيْتُونَةٍ لَا شَرْقِيَّةٍ وَلَا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِىءُ وَلَوْ لَمْ تَمْسَسْهُ نَارٌ نُورٌ عَلَى نُورٍ يَهْدِى اللَّهُ لِنُورِهِ مَنْ يَشَاءُ وَيَضْرِبُ اللَّهُ الْأَمْثَالَ لِلنَّاسِ وَاللَّهُ بِكُلِّ شَىْءٍ عَلِيمٌ ﴾

صدق الله العظيم

سورة النور، الآية 35

Dedication

I dedicate this research to my parents, who gave me and brought me up with their love

Let me say to them 'you who give life, hope and brought up to read and have knowledge.

To my brothers and sister

Acknowledgements

I'd like to thank my supervisor Dr. Siddig T. Kafi for his continuous follow-up and encouraging during this work, I would like to thank Prof. Dr. A. I. Arbab my co-supervisor from Qassim University at Kingdom of Saudi Arabia.

I would like to express my gratitude to Al-Neelain and Sudan Universities for their cooperation and endless support.

Abstract

In this study, a new dispersion law was presented and applied to study the optical properties of human skin, as well as the general behavior of this law, which was developed by Dr. Arbab Ibrahim Arbab, in which stated that the photons could massive in certain phases, i.e., in a media.

The new dispersion formula of Arbab was applied to human skin as an example for biological tissues. Results obtained were compared to previously obtained experimental data.

It was found that there were similarities in certain cases, in case of media, the photon showed different behavior. It was concluded that a photon could massive in a non-vacuum phase.

مستخلص

في هذه الدراسة، تم تقديم قانون تشتت جديد وتطبيقه لدراسة الخصائص البصرية للجلد البشري، فضلا عن السلوك العام لهذا القانون، الذي وضعه الدكتور أرباب إبراهيم أرباب، والذي ذكر أن الفوتون له كتلة.

تم تطبيق صيغة التشتت الجديدة من أرباب على جلد الإنسان كمثال للأنسجة البيولوجية. وتمت مقارنة النتائج التي تم الحصول عليها مع البيانات التجريبية التي تم الحصول عليها سابقاً.

ووجد أن هناك أوجه تشابه في بعض الحالات، وأظهر الفوتون سلوكاً مختلفاً داخل الوسط.

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Chapter One

Introduction

1.1 Introduction

A new theoretical law for the refractive index is proposed. The law provides a limit to the photon mass inside optical materials (skin as example in this work).

Experimental data reveal that the rest mass energy of the photon inside a medium is found to be a few eV. This energy could be related to the energy of the material. The electric (optical) conductivity of the material is found to be related to the photon mass. The photon kinetic energy inside the material, with a refractive index n, and rest mass (m_0c^2).

Energy is

$$E_k = m_0c^2\left(\frac{n-\sqrt{n^2-1}}{\sqrt{n^2-1}}\right) \qquad (1)$$

the skin depth inside the medium is $\delta_+ = (\hbar\sqrt{\varepsilon\text{⍰}}/m_0)$ at very high frequency, and $\delta_- = (\sqrt{2}/m_0)$ at very low frequency. (A. I. Arbab, Apr. 2016)

We have presented in this work, a new dispersion law relating the refractive index to the wavelength of the incident light and the photon mass inside the material. The derived law relies on the idea that photons inside the material have an effective mass. The rest mass energy associated with photons can be related to the energy band gap of the material. The model indicates that the mass of the photon inside the material is of the order of a few eV. The relativistic relation $E = c^2P/v$, where v is the speed of the massive photon, is found to be valid for photons inside the material too. The electric (optical) conductivity is found to depend on the wavelength of the incident light and the photon rest-mass energy inside the material. The penetration depth of the electromagnetic wave inside the medium depends on the refractive index. (A. I. Arbab, Apr. 2016)

The aim of this work is to explore the optical properties (refractive index and wavelength) of a medium availing this equation. In this work, we deal with refractive index from a theoretic quantum point of view, since the interaction of light with material is pure quantum phenomenon, such a treatment has never been considered before, light refraction has been dealt with as having an electromagnetic aspect only. It is completely governed by Maxwell equations with some boundary conditions relating the electric field components of the incident light. Recall that when a moving particle enters a viscous medium. Its energy will be converted into heat. However, when light enters a medium, it shows at a rate proportional to the conversion of energy into mass. This may help explain why light velocity inside the medium is less than that in vacuum. (A. I. Arbab, Apr. 2016)

1.2 Massless and massive photon

In Maxwell theory, the photon is massless when propagating in free space. However, the photon could be massive in propagating in a medium. This is because photons interact with electron inside a medium, and thus, require a mass. This case show up when light gets refracted by a medium where its velocity becomes different from that in free space. As a result, the photon should be described by a quantum theory as well as Maxwell theory. These, also, support the concept of photon duality. (A. I. Arbab, Oct. 2016)

In this work, we study the motion of photon in vacuum and in a medium. The electrical signals are known to travel in electric circuit according to a telegraph equation. Hence, energy flows both inside the circuit (wire), and in the space around it. The energy inside the wire experiences dissipation since it is carried by massive photons. Massive photons are described by Proca equations $\partial_{\mu}(\partial^{\mu}B^{v} - \partial^{v}B^{\mu}) + \left(\frac{mc}{\hbar}\right)^{2} B^{v} = 0$ that generalize the Maxwell equation. This motion is exhibited in super conductivity, where the electromagnetic interaction becomes of short range.

The first theory of superconductivity was advocated by London. However, London theory was classical since be used Newton's law and Maxwell equations, it was successful in describing Meissner effect of magnetic field. In the present study, we provide the quantum London theory, it reflects the propagation of aspin-0 massive photon that is governed by Maxwell and quantum theories. They show the superconductivity is transmitted by spin zero massive photons. It is believed that the carries of superconductivity are Cooper Paris. We, thus, trust that Cooper Paris are the massive photons. (R. del kronig, 1926)

1.2.1 Quantum representation of massive photons

Maxwell's theory treats the photon as massless particle. A treatment of massive photon in vacuum is explored by Proca. He realized that introducing mass for a photon would destroy the gauge in variance of the resulting equations, while presentation the Lorentz invariance. However, the electromagnetic field inside a conducting medium is found to satisfy a telegraph-like equation. This dictates that electromagnetic field suffers a damping as it propagates in the medium. (A. I. Arbab, Oct. 2016)

According to classical electrodynamics, an accelerating electron ought to radiate electromagnetic waves, there was not a treatment, in which the photon can be considered as a gonium particle carrying charge and having non zero mass.

The photon mediates the electromagnetic interactions between charged particles. However, it is deemed to be massless and charge less, there exists no physical law forbidding the photon to have mass.

Massless photon facilities the mathematical manipulation of quantum electrodynamics formulation, owing to classical electrodynamics, the electromagnetic wave is damped when encounter a conducting medium.

The electromagnetic fields in a conducting medium satisfy a telegraph equation

$$\frac{1}{c^2}\frac{\partial^2 \vec{A}}{\partial t^2} - \nabla^2 \vec{A} + \vec{\nabla}\left(\vec{\nabla} - \vec{A} + \frac{1}{c^2}\frac{\partial \varphi}{\partial t}\right) - \mu_0 J = 0 \qquad (2)$$

and

$$\frac{1}{c^2}\frac{\partial^2 \varphi}{\partial t^2} - \nabla^2 \varphi - \frac{\partial}{\partial t}\left(\vec{\nabla} - \vec{A} + \frac{1}{c^2}\frac{\partial \varphi}{\partial t}\right) - \frac{\rho}{\varepsilon_0} = 0 \qquad (3)$$

where electric and magnetic fields are defined as:

$$\vec{E} = \vec{\nabla}\varphi - \frac{\partial \vec{A}}{\partial t} \ , \ \vec{B} = \vec{\nabla} \times \vec{A} \qquad (4)$$

The potential are not independent, but related by the Lorentz gauge condition:

$$\vec{\nabla} - \vec{A} + \frac{1}{c^2}\frac{\partial \varphi}{\partial t} = 0 \qquad (5)$$

The gauge condition render equations (2) and (3) having simple form, and representing wave equations, for these potential ($\vec{A}$ and φ) having their sources in the matter distribution, it is further, assumed that $\vec{A}$ and φ are mathematical constructs (potentials) carrying no physical meaning. However, Aharonove and Bohm demonstrated experimentally that $\vec{A}$ and φ are not mere mathematical entities, but have their physical significance when considering quantum effects. (Y. Aharonov, D. Bohm, 1961)

Now, differentiating Ampere's equation for a conducting medium and use Faraday's equation will give:

$$\frac{1}{c^2}\ \frac{\partial^2 E}{\partial t^2} - \nabla^2\ \vec{E} - \mu_0\sigma\ \frac{\partial^2 \vec{E}}{\partial t^2} + \vec{\nabla}\left(\frac{\rho}{\varepsilon_0}\right) = 0 \qquad (6)$$

and taking the curl of Ampere's equation and using Faraday's equation yields:

$$\frac{1}{c^2}\ \frac{\partial^2 \vec{B}}{\partial t^2}\ - \nabla^2\ \vec{B} + -\mu_0\sigma\ \frac{\partial^2 \vec{B}}{\partial t^2} = 0 \qquad (7)$$

Moreover, using equation (5) and (6) becomes:

$$\frac{1}{c^2}\ \frac{\partial^2 \vec{A}}{\partial t^2} - \nabla^2\ \vec{A} + \mu_0\sigma\ \frac{\partial \vec{A}}{\partial t} + \vec{\nabla}\ \left(\vec{\nabla} - A + \frac{1}{c^2}\ \frac{\partial \varphi}{\partial t} + \mu_0\sigma\ \varphi\right) = 0$$

(8)

Hence, for a medium with no free charges or a medium having uniform charge distribution. Equations (6-8) follow a telegraph-like equation provided that:

$$\vec{\nabla} - \vec{A} + \frac{1}{c^2}\ \frac{\partial \varphi}{\partial t} = +\mu_0\sigma\ \varphi \qquad (9)$$

Therefore, in a conducting medium, the Lorentz gauge is not violated, and consequently gauge invariance is broken. A manifestation of this breaking is that the photon becomes massive inside the medium.

1.3 Optical properties of human skin

Optical properties of a tissue affect both diagnostic and therapeutic applications of light. The ability of light to penetrate a tissue, interrogate the tissue components, then escape the tissue for detection is key to diagnostic applications. The ability of light to penetrate a tissue and deposit energy via the optical absorption properties of the tissue is key to therapeutic applications.

1.4 The complex refractive index

$n = n' + Jn''$, includes the real refractive index n', which describes energy strong, and hence, affects the speed of light in a medium.

The imaginary refractive index n'', describes energy dissipation and specifies the absorption coefficient, $M_a = 4\pi n''/\lambda$. To a first approximation, the value of n' scales as the water content (W) of a tissue:

$$n' = n'_{dry} - \left(n'_{dry} - n'_{water}\right)W \tag{10}$$

where n'_{dry} is the refractive index of the tissue's dry mass and $\left(n'_{dry} - n'_{water}\right)$ is the refractive index of water.

Hence, specifying the optical properties of a tissue is the first step toward, and then use the optical properties in a light transport model to predict the light distribution and energy deposition.

Optical properties of a tissue are described in terms of absorption coefficient, $M_a(cm^{-1})$, the scattering coefficient $M_s(cm^{-1})$, the scattering function $\rho(\theta, \varphi)(s_0 r^{-1})$, where θ is the defection angle off scatter, and φ is the azimuthal angle of scatter, and the real refractive index of the tissue n'.

Here, we introduce the refractive index and its effective:

When some light absorbed by the medium, we should consider a complex refractive index. The imaginary part of the refractive index, which is also called extinction coefficient (k), reflects the amount that has been absorbed (lost) by the medium.

The extinction coefficient is related to the wavelength of light in the medium by the relation $k = \frac{2\pi n_0}{\lambda}$, where the real part of the refractive index. The real and the imaginary parts of the complex refractive index are related by the Kramers-Kronig relations. (Rdel-Kronig, 1926; H. A. Karamers, 1927)

The complex refractive index is tantamount to complex mass, where the imaginary part reflects the damping that the wave will experience while moving in a medium. This wave equation can be obtained from Dirac equation by the transformation $m \rightarrow \mp im$. Moreover, this equation also represents the wave equation for a massless field when propagated in a medium. In this case, the mass appearing in this equation will be related to the medium characteristics, e.g., conductivity, refractive index, number density relaxation time, etc. (Ibrahim Arbab, 2010), (A, Ibrahim Arbab, 2012)

The mass of the photon reflects the interaction in faces with the medium, in which it travels. Hence, this equation can provide optical information about the medium, in which the field is propagating. A complex mass is tantamount to the conductivity, permittivity, or refractive index that amounts to absorption of energy of the incident wave by the medium, in which it propagates.

1.5 Literature review

Work done relative skin parameters, it was preceded by several studies that we will present below.

In 2006, Huafeng Ding, Jun Qlu, William A. Wooden, Peter D. Kragel and Xin – Huatlu, extended a previously developed method of coherent reflectance cure measurement to determine the in vitro values of the complex refractive indices of epidermal and dermal tissues from fresh human skin samples at eight wavelengths between 325 and 1557nm.

Based on these results, dispersion relation of the real refractive index have been obtained and compared in the same spectral region.

In 2015, A. Ibrahim Arbab studied the effects of massive photon on the electric and magnetic field produced by a moving electric charge (current). We find that because of this massive nature of photons, these photons produce their own electric and magnetic fields, these photons, then, become the monopoles satisfying a Dirac-like quantization rule, since massive photons carry electric and magnetic charges, they will then be scattered by the electron of the medium, in which they move. They, also, generate their own currents. Because of this current, a longitudinal force along the particle (charge) direction arises, leading to significant force, when a large current is passed in a wire. This generated current further leads to quantum current inductance and force.

In June 2016, A. Ibrahim Arbab revisited the refraction of light by treating photons to be massive inside the medium, and apply the energy and momentum conservation equations. They have, then, obtained a formula relating the energy and momentum of the photon in the medium, and shown that the momentum of the electron in terms of the incident light wavelength and the refractive index of the medium. Moreover, the initial direction of the photon is deflected by an angel that depends on the incident angle, the wavelength of the incident light and the refractive index of the medium. The Snell's law is obtained as a result of momentum conservation. Their formula relating the energy and momentum of the photon in the medium is consistent with Minkowski and Abraham models, if the former assumes E=E and the latter assumes $E = n^2 E$. Both results stem from the assumption of the validity of the

Einstein relativistic formula $P = VE/c^2$ in the vacuum and in the medium.

The former treating the photon to be massless (wave), and the latter treated can be seen as generalizing the Compton effect to include the effect of a medium.

In Aug. 2016, A. I. Arbab have applied a quantum treatment to light and obtained a relation between the refractive index of a material, in which light is propagated and its mass.

Refraction of light has been dealt before relying only on Maxwell equations, and some boundary conditions relating the different electric field components at these boundaries to the refractive index of the material.

In Oct. 2016, A. I. Arbab studied the propagation of matter wave in a medium and found that the propagation of matter wave to be governed by a damped Klein-Cordon (or telegraph) equation are treated as describing a wave packet propagating at seed of light, Matter field analogous to electric and magnetic fields that are associated with the electric charge are found to be associated with particle mass. In this formulation, the matter magnetic field vanishes. Moreover, the mass of the moving damped spin-O article in a conducting medium is found to be related to the conductivity of the medium. The electromagnetic field of massive photon following Klein-Cordon equation in a conducting medium is created from the spatial and temporal variation of the charge and current densities. The variation of Lorentz gauge condition is found to give rise to longitudinal wave with zero spin.

In Apr. 2016, A. I. Arbab presented a new dispersion law relating the refractive index to the wave length of the incident light and the photon mass inside the material. We, also, outlined several other competing empirical models hither to known. The rest mass energy associated with photons can be related to the energy band gap of the material. The model indicates that the mass of the photon inside the material is of the order of a few eV. The relativistic relation $E = C^2\, P/V$, where V is the speed of the massive photon, is found to be valid for photons inside the material too. The electric (optical) conductivity is found to depend on the wavelength of the incident light and the photon rest-mass energy inside the material. The penetration depth of the electromagnetic wave inside the medium depends on the refractive index.

This is the subject of our study in this thesis.

1.6 Objectives

- Introducing the massive photon theory in biological tissue studies taking human skin as an example.
- Revisit skin parameters with medical lasers.
- Compare between massive photon and massless photon results.

Chapter Two

Materials and Methods

2.1 Mathematical formula

A new dispersion law, relating the refractive index to the wavelength of the incident light and the photon mass inside the material.

:

$$\delta^{-1} = \frac{1}{\sqrt{2}} \frac{2\pi}{\lambda} \left\{ (n^4 - 2n^2 \propto^2 + \propto^4 + 4 \propto^2)^{\frac{1}{2}} - n^2 + \propto^2 \right\}^{\frac{1}{2}} \qquad (11)$$

$$\propto = \sqrt{\frac{n^2 - 1}{n^2}}$$

where:

n ≡ refractive index

δ ≡ depth of skin

λ ≡ wavelength

2.2 Laser parameters

Input laser wavelengths needs for this study were: Nd-YAG lasers, KTP YAG laser, and Excimer lasers. These lasers were chosen based the output wavelengths of the medical lasers applied for skin treatment, there are:

1. **Nd-YAG lasers:**

   (Neodymum) the Nd ion when doped in (YAF) "Yottrium Aluminum Garanite – $Y_3Al_5O_{12}$" is a solid laser. This laser emits a near infra-red (NIR) light at (1064nm– 1320nm), a CW or long pulsed (millisecond domain) mode, it has deep penetration in the tissues.

   The Nd-YAG laser is used in:

- Remove black tattoo.
- Remove hair from face and body.

2. **KTP YAG laser:**

   KTP (Potassium Titanyl Phosphate) is the most commonly used material for frequency doubling of Nd-YAG lasers. This is done when the laser beam passes through a non-linear crystal (KTP), its wavelength is 532nm a green color.

   The KTP laser is used in:

   - Vascular lesions.
   - Pigmented lesions.
   - Spider veins.
   - Leg veins.
   - Part-wine stain.

3. **Excimer lasers:**

   These lasers are group of pulsed laser operating in the ultraviolet range (e.g., 351nm Xenon fluoride)

   The XeF is used in:

   - UVB phototherapy.

   - UV-Responsive diseases, such as a topic dermatitis and Cutaneous T-cell Lymphocyte (CTCL).

2.3 Skin layers

The skin is the largest organ in the human body. For the average adult human, the skin has a surface area of between 1.5-2.0 square meters (16.1-21.5sq ft.). The thickness of the skin varies considerably over all parts of the body, and between men and women and the young and the old. An example is the skin on the forearm which is on average 1.3 mm in the male and 1.26 mm in the female. The average square inch ($6.5cm^2$) of skin holds 650 sweat glands, 20 blood vessels, 60,000 melanocytes, and more than 1,000 nerve endings. The average human skin cell is about 30 micrometers in diameter, but there are variants. A skin cell usually ranges from 25-40 micrometers (squared), depending on a variety of factors.

Skin is composed of three primary layers: the epidermis, the dermis and the hypodermis.

2.3.1 Epidermis

Epidermis, "epi" coming from the Greek meaning "over" or "upon", is the outermost layer of the skin. It forms the waterproof, protective wrap over the body's surface which also serves as a barrier to infection and is made up of stratified squamous epithelium with an underlying basal lamina.

The epidermis contains no blood vessels, and cells in the deepest layers are nourished almost exclusively by diffused oxygen from the surrounding air and to a far lesser degree by blood capillaries extending to the outer layers of the dermis.

2.3.2 Components

The epidermis contains no blood vessels, and is nourished by diffusion from the dermis. The main type of cells which make up the epidermis are keratinocytes, melanocytes, Langerhans cells and Merkels cells. The epidermis helps the skin to regulate body temperature.

2.3.3 Layers

Epidermis is divided into several layers where cells are formed through mitosis at the innermost layers. They move up the strata changing shape and composition as they differentiate and become filled with keratin. They eventually reach the top layer called stratum corneum and are sloughed off, or desquamated. This process is called keratinization and takes place within weeks. The outermost layer of the epidermis consists of 25 to 30 layers of dead cells.

2.3.4 Sub layers

Epidermis is divided into the following 5 sublayers or strata:

- Stratum corneum
- Stratum lucidum
- Stratum granulosum
- Stratum spinosum
- Stratum germinativum (also called "stratum basale").

Blood capillaries are found beneath the epidermis, and are linked to an arteriole and a venule. Arterial shunt vessels may bypass the network in ears, the nose and fingertips.

2.4 Dermis

The dermis is the layer of skin beneath the epidermis that consists of epithelial tissue and cushions the body from stress and strain. The dermis is tightly connected to the epidermis by a basement membrane. It also harbors many nerve endings that provide the sense of touch and heat. It contains the hair follicles, sweat glands, sebaceous glands, apocrine glands, lymphatic vessels and blood vessels. The blood vessels in the dermis provide nourishment and waste removal from its own cells as well as from the Stratum basal of the epidermis.

The dermis is structurally divided into two areas: a superficial area adjacent to the epidermis, called the papillary region, and a deep thicker area known as the reticular region.

2.5 Hypodermis

The hypodermis is not part of the skin, and lies below the dermis. Its purpose is to attach the skin to underlying bone and muscle as well as supplying it with blood vessels and nerves. It consists of loose connective tissue, adipose tissue and elastin. The main cell types are fibroblasts, macrophages and adipocytes (the hypodermis contains 50% of body fat). Fat serves as padding and insulation for the body.

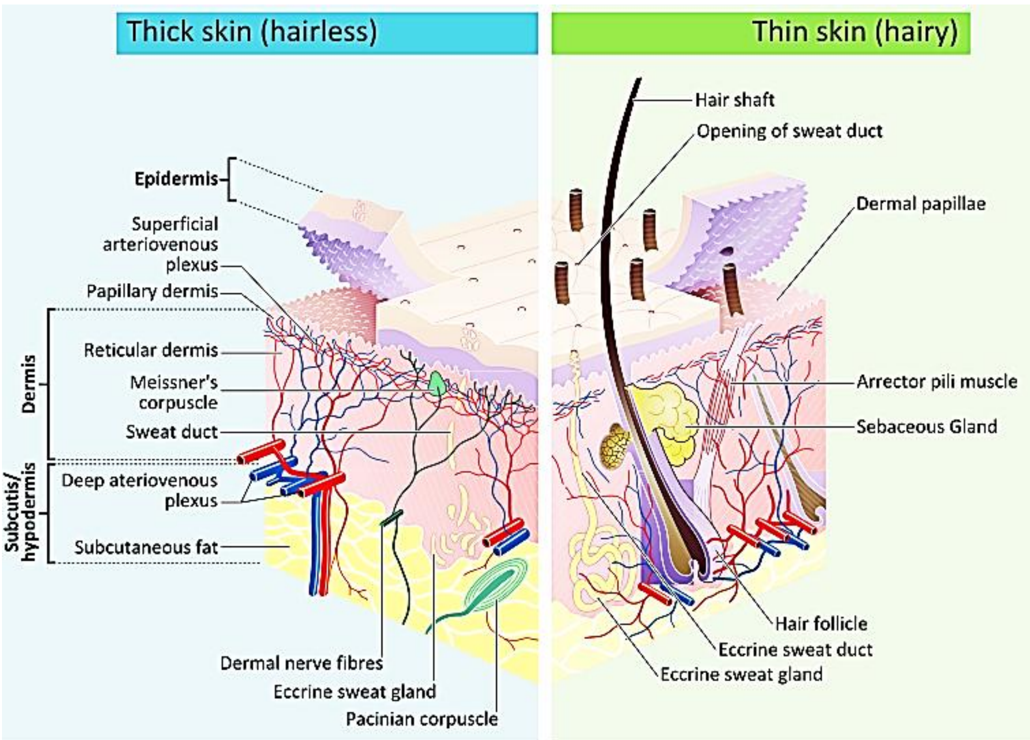

Figure (2.1) Skin layers of both hairy and hairless skin

https://en.wikipedia.org/wiki/File:Skin_layers.png Madhero88 and M.Komorniczak

2.6 Software

Plots are a very useful tool for presenting information. This is true in any field, but especially in science and engineering, where MATLAB is mostly used. MATLAB has many commands that can be used for creating different types of plots.

These include standard plots with linear axes, plots with logarithmic and semi-logarithmic axes, bar and stairs plots, polar plots, three-dimensional contour surface and mesh plots, and many more. The plots can be formatted to have a desired appearance. The line type (solid, dashed, etc.), color, and thickness can be prescribed, line markers and grid lines can be added, as can titles and text comments. Several graphs can be created in the same plot, and several plots can be placed on the same page. When a plot contains several graphs and/or data points, a legend can be added to the plot as well.

This chapter describes how MATLAB can be used to create and format many types of two-dimensional plots. An example of a simple two-dimensional plot that was created with MATLAB.

2.6.1 The code

```
clear
clc
h=6.62*10^-34;c=3*10^8;
me=1.5*10^-19;
wc=h/(me*c^2);
 n=[1:1:3];
B=zeros(12,3)
 m=0;
for n=[1.4,1.6,1.8];
     m=1+m;
    z=1;
    AL=sqrt(1-(1./(n.^2)))
    for  w=[200*10.^-9:10*10.^-9:1500*10.^-9];
S=(2.^-0.5)*(2*pi*[(sqrt([((n.^4)-
(2*(n.^2))*((AL).^2))+((AL).^4)+(4*((AL).^2))]^0.5))-
((n.^2)+((AL).^2))]./w);
sf=(S)*-1;
  B(z,m)=sf;
  if z<131;
  z=z+1;
```

```
  else
  end
    end
end
AL
B
 n=[1.4,1.6,1.8];
 w=[200*10.^-9:10*10.^-9:1500*10.^-9]
figure
plot(w,B(:,1),'*-');
xlabel(' (wave length)','FontSize',14);
 ylabel('depth of skin ','FontSize',14);
figure
plot(w,B(:,2),'o-');
 xlabel(' (wave length)','FontSize',14);
 ylabel('depth of skin ','FontSize',14);
 figure
 plot(w,B(:,3),'--');
 xlabel(' (wave length)','FontSize',14);
 ylabel('depth of skin ','FontSize',14);
 figure
plot(w,B(:,1),'*-',w,B(:,2),'o-',w,B(:,3),'--');
xlabel(' (wave length)','FontSize',14);
 ylabel('depth of skin ','FontSize',14);
 title('COM.','FontSize',14);
 grid on
 w=[500*10.^-9,1064*10.^-9,1164*10.^-9];
[u,v] = meshgrid(w,B(:,1));
  grid on
```

Chapter Three

Results & Analysis

Chapter Three

Results & Analysis

3.1 Method

In this work, MATLAB program was used to find:

1. The relation between skin depth and wavelength at a given refractive indices, using of the new dispersion law of Arbab.
2. The relation between the skin depth and refractive index at a given wavelength, using new dispersion law.

Results obtained writing formula and parameters presented in the previous chapter are shown here.

The variation of skin depth with the wavelength and refractive index are shown in figure (3.1), (3.2), (3.3), (3.4), (3.5), (3.6), (3.7), and (3.8) respectively.

3.2 Results

The variation of penetration depth of human skin with the refractive index through different wavelengths.

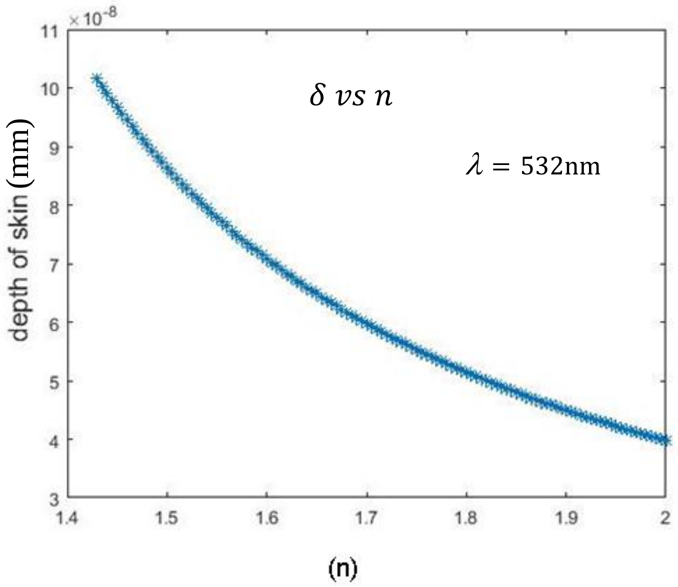

Figure (3.1) The relation between skin depth and the refractive index at wave length=532nm using Arbab's formula

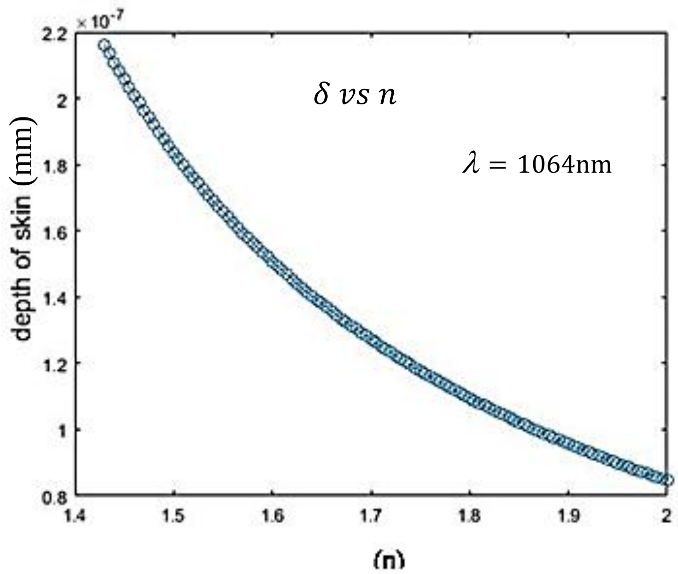

Figure (3.2) The relation between depth of skin and the refractive index at wave length=1064nm using Arbab's formula

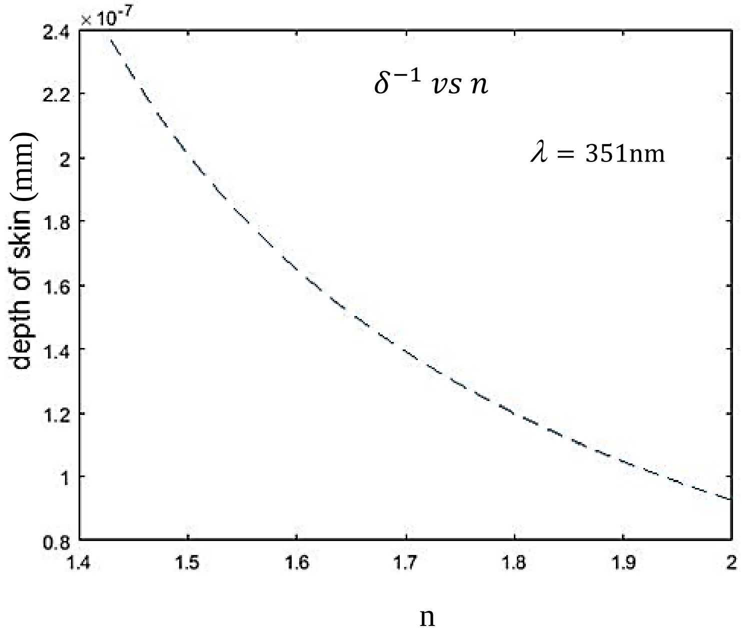

Figure (3.3) The relation between depth of skin and the refractive index at wave length=351nm using Arbab's formula

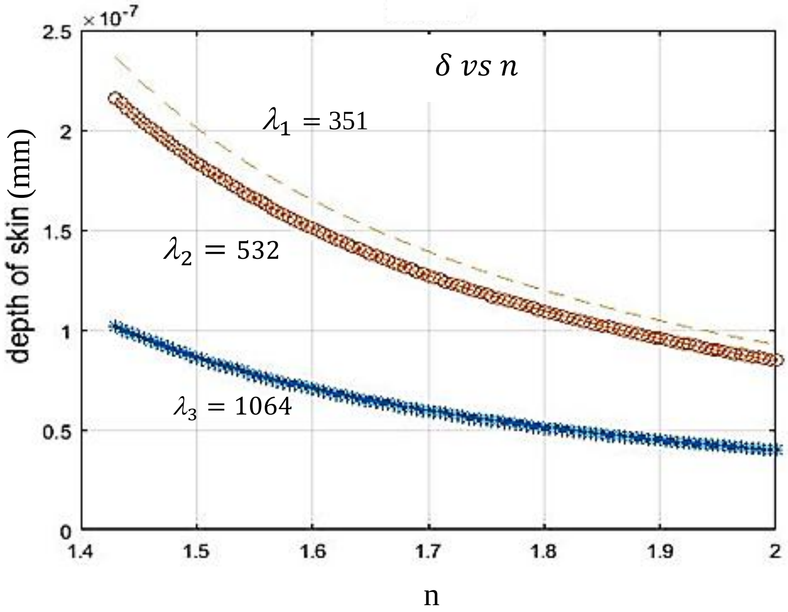

Figure (3.4) Behavior of massive photons in human skin

The variation of the penetration depth of the skin with the wavelength through different refractive indexes.

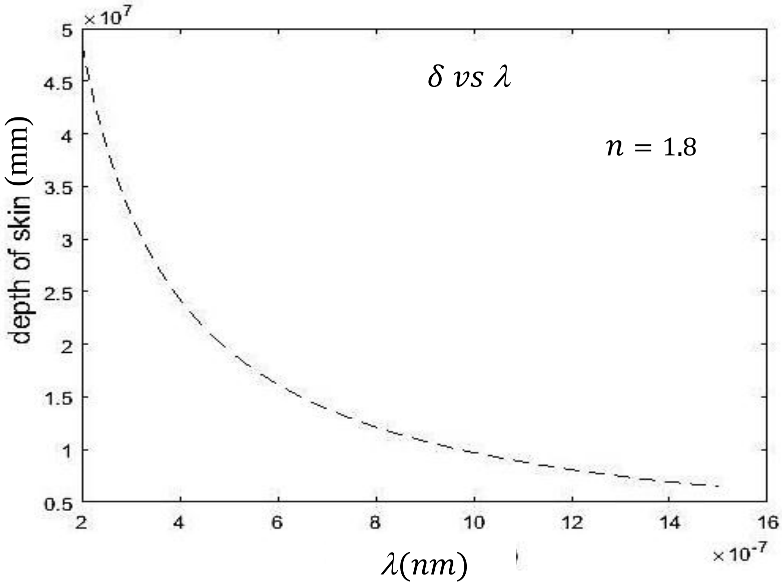

Figure (3.5) The relation between depth of skin and wavelength at n= 1.8 using Arbab's formula

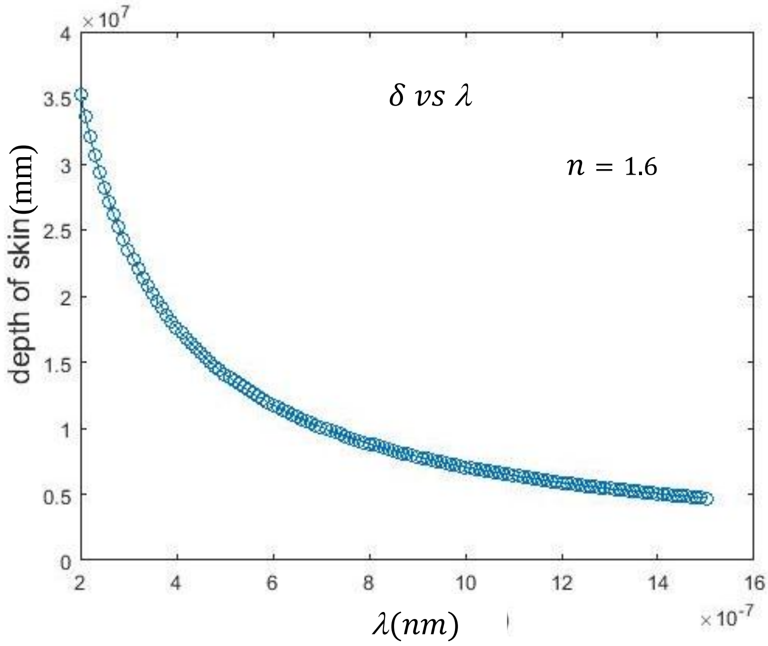

Figure (3.6) The relation between depth of skin and wavelength at n= 1.6 using Arbab's formula

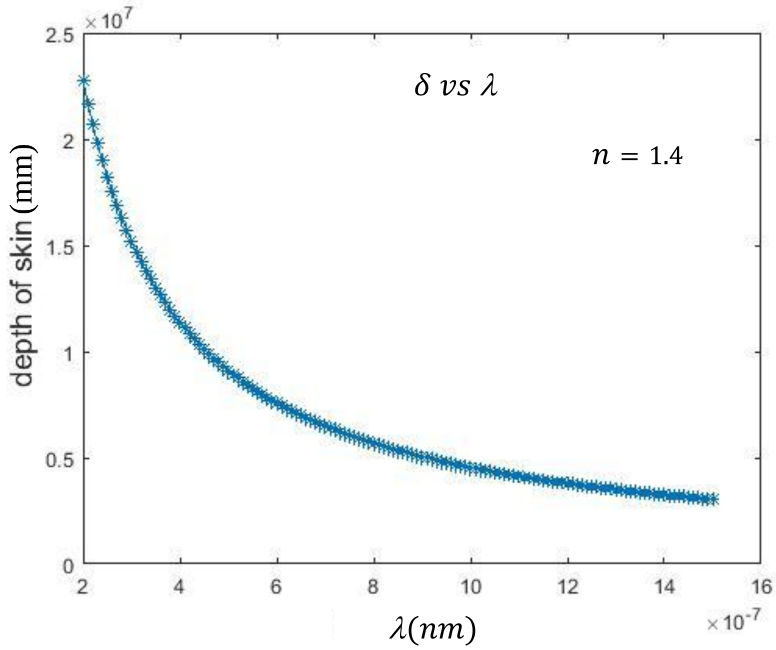

Figure (3.7) The relation between depth of skin and wavelength at n= 1.4 using Arbab's formula

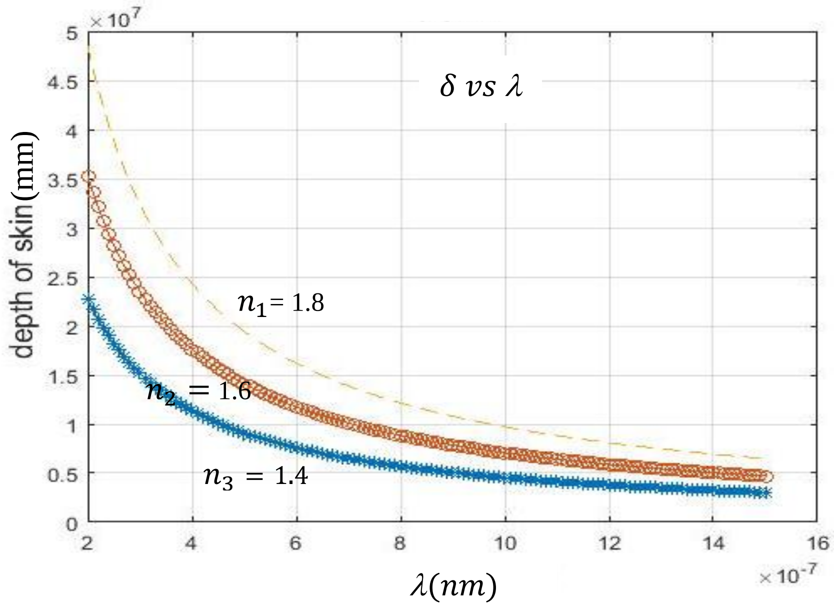

Figure (3.8) The relation between depth of skin, wavelength at different refractive indexes and the photon-mass inside the media (skin)

Comparing between the theoretical data (Cauchy's model) and the experimental data.

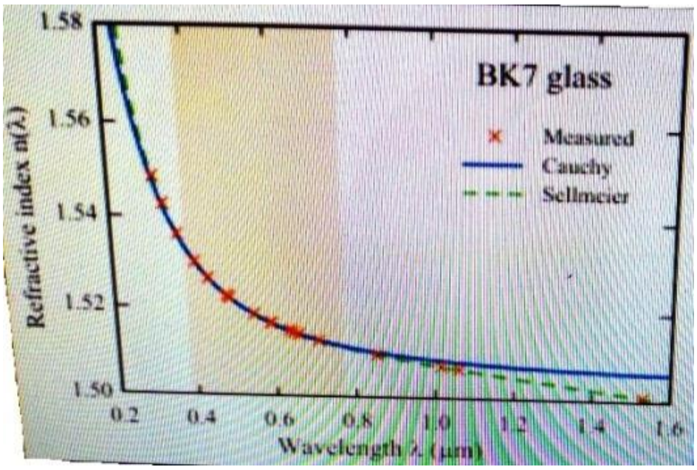

Figure (3.9) Cauchy's model

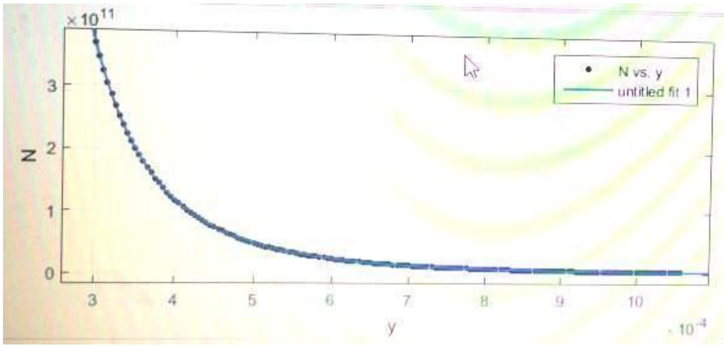

Figure (3.10) Experimental model

3.3 Discussion

A quantum treatment to light was applied and a relation between the refractive index of a medium was obtained, in which light is propagating and its mass.

Refractive index plays an important role in characterization of the biological tissues response to optical illumination, particularly for tissues of heterogeneous composition, such as the layered skin tissues.

The refractive index is defined as the ratio between the velocities of light in vacuum to the phase, velocity (Vp) of light in a medium: $n = c/Vp$

The refractive index of the skin varies with wavelength (λ), when light enters the skin, its wavelength (λ) changes.

The particle nature of the photon appear if only the photon exists inside a medium and not in vacuum (free space), where it is massless.

The rest-mass of the photon depends on the properties of the medium (e.g., refractive index).

The penetration behavior was plotted as a function of wavelength as we've shown that in the figures (3.4) and (3.8).

Note from the diagram that the small wavelengths (high-energy), it should be found that the depth of penetration is small. That occurs different absorption of different layers of skin via the effect of the massive photon. Also we noted that the refractive index values are significant at large δ.

The extent use of refractive index data on a limited number of wavelengths, different dispersion schemes have been tested based on new equation (11) by Dr. A. I. Arbab, it was found that a great similarly between the experimental and theoretical data from Cauchy model.

The exponential decay in figure (3.4) and figure (3.8). It should explain the behavior of light in short and long wavelengths.

3.4 Conclusion

A new dispersion law was presented in this thesis, relating the wavelength of the incident light and the photon mass inside the material. The derived law relies on the idea that photons inside the material have an effective mass. The rest mass energy of the photon:

- The new dispersion law was approved using human skin as an example for biological tissues, the penetration depth of the electromagnetic wave inside the (medium human skin) depends on the refractive index.

3.5 Recommendations

I recommend in the future to study:

1. Range of wavelength have to be extended to include far infrared, microwave, … etc.
2. Behavior for different materials listed.
3. It has to be applied to detailed structure of the human skin.

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Appendix

The following tables contain readings of the refractive indices, penetration depths and number of wavelengths calculated from the dispersion law, which is the subject of our study through the MATLAB program.

10^-7

ʎ=351*10^-9	**ʎ =1064*10^-9**	**ʎ =532*10^-9**	**ʎ=351*10^-9**	**ʎ =1064*10^-9**	**ʎ =532*10^-9**
0.4228	0.4626	0.9844	0.5461	0.5974	1.2713
0.4281	0.4684	0.9967	0.5515	0.6034	1.2840
0.4334	0.4742	1.0090	0.5570	0.6093	1.2967
0.4387	0.4800	1.0214	0.5625	0.6153	1.3094
0.4440	0.4858	1.0337	0.5679	0.6213	1.3221
0.4493	0.4916	1.0461	0.5734	0.6273	1.3349
0.4547	0.4974	1.0585	0.5789	0.6333	1.3476
0.4600	0.5032	1.0709	0.5844	0.6393	1.3604
0.4653	0.5091	1.0833	0.5899	0.6453	1.3732
0.4707	0.5149	1.0957	0.5954	0.6513	1.3860
0.4760	0.5207	1.1081	0.6009	0.6574	1.3988
0.4814	0.5266	1.1206	0.6064	0.6634	1.4117
0.4867	0.5325	1.1331	0.6119	0.6694	1.4246
0.4921	0.5383	1.1456	0.6175	0.6755	1.4375
0.4974	0.5442	1.1581	0.6230	0.6816	1.4504
0.5028	0.5501	1.1706	0.6286	0.6876	1.4633
0.5082	0.5560	1.1831	0.6341	0.6937	1.4762
0.5136	0.5619	1.1957	0.6397	0.6998	1.4892

0.5190	0.5678	1.2082	0.6453	0.7059	1.5022
0.5244	0.5737	1.2208	0.6509	0.7120	1.5152
0.5298	0.5796	1.2334	0.6565	0.7182	1.5282
0.5352	0.5855	1.2460	0.6621	0.7243	1.5413
0.5407	0.5915	1.2587	0.6677	0.7304	1.5544
0.6733	0.7366	1.5675	0.8112	0.8874	1.8884
0.6789	0.7428	1.5806	0.8170	0.8938	1.9021
0.6846	0.7489	1.5937	0.8229	0.9003	1.9157
0.6902	0.7551	1.6069	0.8288	0.9067	1.9295
0.6959	0.7613	1.6200	0.8347	0.9132	1.9432
0.7016	0.7675	1.6332	0.8406	0.9196	1.9570
0.7072	0.7737	1.6465	0.8466	0.9261	1.9708
0.7129	0.7799	1.6597	0.8525	0.9326	1.9846
0.7186	0.7862	1.6730	0.8584	0.9391	1.9984
0.7243	0.7924	1.6863	0.8644	0.9456	2.0123
0.7301	0.7987	1.6996	0.8704	0.9522	2.0262
0.7358	0.8049	1.7129	0.8764	0.9587	2.0402
0.7415	0.8112	1.7263	0.8823	0.9653	2.0541
0.7473	0.8175	1.7396	0.8884	0.9718	2.0681
0.7530	0.8238	1.7530	0.8944	0.9784	2.0821
0.7588	0.8301	1.7665	0.9004	0.9850	2.0961
0.7646	0.8364	1.7799	0.9064	0.9916	2.1102
0.7704	0.8428	1.7934	0.9125	0.9983	2.1243
0.7762	0.8491	1.8069	0.9186	1.0049	2.1384

0.7820	0.8555	1.8204	0.9246	1.0115	2.1525
0.7878	0.8618	1.8340	0.9307	1.0182	2.1667
0.7936	0.8682	1.8475	0.9368	1.0249	2.1809
0.7995	0.8746	1.8611	0.9429	1.0315	2.1951
0.8053	0.8810	1.8747	0.9491	1.0382	2.2094
0.9552	1.0450	2.2237	1.0235	1.1197	2.3827
0.9613	1.0517	2.2380	1.0298	1.1266	2.3973
0.9675	1.0584	2.2523	1.0361	1.1335	2.4120
0.9737	1.0652	2.2667	1.0424	1.1404	2.4267
0.9799	1.0719	2.2811	1.0487	1.1473	2.4414
0.9861	1.0787	2.2955	1.0551	1.1542	2.4562
0.9923	1.0855	2.3100	1.0614	1.1612	2.4710
0.9985	1.0923	2.3245	1.0678	1.1681	2.4858
1.0047	1.0991	2.3390	1.0742	1.1751	2.5006
1.0110	1.1060	2.3535	1.0806	1.1821	2.5155
1.0172	1.1128	2.3681			