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Effective Atomic Numbers, Electron Densities and CT Numbers of Some Hormones of Dosimetric Interest

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Abstract: ***The Effective atomic number, electron density and CT numbers of hormones such as testosterone, methandienone, oestradiol and progesterone for partial (coherent scattering, incoherent scattering, photoelectric absorption, and pair production in the field of the atomic nucleus and in the field of the atomic electrons) and total photon interactions in the wide energy region 10^{-3}MeV to 10^{5}MeV using WinXCOM programme. These values are found to vary with energy and composition of hormones and Z_{eff} vary from the element with lowest Z to the highest Z present in their composition of them. The significant variation of Z_{eff} and Electron density with photon energy is shown in the graphs. Even CT numbers are also not remaining constant with energy and it helps in visualizing the image of the biological samples.***

Keywords: Effective atomic number, Electron density, CT numbers, Hormones

1. Introduction

Cross-sectional image of internal organs is prime importance in the field of medicine for diagnosing the diseases. Computed tomography (CT) measures the accurate radiographic density of the small parts of the body which helps in visualizing the image. The CT number is not only outlining the inhomogeneities of the tissues but also give the direct information of the tissue electron density from which accurate corrections can be made by suitable treatments. Even dose calculations are made based on the patient specific information obtained from X-ray computed tomography.

Mass attenuation co-efficient (μ/ρ) is a measure of probability of interaction that occur between a photon and a matter of unit mass per unit area. The extent to which the compound gets affected due to ionizing radiation depends on μ/ρ of the compound which can be obtained by WinXCOM programme or mixture rule. The knowledge of mass attenuation of coefficient is prime importance. Exact values of mass attenuation of coefficient are necessary to establish the regions of validity of theory based parameterization in addition to provide essential data in the field of computer assisted tomography, gamma ray fluorescence, radiation bio physics, radiation dosimetry, calculation of dose, radiation therapy and medical imaging etc. The mass attenuation of coefficient of gamma-ray is found to be great important for industrial, biological, agricultural, medical studies etc.

Atomic number is an important parameter for characterization of any materials but, for the composite materials or biomolecules composed of various elements a single number cannot represent the atomic number for a photon interaction uniquely across the entire energy region, as in the case of pure elements. This number in composite materials or biomolecule is called effective atomic number Z_{eff}. It was pointed out by Hine that Effective atomic number for gamma interaction for biomolecule composed of various elements can not be expressed by the single atomic number uniquely across the entire energy region as in the case of pure elements. Parthasaradhi and Siddappa *et al* studied and reported Z_{eff} of composites for gamma interactions and concluded that Hine's predictions were correct. El-Kateb.A.H. and Abdul Hamid determines that Z_{eff} in case of materials containing carbon, hydrogen and oxygen atoms. Govind Nayak *et al* calculated Z_{eff} for some polymers. Shivaramu *et al* determined Z_{eff} for photon energy absorption of some low-Z substances of dosimetric interest. Orhan Icelli focused on the Z_{eff} for vanadium and Nickel compounds for photon interaction. S Bhadal and K Singh determined Z_{eff} for total photon interaction in the energy region 10^{-3} MeV to 10^{5}MeV for biological samples containing several elements. Shivaramu determined Z_{eff} for some major tissues from human organs total photon interactions .Then Shivalinge Gowda *et al* evaluated Z_{eff} and electron density of some amino acids in the energy region 30-1333KeV. The evaluation of Z_{eff}, electron density of biological samples is very few.

But Z_{eff}, electron density and CT number calculations of hormones have not been found in literature survey.

Hence the present work focuses the determination of Z_{eff} and electron density of some important steroid sex hormones such as testosterone, methandienone, oestradiol and progesterone in the energy region 10^{-3}MeV to 10^{5}MeV for all photon interactions. Testosterone is the main androgen which is produced in the testes helps in development and maintenance of secondary male sex characters.

Methandienone is an anabolic steroid Oestradiol is important oestrogenic hormones produced in ovaries and it influence the development and maintenance of secondary female sex characters. Progesterone is the main hormone produced by corpus luteum and placenta. These hormones are required for the normal functioning of an organism. Hence the study of Z_{eff}, electron density and CT numbers for photon interaction of above hormones is very important in radiation medical physics. The Chemical composition of Testosterone, Methandienone, Oestradiol and Progesterone is given in table

Hormones	Chemical composition		
	Hydrogen	Carbon	Oxygen
Testosterone	0.09784	0.79121	0.11094
Methandienone	0.09393	0.79955	0.10650
Oestradiol	0.08542	0.79666	0.117912
Progesterone	0.09325	0.80466	0.10208

2. Theory and Methodology

When electro magnetic radiation passes through matter, their intensity is attenuated according to the exponential law. If a beam of these radiations having an intensity I_0 passes through a thickness x of an absorber, the transmitted intensity I is given as

$$I = I_0 \exp\left(-\mu/\rho\right)x$$

where ρ is the density of the material.

(μ/ρ) is the mass attenuation coefficient & is independent of density of the absorber.

The mass attenuation co-efficient of a compound or a mixture (biomolecule) consists of various elements is given by mixture rule (Jackson. D. F and Hawkes)

$$\left(\frac{\mu}{\rho}\right)_{bio} = \sum_i W_i \left(\frac{\mu}{\rho}\right)_i$$

Where, $(\mu/\rho)_i$ and W_i are mass attenuation co-efficient and fractional abundance by weight of i^{th} element present in a molecule respectively.

When a beam of photons passes through an absorber, the photons interact with the atoms and are either absorbed (photoelectric effect, pair and triplet production, photo nuclear) or scattered away form the beam (Coherent and incoherent scattering). The intensity of the transmitted beam of photons is the sum of the cross-sections, per atom for all the above processes, hence total cross-sections σ_{tot} is given by () Berger.M.J. and Hubbell.J.H & Hubbell. J H; Seltzer)

$$\sigma_{tot} = \sigma_{pe} + \sigma_{c0h} + \sigma_{incoh} + \sigma_{pair} + \sigma_{ph.n}$$

Where σ_{pe} is the photo electric absorption cross section.
σ_{coh} is the coherent scattering cross section.
σ_{incoh} is the incoherent scattering cross section.
σ_{pair} is the pair production absorption cross section.
σ_{phn} is the photo nuclear absorption cross section.

The total molecular cross section σ_{mol} is determined from the following equation using the values of mass attenuation coefficient of biomolecules $(\mu/\rho)_{bio}$

$$\sigma_{mol} = \left(\frac{1}{N}\right)\left(\frac{\mu}{\rho}\right)_{bio} \sum_i n_i A_i$$

Where N is Avogadro number, n_i is the number of atoms of i^{th} element and A_i is its atomic weight in a given molecule.
The effective atomic cross section σ_{atm} are determined by

$$\sigma_{atm} = \frac{\left(\mu/\rho\right)_{bio}}{N \sum_i W_i A_i}$$

$$\sigma_{atm} = \frac{1}{N} \sum_i f_i A_i \left(\frac{\mu}{\rho}\right)_i$$

Where f_i is the fractional abundance $(\mu/\rho)_i$ is mass attenuation co-efficient of i^{th} element.

$$\sigma_{atm} = \frac{\sigma_{mol}}{\sum_i n_i}$$

The effective electronic cross section σ_{ele} are determined by

$$\sigma_{ele} = \left(\frac{1}{N}\right) \sum_i \left\{ \left(\frac{f_i A_i}{Z_i}\right) \left(\frac{\mu}{\rho}\right)_i \right\}$$

Where, and Z_i is the atomic number of i^{th} element in a molecule respectively.

Then effective atomic number is calculated using

$$Z_{eff} = \frac{\sigma_{atm}}{\sigma_{eie}}$$

The effective electron density is obtained from

$$N_e = \frac{N}{\sum_i n_i A_i} Z_{eff} \sum_i n_i$$

The CT number (Thomas. S J)is estimated from

$$CT = \frac{(\mu_m - \mu_w)}{\mu_w} 1000$$

Where μ_m and μ_w are the attenuation co-efficient of hormones and water respectively.

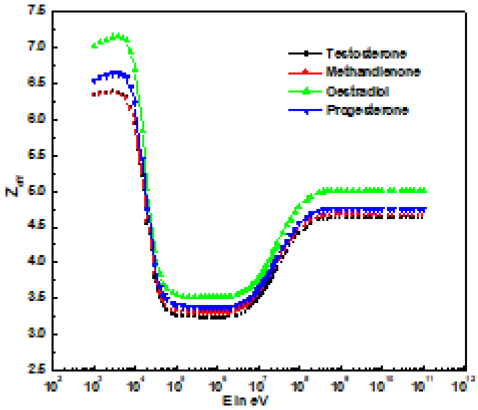
In the present work instead of calculating the mass attenuation co-efficient of hormones using the mixture rule (Jakson. D. F and Hawkes.D) from the μ/ρ of elements obtained from Hubbell.J.H *et al*, tables, we had run the WinXCOM computer programme for calculating mass attenuation co-efficient for all photon interactions, which have saved the time and reduces the manual work. From the $(\mu/\rho)_{bio,}$ for different photon interactions, the Z_{eff} and N_e for hormones have been calculated.

3. Results and Discussions

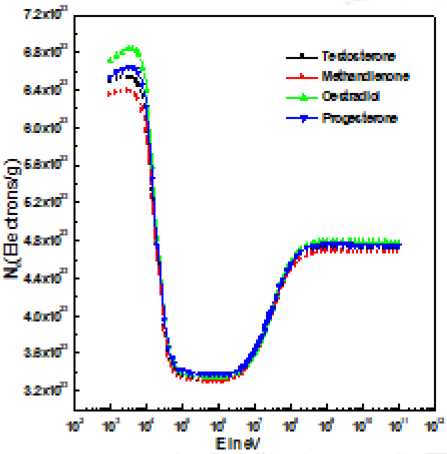
The variation of Z_{eff} and electron density N_e for photon interaction of above hormones testosterone, methandienone, oestradiol and progesterone is as shown in the following graphs.

Total photon interaction:
The variation of Z_{eff} and N_e with photon energy for total photon interactions is as shown in the figure 1 and this variation is because of dominance of different photon interactions with hormones. In lower energy region, photo electric interaction dominates, hence Z_{eff} varies similar to photo interaction. There is a slight increase in the Z_{eff} up to 6keVand becomes maximum then decreases sharply. It remains constant from 50keV to 5MeV which shows that coherent and incoherent processes increases. From 5MeV to200MeV, there is regular increase in the Z_{eff} with photon energy. This is due to the increase in incoherent and pair production processes. From 200MeV onwards Z_{eff} remains

constant which is due to dominance in pair production processes. It is found that Z_{eff} values of hormones vary from the element with lowest Z to the highest Z present in their composition. Similar variation is observed for electron density N_e with Photon energy E for total photon interaction.



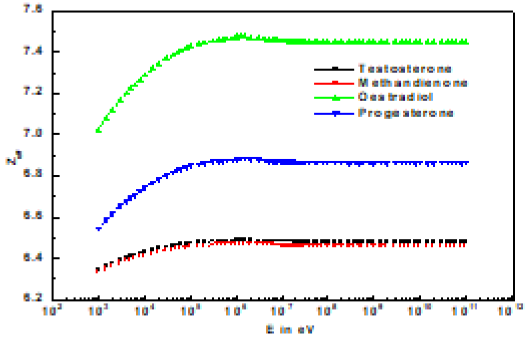
Variation of Z_{eff} with Photon energy E in eV for total photon interaction



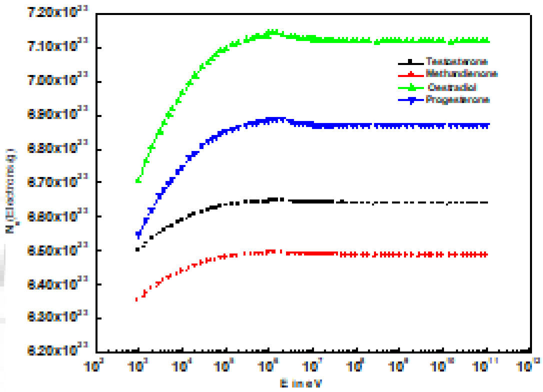
Variation of N_e with Photon energy E in eV for total photon interaction

Photo electric absorption

The variation of Z_{eff} and N_e with photon energy for photo electric absorption interaction is as shown in the following figures and this shows that Z_{eff} increases gradually up to the photon energy 1MeV. It remains constant thereafter i.e. independent of photon energy. This is due to the dominance in photoelectric absorption in low energy region i.e. less than 1MeV and for the substances of higher atomic number (Z) than for low Z substances. Z_{eff} is constant and independent of energy due to the fact that the hormones consist of number of constituent elements of close atomic number. Similar variation is observed for electron density N_e with Photon energy E for photo electric interaction



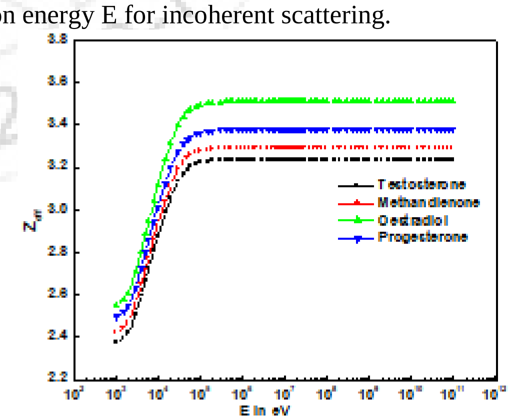
Variation of Z_{eff} with Photon energy E in eV for photo electric absorption



Variation of N_e with Photon energy E in eV for photo electric absorption

Incoherent scattering

The variation of Z_{eff} and N_e with photon energy for incoherent scattering is as shown in the figures and it indicates that Z_{eff} increases from1keV to 100keV shows that it depend on energy. This variation is because of the proportion and the range of atomic numbers of the elements present in hormones. Above 100keV Z_{eff} remains constant and independent of energy for all hormones. This is result is similar to the experimental findings of Parthasaradhi. Similar variation is observed for electron density N_e with Photon energy E for incoherent scattering.



Variation of Z_{eff} with Photon energy E in eV for incoherent scattering

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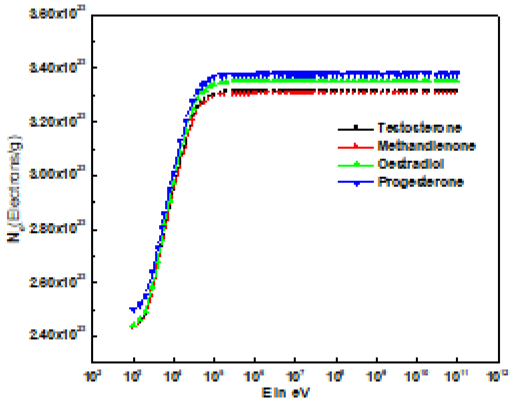
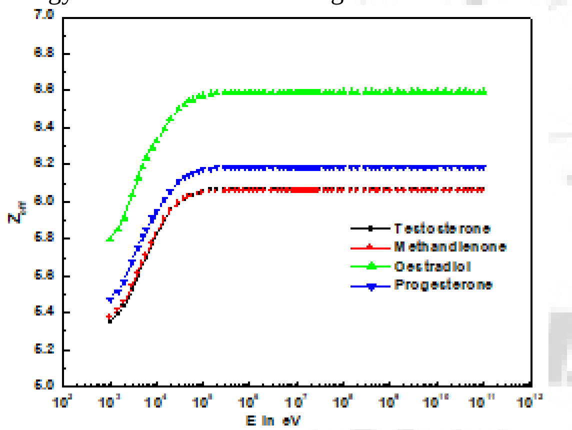


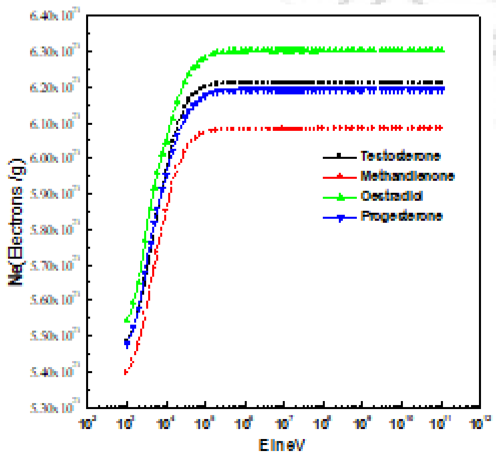
Variation of N_e with Photon energy E in eV for incoherent scattering

Coherent scattering:

The variation of Z_{eff} and N_e with photon energy for coherent scattering is as shown in the figures and it indicates that Z_{eff} increases from 1keV to 60keV. Thereafter remains constant i.e. independent of energy. The Z_{eff} of hormones lies between 6.06 and 6.59 at higher energy region. Similar variation is observed for electron density N_e with Photon energy E for coherent scattering



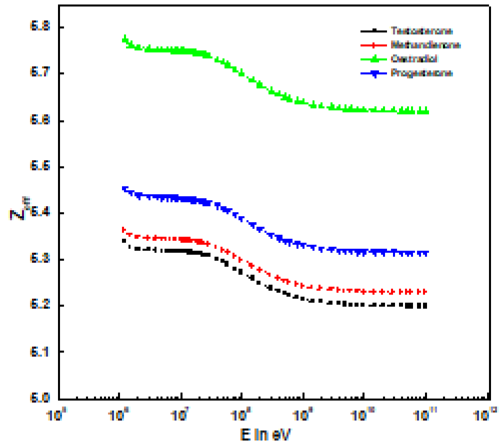
Variation of Z_{eff} with Photon energy E in eV for coherent scattering



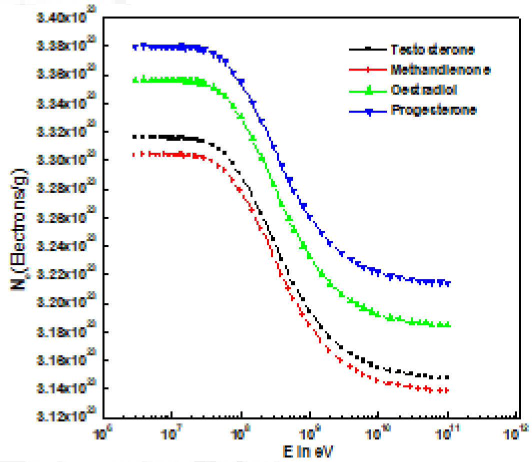
Variation of N_e with Photon energy E in eV for coherent scattering

Pair production in nuclear field:

The variation of Z_{eff} and N_e with photon energy for pair production in nuclear field is as shown in the figures and it shows that Z_{eff} slightly decreases with increase in photon energy from 1.25MeV onwards and found to remain constant after 800MeV.This is because of the fact that pair production in nuclear field is Z^2 dependent. Similar variation is observed for electron density N_e with Photon energy E in this interaction.



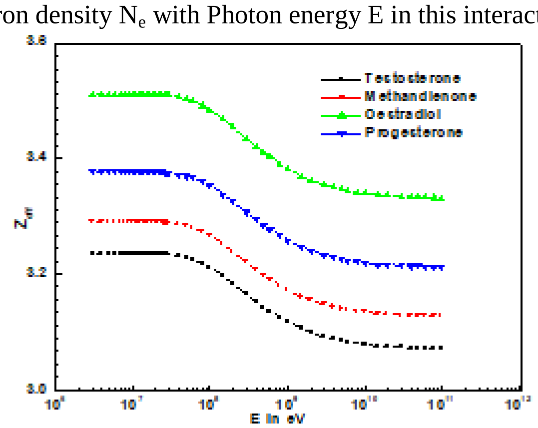
Variation of Z_{eff} with Photon energy E in eV for pair production in nuclear field



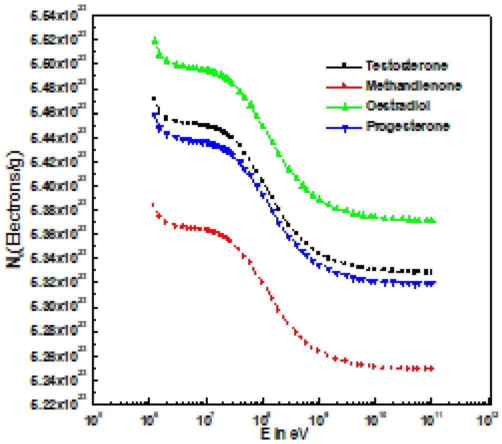
Variation of N_e with Photon energy E in eV for pair production in nuclear field

Pair production in electric field:

The variation of Z_{eff} and N_e with photon energy for pair production in electric field is as shown in the figures. It shows that Z_{eff} is constant with increase in photon energy from 3MeV to 30MeV i.e. independent of energy. It slightly decreases from 30MeV to 3000MeV and thereafter remains constant for all hormones. Similar variation is observed for electron density N_e with Photon energy E in this interaction.



Variation of Z_{eff} with Photon energy E in eV for pair production in electric field



Variation of N_e with Photon energy E in eV for pair production in electric field

The values of Z_{eff} and N_e are used for planning and treatment in radiotherapy.

Steroid sex hormones are formed in gonads, ovaries or testes and these are also formed in varying proportions in the adrenal cortex and placenta. These are able to effect the development and maintenance of the structures which are directly and indirectly associated with reproduction. Hence while treating tissue inhomogenity of the patient during radiotherapy, the contribution of CT numbers of hormones which is secreted has to be considered. The CT numbers for total photon interaction for some energies is given in the table.

	Testosterone	Methandienone	Oestradiol	Progesterone
E in eV	CT	CT	CT	CT
1.000E+03	-445.9	-446.38	-435.1	-448.5
5.000E+03	-519.1	-520.42	-508.9	-523.1
1.000E+04	-516.7	-518.26	-507.4	-520.9
5.000E+04	-98.79	-101.88	-106.1	-102.8
1.000E+05	-29.05	-32.39	-39.3	-33.09
5.000E+05	-13.59	-17.05	-24.5	-17.67
1.000E+06	-13.56	-17.03	-24.5	-17.64
5.000E+06	-28.50	-31.63	-37.9	-32.26
1.000E+07	-53.57	-56.09	-60.42	-56.77
5.000E+07	-130.1	-130.8	-128.9	-131.6
1.000E+08	-149.8	-150.1	-146.6	-150.8
5.000E+08	-161.0	-160.9	-156.3	-161.6
1.000E+09	-160.1	-160.03	-155.3	-160.7
5.000E+09	-157.8	-157.6	-153.0	-158.4
1.000E+10	-157.3	-157.2	-152.6	-157.9
5.000E+10	-156.8	-156.7	-152.1	-157.4
1.000E+11	-156.8	-156.7	-152.1	-157.4

The CT numbers for coherent, incoherent, and photoelectric absorption region and total photon interaction helps in visualizing the image of the organs and precise accuracy in treating the inhomogenity of them in medical radiology.

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