ACTIVATION ENERGY OF HUMAN NAIL

P. VENKAT RAO[1*], ADEEL AHMAD[2], B.S.BELLUBBI[3]

[1]Professor, Department of Physics, Narsimha Reddy Engineering College, Hyderabad-500100
[2,3]Biophysics Unit, Department of Physics, Nizam College (Autonomous)
Osmania University, Hyderabad-500001
* Corresponding author email: professor.venkatrao@gmail.com

Abstract –

This paper is concerned with the activation energy of human male and female finger nail. The Variation of electrical resistivity of human finger nail, with temperature is notated to calculate activation energy. The average value along with S.D. of activation energy of male human nail is slightly more than that of female human nail. The activation energy values are in the range of semiconductors arising from an electron tunneling mechanism.

Key Words – Human finger nail, jig instrument, activation energy

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1. Introduction

Vertebrate body contains both soft and hard tissues to carry out life processes. Among the hard tissues horn, hoof, feather, claw and nail are the derivatives of the skin. Generally, skin is known as integument. However, the hard tissues, which serve as exoskeleton, can also be referred as integuments as they are highly useful in protecting the body from the environmental influences, acting as thermo-insulators and thermo – regulators.

The study of the electronic properties of biomacromolecules should, therefore, become part of the interdisciplinary armory of the biological sciences. Advances in such studies should certainly be of benefit to some branches of medicine, and it could well be that progress in cancer research, for example, will be greatly accelerated by an increased understanding of the sub molecular processes involved in cellular activity.

Solid-state physics adds extra dimensions to the models of biological mechanisms. It suggests, among other things, the presence of free, mobile, electronic charge carriers in organized structures. Such structures, which may be crystalline or amorphous, are well documented as present in many biological organelles such as chloroplasts, mitochondria, membranes and finally in individual biomacromolecules such as nucleic acids and proteins.

Electronic charge carriers may be delocalized over relatively large distances in such structures and will contribute to the electrical conductivity of the structures, energy transfer, information transfer, spatial separation of oxidizing and reducing entities and generation of free radicals. These all represent important mechanisms in biology.

A free electron, with kinetic energy of 3/2 KT, may have thermal velocities at room temperature about 10^7 cm sec^{-1}, and therefore, depending on the life time, □ of the free carrier, may wander over large distances on a molecular scale. In the presence of an electric field, a small component of drift in the direction of the electric field is added to the random thermal motions, and this makes a contribution to the electrical conductivity of the structure. This contribution to the velocity ν in the field direction is proportional to the strength of the field, E or $\nu = \mu E$, and the constant of proportionality, μ is called the drift mobility of the carrier. The electrical current per unit cross-sectional area j, which flows in a material, is also proportional to the strength of field and $j = \sigma E$. The constant of proportionality σ is the conductivity of the structure. The conductivity is related to the mobility by simple formula $\sigma = n\, e\, \mu$ where n is the density of free charge carriers and e is the electronic charge.

Generally, in any structure, there are many kinds of charge carriers, ions of both signs, protons, electrons and holes. For sufficiently low charge carrier densities, which usually occur in non-metallic materials, the charges move independently of all other charges and the total conductivity is the sum of the contributions of each charge carrier type. Therefore, we have

$$j/e = \varepsilon_i\, n_i\, e\, \mu_i \qquad \text{----- 1}$$

Where, the sum is taken over all charge carrier types and signs. It is therefore, necessary to know the charge carrier density n and the mobility μ of each charge carrier type in order to fully understand the conduction processes. The charge carrier density will be the product of the rate of generation of charge carriers, dn/dt multiplied by the lifetime of carriers □. The life time reflects the processes of loss of carriers either by recombination or localization. Thus, measurements of the electrical properties of substance can give significant information on the mechanisms and rates of generation of charge carriers, the equilibrium densities, the life time and the mobilities. Substances, whose electrical conductivity as a function of temperature follow the relation are operationally defined as semiconductors.

$$\sigma(T) = \sigma_o \, \text{Exp.}(-E/2\,KT) \quad \text{-- } 2$$

Representative molecules of four categories of bio-chemicals, such as carbohydrates, proteins, lipids and nucleic acids, several complex organelles, as well as organic substances tested have been demonstrated to be semiconductors in the solid state.

At about the same time as Szent-Gyorgyi (1946) was proposing that the semiconduction properties of protein were of biological relevance, Baxter and Cassie (1941 & 1943) were demonstrated that moist specimens of wool behave as electrical conductors, with their conductivity σ varying with temperature according to the Arrhenius-type equation in the manner commonly observed for semiconductors.

$$\sigma = \sigma_o \, \text{Exp.}(-E/KT) \quad \text{------ } 3$$

E in the above equation is the activation energy of semiconduction, and σ_o is a constant whose value depends on the test material. For wool the activation energy was found to have a value of 1.1 ev, and the semiconductivity was considered to arise from an electron tunneling mechanism between absorbed water molecules rather than from energy band conduction associated with the protein structure. The various features of water in heated 100 – 1000 ºC hard dental tissues was studied by Luciano Bachmann et al (2004) using IR spectroscopy and analysied water bonds between 3800 cm^{-1} to 2500 cm^{-1}. Dependence of water band with temperature in two regions (100 – 400 ºC and 700 – 1000 ºC) was compare with Arrhenius equation and their activation energy was calculated and found similar values for enamel and dentin tissues. The conclusion given by them is that loosely bond and tightly bond water may be assigned by these two activation energies. The dielectric studies of the nail plate studied by Ewa Marzec (2019) enable deeper analysis of the matrix–keratin–water system, which can facilitate the assessment of the electrical conductivity of this tissue in the state of health and diseased. The human toenail was measured in vitro in the alpha-dispersion region of the electric field and the temperature from 22 to 150 °C. The values of dielectric properties are much higher in the wet nails than in those without water of the same temperature and frequency.

The temperature dependence of a semiconductor is given by equation (2). If the logarithm of the conductivity σ (T) is plotted on the ordinate against the reciprocal of the absolute temperature on the abscissa, a straight line is generated whose slope is E/2K. The straight line may be extrapolated to intercept the ordinate at 1/T = 0. This intercept point is the value of σ_o. The temperature dependence of the conductivity is, therefore, characterized by two constants, E and σ_o. Activation energies can be determined by measuring the current flow through a sample as the temperature is varied. In order to test the semi conduction theory, the measurements should be made with a variety of ambient atmospheres. The sample clamped between two metals electrodes is placed in a chamber which may either be sealed, evacuated, may allow the passage of vapour through it. For low conductivity materials the chamber must be shielded, and therefore if the chamber is not constructed of metal it should be placed in the Faraday cage. If photo conductive process is of interest, an optical port must be included in the chamber. The conductivity is measured as a function of the sample temperature. When the log of the conductivity is plotted as a function of reciprocal absolute temperature a straight line results whose slope according to equation (2) is E/2K, from which the activation energy for semiconduction can be calculated.

The three stranded collagen molecule, having a molecular weight of the order 3×10^5, is much larger than most of the other proteins investigated. This could result being well defined energy bands with the collagen molecules, with the intermolecular barriers limiting long range charge carrier transport being less pronounced. Such factors would suggest that collagen may prove to be an important protein regarding further electrical conduction studies. The electronic conduction properties of the protein molecules are more clearly emphasized. The range of experimental investigations on these protein complexes has been extended so as to include piezoelectric, hydration isotherm, microwave Hall Effect, and dielectric studies. Piezoelectric studies have been observed in wood, bone, nerve, membranes, DNA and in proteins such as collagen, fibrin, myosin, actins, keratin and synthetic polypeptide. Survey of literature reveals that though exclusive studies were made on piezoelectricity and electrical conductivity of many hard and soft biological tissues, such as wood, collagen, tendon, bone (cortical), horn, hoof, muscle, nerve, blood etc. But the electrical properties of the human nail have not been studied in detail by the researchers. The voltage-current characteristics, variation of resistivity with the variation of voltage and temperature, activation energy of human nail samples are studied. In view of this an attempt is made to study the different electrical properties of the human nail, in order to understand mechanisms involved in the electrical conduction processes with temperature of the human nail.

2. Materials and Methods

For the study of solid state properties of the human nail, male and female volunteers were selected. The finger nails were allowed to grow up to 12 weeks i.e. 84 days in female volunteers and nearly 11 weeks i.e. 75 days in male volunteers. The grown free edge nails (whitish grown part from the tip of nail i.e., cut nail) were cut smoothly and washed, dried and used for the investigation. For the study of solid state properties specimens of both gender, were prepared flat surface shape by pressing them under 1Kg weight for a day or two which is suitable for placing in jig instrument.

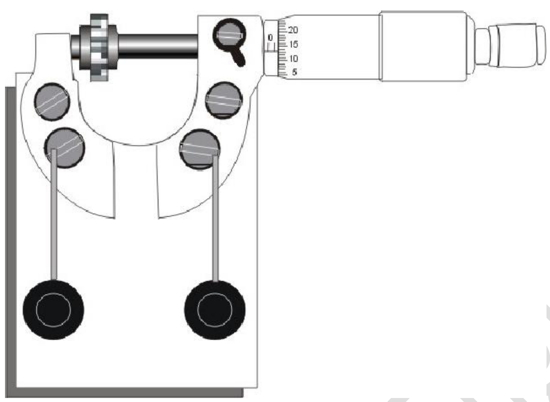

Fig.1 Jig instrument

For the measurement of activation energy of human nail, a two terminal cell (Jig) is constructed in the laboratory. The cell consists of two parallel circular plates made up of copper. The diameter and thickness of the plates are 1.2 cm and 0.5 cm respectively. The samples were fixed between the two circular plates to apply the voltage. The applied voltage is fixed and the current is measured with increasing temperature. By taking the different samples of the male and female human nail using jig resistance is measured by changing the temperature of sample which is kept in oven. Knowing the voltage and current each time, resistance is calculated and a graph is plotted between 1/T on x-axis Ln R on y-axis which is obtained as a straight line. By knowing the slope the activation energy is calculated.

3. Results and Discussion

Table 1 and 2 show the data on electrical resistance of male and female human nail measured as a function of temperature ranging from 313 ^{0}K to 333 ^{0}K, with an interval of 2 ^{0}K. Fig. 2 and 3 shows the plots between reciprocal of absolute temperature on x-axis and Ln of resistance on y-axis. Table 3 and 4 present the data on activation energy of male and female human nail.

The present investigation is carried out to study electrical properties with regard to semiconducting properties. In the past, biomacromolecules such as proteins and nucleic acids have been regarded as semiconducting material. But no authentic information is available to say that human nail is a semiconductor. Hence, in the present investigation, an attempt is made to study some electrical properties of human nail, which could throw light on semiconducting nature of human nail. Semiconductors have resistivity in the range between 10^{-8} and 10^{9} Ωm. as measured at room temperature, and hence occupy an intermediate position between metals and dielectrics. Semiconductors display a series of specific properties that distinguish them from other substances.

1. First and basic one is voltage -current characteristics. V-I characteristics may be ohmic or non-ohmic but devices should have non-ohmic nature
2. In contract to metals, semiconductors should have a negative temperature coefficient of resistivity.
3. Semiconductors are noted for heavy dependence of conductivity on the kind and amount of impurity present.
4. Semiconductor should have energy gap in the range of 0.18 ev to 2.86 ev.
5. Semiconductors are sensitivity to various external influences such as light, electric and magnetic fields,pressure, temperature, humidity, etc.
6. Semiconductors are differentiated on the basis of conduction properties such as nature of charge carriers, concentration and mobility of charge carrier.

Hence, the above properties have been studied to categorise the human nail as semiconducting material. From Voltage-Current characteristics of human nail, it is obvious that human nail is exhibit ohmic behaviour. It is a well established fact that semiconduction properties of biomacromolecules, mainly, proteins and nucleic acids, have biological relevance. It is reported in literature that moist wool behaves as electrical conductor, the conductivity varying with temperature according to the Arrhenius-type equation.

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$$\sigma = \sigma_0 \exp(-E/KT)$$

Where σ is electrical conductivity; E is the activation energy; K is Boltzmann's constant whose value depends upon the material under investigation. This type of conductivity-temperature behaviour is commonly observed for semiconductors. The plots between reciprocal of absolute temperature (1/T) on x-axis and natural logarithm of resistance (Ln R) for male and female human nail samples give straight line with a slope (Fig.2 and 3). Here, slope may be attributed to extrinsic nature of semicoduction of human nail. As is know human nail is a highly heterogeneous material, its major components are keratin and inorganic materials, in small quantities which may contribute substantially to the semiconduction of human nail. The electrical conductivity is a parameter which gives information about the conduction of human nail and its components at bulk level. As is known, the energy gap of a material can be considered as the index for the characterization of materials as conductor, semi-conductor and insulator. The mean values of energy gap of male and female human nail are 0.2735 ± 0.0529 eV and 0.2565 ± 0.0349 eV respectively, which are in the range of semiconductors. It is interesting to note, from the present investigation, that the resistivity of human nail is very high at the order of G Ω-cm, while the activation energy values are in the range of semiconductors (Table 3. and 4.). Mostly, the resistivity of commonly used semiconductor is in the order of M Ω-m. The activation energy in the range of semiconductors coupled with high resistivity of human nail can be explained as semiconductivity arising from an electron tunneling mechanism between absorbed water molecules rather than from energy band conduction associated with molecular architecture of human nail. Lastly, human nail is an insulator due to its high resistivity. On the other hand, human nail is a semiconductor, possessing activation energy in the range of electronic semiconducting material. Keeping this in view, it is appropriate to call a human nail, at different physiological conditions, as a semi-insulator.

Table 1.Variation of electrical resistivity of male human nail with temperature

Applied Voltage 100 V

t (°C)	T (°K)	1/T	Resistance(G?)			
			NM4	NM5	NM7	NM10
40	313	0.00320	9.71	27.78	13.89	18.87
42	315	0.00318	9.17	26.32	12.99	17.24
44	317	0.00316	8.55	25.00	12.20	16.13
46	319	0.00314	8.06	23.81	11.36	14.71
48	321	0.00312	7.41	22.73	10.75	13.51
50	323	0.00310	7.09	21.74	10.20	12.50
52	325	0.00308	6.49	20.83	9.62	11.63
54	327	0.00306	6.17	19.61	9.09	10.87
56	329	0.00304	5.75	18.87	8.62	10.20
58	331	0.00302	5.38	18.18	8.20	9.52
60	333	0.00300	5.03	17.24	7.87	9.01

Table 2 Variation of electrical resistivity of female human nail, with temperature

Applied Voltage 100 V

Sample	slope(1/T versus Ln R)	Activation energy	
		10^{-20} J/K	eV
NM4	3447	4.75	0.296
NM5	2453	3.38	0.210
NM7	2972	4.10	0.255
NM10	3882	5.35	0.333

Table 3: Data on activation energy of male human nail in the temperature range of 40^0C to 60^0C

t (°C)	T (°K)	1/T	Resistance(G?)			
			NF2	NF3	NF7	NF12
40	313	0.00320	40.00	29.41	17.86	32.26
42	315	0.00318	37.04	27.78	17.24	30.30
44	317	0.00316	34.48	26.32	16.39	28.57
46	319	0.00314	32.26	25.00	15.63	27.03
48	321	0.00312	30.30	23.81	14.49	25.64
50	323	0.00310	28.57	22.73	13.70	24.39
52	325	0.00308	27.03	21.74	12.82	23.26
54	327	0.00306	25.64	20.83	12.05	22.22
56	329	0.00304	23.81	20.00	11.49	21.28
58	331	0.00302	22.22	19.23	10.87	20.41
60	333	0.00300	21.28	18.52	10.10	19.61

Mean = 4.395   Mean = 0.2735

S.D = ± 0.8476   S.D = ±0.0529

Table 4: Data on activation energy of female human nail in the temperature range of 40^0C to 60^0C

Sample	Slope(1/T versus Ln R)	Activation energy	
		10^{-20} J/K	eV
NF2	3258	4.49	0.280
NF3	2398	3.31	0.206
NF7	3027	4.17	0.260
NF12	3258	4.49	0.280

Mean = 4.115 Mean = 0.2563 S.D = ± 0.5574
S.D = ±0.0349

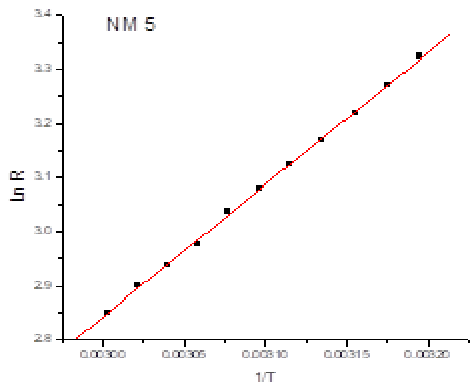

Fig. 2 A typical plot between inverse of absolute temperature and Ln of resistance for male finger nail

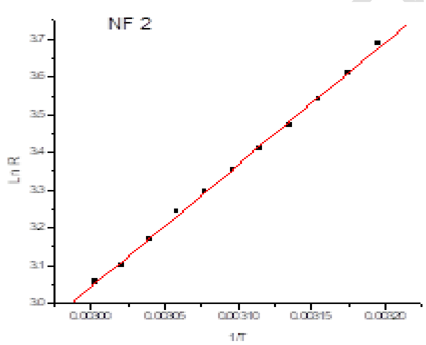

Fig. 3 A typical plot between inverse of absolute temperature and Ln of resistance for female finger nail

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