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Electrical, Thermal Parameter Calculations of Artificially Removed Human Renal Stones by Two-Probes Method

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Electrical, thermal conductivity studies play a vital role in the field of science and technology. According to the conductivity terms, the world materials can be classified in to good conductors, bad conductors, semiconductors and super conductors. As per the free electron theory, the free electron only acts as carrier and carries their energy from one point to another point either natural or forced. In the present investigation, five renal stones were collected from the poor hard working males who are affected with mineral deposition in the urinary tracts. The stones were collected from the hospital by lithotropic treatment process. Using two-probes method, the electrical conductivity was measured at different temperatures. The thermal conductivity and temperature coefficients were calculated.

Key Words: Electrical, Thermal, Human renal stones.

INTRODUCTION

The conductivity of many biomaterial have been reported[1]. The problems, such as thrombogenesis and enzymatic activity of cytochrome oxides, have been dealt with either semi conductivity or electrets behaviour of different biomaterials. In the present study, these aspects have been attempted on the same materials, namely renal stones or renal calculi. The study of electrets behaviour and conductivity becomes essential in order to find an inhibitor for renal stones or present its growth. The electrets behaviour of the renal stone material through temperature dependent sex determination (TSD) and temperature sensitive period (TSP)[2-4]. Herein, this work reports the d.c conductivity of kidney stones as a function of temperature and applied electric field.

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EXPERIMENTAL

Kidney stones were removed from the affected patients by lithotropic process in the Rasi Stones Diagnosing Center in Rasipuram, Namakkal, India and used in the present investigations. These stones constituents were analyzed by biochemical analysis process. The stone constituents are reported in the Table-1. The major constituents of the samples are calcium phosphate and/or oxalate ions bond to an organic and sulponated musco-proteins[5]. The investigation results on TSP and TSD were reproducible from sample to sample of stone. However, it varied slightly from stone to stone depending upon either oxalate contents or phosphate contents. Due to the lengthy process of conductivity measurement, five samples only used.

TABLE-1
CHEMICAL COMPOSITION PRESENT IN THE RENAL STONES

Stones	Chemical constituents
A	Calcium oxalate dihydrate, calcium phosphate.
B	Calcium oxalate monohydrate, calcium oxalate dihydrate.
C	Calcium oxalate monohydrate, phosphates.
D	Calcium oxalate monohydrate, phosphate, calcium oxalate dihydrate
E	Calcium oxalate monohydrate

Stone samples were prepared for conductivity measurement. Initially the bloodstains and other impurities were removed from the surfaces of the sample and dried naturally. Then the sample surfaces were smoothened by using very thin grain grinder. The renal stone samples were placed in between two aluminum probes with deep contact. The sample holder with the sample was kept inside the micro oven, which is automatic heater with electronic temperature monitor and controller (the accuracy is ± 2 ºC). The d.c conductivity was studied at a temperature from 295 to 373K at a certain temperature intervals. The electric field applied to the probes starts from 1 to 20 V and corresponding currents were measured. All the samples were kept at a particular temperature at least for 15 min to reach the saturation. Then the measurements were started. At higher voltage and higher temperature the current settling time were observed which is less. The transient current of the sample mainly depends upon the presence of carriers in a sample according to the Curie-Von-Schweidlar law. The conductivity of polymer samples has been reported[6-8] and ionic materials[9,10].

RESULTS AND DISCUSSION

The approximate area of each samples were measured by using graph sheet. The temperatures are varied from 295 to 373 K. The applied voltage (V), corresponding current measurements (I), resistance (R), resistivity (ρ), conductivity (σ) and current density (J) of each sample at a particular temperature were reported in the Tables 2-6.

TABLE-2a

Temperature = 30 ºC; $A = 152 \times 10^{-6}$ m^2, $L = 10 \times 10^{-3}$ m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
4	4.0	1.000	6.5789	0.026
5	4.0	1.250	8.2236	0.026
6	5.0	1.200	7.8947	0.033
7	6.5	1.076	7.0789	0.039
8	7.0	1.142	7.5131	0.046
9	8.0	1.125	7.4013	0.053
10	8.0	1.250	8.2236	0.053

$R = 1.149 \times 10^6$; $\rho = 7.5591 \times 10^7$; $J = 0.0409$

Coefficient of electrical conductivity (σ) = 1.328×10^{-8} mho m^{-1}

TABLE-2b

Temperature = 60 ºC; $A = 152 \times 10^{-6}$ m^2, $L = 10 \times 10^{-3}$ m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
4	3	1.330	8.7670	0.021
5	3	1.660	10.9650	0.021
6	4	1.500	9.8684	0.026
7	5	1.400	9.2105	0.032
8	6	1.333	8.7697	0.039
9	7	1.285	8.4539	0.046
10	7	1.428	9.3947	0.046

$R = 1.4207 \times 10^6$; $\rho = 9.3469 \times 10^7$; $J = 0.033$

Coefficient of electrical conductivity (σ) = 1.0398×10^{-8} mho m^{-1}

We are unable to measure the hall coefficient of the renal stones. The stones containing collagan like micro-protein and apatite, have also some organic matrix like protein at 5 % of the total weight[11]. The protein matrix is clearly visible under a scanning micro. The d.c electrical conductivity of the renal stones was compared and calculated with the standard ionic conductors[12] and semiconductors[13].

TABLE-2c

Temperature = 96 °C; A = 152 × 10^{-6} m^2, L = 10 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
4	2	2.000	13.1578	0.013
5	2	2.500	16.4473	0.013
6	3	2.000	13.1578	0.019
7	3	2.333	15.3486	0.019
8	3	2.666	17.5394	0.026
9	4	2.250	14.8026	0.026
10	4	2.500	16.4473	0.026

R = 1.149 × 10^6; ρ = 15.2715 × 10^7; J = 0.202

Coefficient of electrical conductivity (σ) = 6.548 × 10^{-9} mho m^{-1}

TABLE-3a

Temperature = 28 °C; A = 33 × 10^{-6} m^2, L = 6 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
3	100	0.0300	5.4545	3.03
4	110	0.0364	6.4182	3.33
5	120	0.0417	7.5818	3.63
6	140	0.0429	7.8000	4.24
7	150	0.0467	8.4909	4.54
8	165	0.0485	8.8182	5.10
9	175	0.0514	9.3454	5.30
10	180	0.0556	10.1090	5.45

R = 1.149 × 10^6; ρ = 8.02725 × 10^7; J = 4.2525

Coefficient of electrical conductivity (σ) = 1.2457 × 10^{-7} mho m^{-1}

TABLE-3b

Temperature = 58 °C; A = 33 × 10^{-6} m^2, L = 6 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
4	3	1.3330	2.9556	0.1330
6	5	1.2000	2.6667	0.2220
8	6	1.3330	2.9556	0.2660
10	8	1.2500	2.7778	0.3550
12	9	1.3330	2.6667	0.4000
14	11	1.2720	2.8267	0.4890
16	15	1.0667	2.3704	0.6690
18	19	0.9474	2.1053	0.8440
20	22	0.9090	2.0200	0.9780

R = 1.1826 × 10^6; ρ = 2.5938 × 10^6; J = 0.848

Coefficient of electrical conductivity (σ) = 3.855 × 10^{-9} mho m^{-1}

TABLE-3c

Temperature = 65 ºC; A = 33 × 10^{-6} m^2, L = 6 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
2	40	0.0500	9.0909	1.12
3	70	0.0429	7.8600	2.12
4	80	0.0500	9.0909	2.42
5	85	0.0589	10.7690	2.57
6	100	0.0600	10.9090	303
7	118	0.0590	10.7272	3.57
8	130	0.0615	11.1818	3.93
9	140	0.0642	11.6727	4.42
10	150	0.0667	12.1272	4.45

R = 0.05702 × 10^6; ρ = 10.3676 × 10^6; J = 3.07

Coefficient of electrical conductivity (σ) = 9.645 × 10^{-8} mho m^{-1}

TABLE-3d

Temperature = 98 ºC; A = 33 × 10^{-6} m^2, L = 6 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
2	25	0.1000	1.8182	0.75
3	35	0.0857	1.5582	1.06
4	50	0.0800	1.4545	1.51
5	60	0.0833	1.5145	1.18
6	65	0.0923	1.6782	1.96
7	75	0.0933	1.6964	2.27
8	90	0.0889	1.6164	2.73
9	100	0.0900	1.6364	3.63
10	120	0.0833	1.5145	3.64

R = 0.0885 × 10^6; ρ = 1.6097 × 10^6; J = 2.087

Coefficient of electrical conductivity (σ) = 6.212 × 10^{-8} mho m^{-1}

The ionic conduction for the renal stone is

$$\sigma = \sigma_1 \exp^{(A/KT)} + \sigma_2 \exp^{(-B/KT)}$$

where σ_1, σ_2 are the zero field conductivity, A and B are constants. The two exponential terms are nature of normal conductors.

In semiconductors the conductivity

$$\sigma = \sigma_0 \exp^{(-Eg/2KT)}$$

here σ_0 is the zero field conductivity and E_g is the activation energy of the conductors at a particular temperature (T). From the observation a fine powder of kidney stone also shows fibrils of protein under a high resolution optical microscope.

TABLE-4a

Temperature = 30 ºC; A = 22.5 × 10^{-6} m^2, L = 5 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
2	5	0.400	8.8890	0.221
5	7	0.571	12.6889	0.311
6	10	0.600	13.3330	0.444
8	12	0.667	14.8222	0.533
10	15	0.667	14.8222	0.666
12	17	0.706	15.6889	0.755
14	20	0.700	15.5516	0.889
16	22	0.727	16.1556	0.978
20	25	0.800	17.7778	1.111

R = 0.6486 × 10^6; ρ = 14.4151 × 10^6; J = 0.6569

Coefficient of electrical conductivity (σ) = 6.937 × 10^{-9} mho m^{-1}

TABLE-4b

Temperature = 58 ºC; A = 33 × 10^{-6} m^2, L = 6 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
4	3	1.3330	2.9556	0.133
6	5	1.2000	2.6667	0.222
8	6	1.3330	2.9556	0.266
10	8	1.2500	2.7778	0.355
12	9	1.3330	2.6667	0.400
14	11	1.2720	2.8267	0.489
16	15	1.0667	2.3704	0.669
18	19	0.9474	2.1053	0.844
20	22	0.9090	2.0200	0.978

R = 1.1826 × 10^6; ρ = 2.5938 × 10^6; J = 0.484

Coefficient of electrical conductivity (σ) = 3.855 × 10^{-9} mho m^{-1}

Thus renal stones can be regarded as a mixture of semi conducting materials like N or P type. But it behaves like N type material or conductors. Hence, conductivity of a kidney stone shows a partially compensated semi-conductor.

Available mechanism for conduction of renal stones may be sought with the help of various scattering mechanism of conductors and semiconductors[14]. The conductivity of samples depends upon the scattering by lattice vibrations. In conductor the curve between conductivity and temperature should be straight line, but in semiconductor is not in usual[15]. The TSP and TSD data of kidney stones also give added information about its conduction mechanism[2,3].

TABLE-4c
Temperature = 95 ºC; A = 22.5×10^{-6} m^2, L = 5×10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
4	2	2.0000	4.4440	0.880
6	3	3.0000	6.6667	0.133
8	4	2.0000	4.4444	0.177
10	6	1.6670	3.7044	0.267
12	7	1.7142	3.8093	0.311
14	9	1.5556	3.4569	0.400
16	13	1.2308	2.6667	0.578
18	15	1.2000	2.4689	0.667
20	18	1.1100	2.1268	0.800

R = 1.7198×10^6; ρ = 3.9577×10^6; J = 0.464
Coefficient of electrical conductivity (σ) = 2.661×10^{-9} mho m^{-1}

TABLE-5a
Temperature = 28 ºC; A = 20×10^{-6} m^2, L = 4×10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
2	10	0.2000	4.0000	0.50
4	15	0.2667	5.3340	0.75
6	19	0.3157	6.3140	0.95
8	25	0.3200	6.4000	1.25
10	30	0.3330	6.6000	1.50
12	38	0.3157	6.3140	1.90
14	45	0.3110	6.2220	2.25
16	70	0.2286	4.5720	3.50
18	78	0.2308	4.6160	3.90
20	90	0.2220	4.4440	4.50

R = 0.2743×10^6; ρ = 5.4874×10^7; J = 2.049
Coefficient of electrical conductivity (σ) = 1.822×10^{-8} mho m^{-1}

The TSP and TSD conductivity of a sample, changing current is composed of three components, which is conduction, polarization and depolarization. When temperature increases, the conductivity of a samples is increased, the polarization and depolarization peaks merges in the conduction current or only a part of its observable[16]. The voltage dependence of conductivity decreases with rise of temperature (T). The current density decrease shows that the conduction is in non-ohmic. This change suggests a warm electron effect[17]. At higher temperature, the current density is directly proportional to voltage and gives the ohmic behaviour. It is clear that a sample at higher

TABLE-5b

Temperature = 70 °C; A = 20 × 10^{-6} m^2, L = 4 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
2	6	0.3330	6.6600	0.30
4	10	0.4000	8.0000	0.50
6	15	0.4000	8.0000	1.10
8	20	0.4000	8.0000	1.30
10	26	0.3847	7.6940	1.60
12	32	0.3750	7.5000	2.00
14	40	0.3500	7.0000	2.60
16	52	0.3077	6.1540	2.70
18	60	0.3000	6.0000	3.00
20	75	0.2667	5.3340	3.75

R = 0.3517 × 10^6; ρ = 7.0342 × 10^7; J = 1.885

Coefficient of electrical conductivity (σ) = 1.422 × 10^{-8} mho m^{-1}

TABLE-5c

Temperature = 98 °C; A = 20 × 10^{-6} m^2, L = 4 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
2	3	0.6670	1.3334	0.15
4	8	0.5000	1.0000	0.40
6	12	0.5000	1.0000	0.60
8	15	0.5333	1.0666	0.75
10	18	0.5556	1.1112	0.90
12	25	0.4800	0.9600	1.25
14	32	0.4375	0.8750	1.60
16	40	0.4000	0.8000	2.00
18	46	0.3913	0.7826	2.30
20	50	0.4000	0.8000	2.50

R = 0.4864 × 10^6; ρ = 0.9728 × 10^8; J = 1.246

Coefficient of electrical conductivity (σ) = 1.0279 × 10^{-9} mho m^{-1}

temperature shows that the thermal energy difference between the charge carriers and lattice was relatively low or due to asymmetric effect[18] formed inside the crystals of calcium oxalates and calcium phosphates (major chemical constituent present in the samples).

TABLE-6a
Temperature = 28 ºC; A = 9×10^{-6} m^2, L = 3×10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
2	26	0.07690	2.5633	3.32
4	35	0.11420	3.5067	3.88
6	45	0.12500	4.1667	5.33
8	48	0.12300	4.1000	5.00
10	78	0.12820	4.2733	8.66
12	90	0.13300	4.4433	10.00
14	109	0.31284	5.2800	12.11
16	122	0.13110	4.3700	13.55
18	140	0.12860	4.2867	15.55
20	170	0.11760	3.9200	18.88

R = 0.1263×10^6; ρ = 4.1210×10^7; J = 9.628

Coefficient of electrical conductivity (σ) = 2.426×10^{-8} mho m^{-1}

TABLE-6b
Temperature = 65 ºC; A = 9×10^{-6} m^2, L = 3×10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
2	15	0.1338	3.7933	1.66
4	25	0.1600	5.3330	2.77
6	30	0.2000	6.6670	3.33
8	38	0.2105	7.0167	4.22
10	50	0.2000	6.6667	5.55
12	57	0.2105	7.0167	6.33
14	65	0.2154	7.1800	7.22
16	74	0.2162	7.2666	8.22
18	82	0.2195	7.3167	9.11
20	100	0.2000	6.6667	11.11

R = 0.19654×10^6; ρ = 6.4863×10^7; J = 5.952

Coefficient of electrical conductivity (σ) = 1.542×10^{-8} mho m^{-1}

Conclusion

At higher temperature, the thermal conductivity of all the samples was constant, but the electrical conductivity varied (Table-7). The investigation result shows that all the stones are positive temperature coefficient materials. The entire sample shows high conductivity at low temperature, but when the temperature increases, the conductivity decreases. The thermal coefficient of all the stones are calculated and recorded.

TABLE-6c
Temperature = 99 ºC; A = 9 × 10^{-6} m^2, L = 3 × 10^{-3} m

Voltage (V)	Current (μA)	Resistance 10^6 (Ω)	Resistivity in 10^7 ohm M (ρ)	Current density (amp/m^2)
2	8	0.2500	8.3330	0.88
4	15	0.2667	8.8900	4.66
5	20	0.2500	8.3333	2.22
6	26	0.2308	7.6933	2.88
7	34	0.2059	6.8633	3.77
8	38	0.2105	7.0167	4.22
9	42	0.2145	7.1433	4.66
10	45	0.2222	7.4000	5.00
11	50	0.2200	7.4000	5.55
12	58	0.2069	6.8967	6.44
13	65	0.2350	7.8333	7.22
14	70	0.2000	6.6667	7.77
15	74	0.2027	6.7567	8.22
16	78	0.2000	6.6667	8.66

R = 0.22 × 10^6; ρ = 7.4209 × 10^7; J = 4.399

Coefficient of electrical conductivity (σ) = 1.3475 × 10^{-8} mho m^{-1}

TABLE-7a
ELECTRICAL PARAMETERS OF RENAL STONE SAMPLES

Stones	Temperature (ºC)	R × 10^6 (Ω)	ρ (Ωm)	J (amp/m^2)
A	30	1.1490	7.55910 × 10^7	0.0409
	60	1.4207	9.34690 × 10^7	0.0330
	96	1.1490	15.2715 × 10^7	0.0202
B	28	1.14900	8.02725 × 10^7	4.2525
	65	0.05702	10.3676 × 10^6	3.0700
	98	0.08850	1.60970 × 10^6	2.0870
C	30	0.6486	14.4151 × 10^6	0.6569
	58	1.1826	2.59380 × 10^6	0.4840
	95	1.7198	3.95770 × 10^6	0.4640
D	28	0.2743	5.4874 × 10^7	2.049
	70	0.3517	7.0342 × 10^7	1.885
	98	0.4864	0.9728 × 10^8	1.246
E	28	0.12063	4.1210 × 10^7	9.628
	65	0.19654	6.4863 × 10^7	5.952
	99	0.22000	7.4209 × 10^7	4.399

TABLE-7b
THERMAL AND ELECTRICAL CONDUCTIVITY RELATION WITH THE TEMPERATURE
LORAZNTS CONSTANT (L) = 2.44×10^{-8} WΩ K^{-2}

Name of the sample	Conductivity (σ) × 10^{-8}	Temperature (ºC)	Thermal conductivity K = σLT × 10^{-14} W/MK
A	1.3280	30	0.9721
	1.0698	60	1.5662
	0.6548	96	15.3381
B	12.457	28	8.5106
	9.6450	65	15.2970
	6.2120	98	14.5510
C	0.6937	30	0.5077
	0.3855	58	0.5456
	0.2661	95	6.1682
D	1.82200	28	1.2448
	1.42200	70	2.4288
	0.10279	98	2.4941
E	2.4260	28	1.6570
	1.5420	65	2.4456
	1.3475	99	3.2550

TABLE-7c
TEMPERATURE COEFFICIENT OF THE RENAL STONE AT DIFFERENT TEMPERATURES

Sample	Temperature minimum (ºC)	Temperature maximum (ºC)	Temperature coefficient of the sample $\alpha = (R_2-R_1)/(R_1T_2-R_2T_1)$
A	30	60	0.01032
	30	96	0.02882
B	28	65	0.01010
	28	98	0.02390
C	30	95	0.09122
	58	95	0.04266
D	28	98	0.01590
	28	70	0.00827
E	28	99	0.01718
	28	65	0.03642

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