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THE RELATION BETWEEN THERMAL CONDUCTIVITY AND ELECTRICAL CONDUCTIVITY OF ASSORTED MATERIALS

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Abstract: New techniques to enhance the quality of modern materials and their processing is imperative because of the variety of application requirement, the introduction of new materials and need of specific characteristics of these materials. The study of the relation between thermal and electrical properties is useful to decide on the machining processes to shape the modern materials, testing methods for modern materials like nanomaterial, composites, alloys, carbon structures. Thermal conductivity builds the best linear and logarithmic relation with electrical conductivity. Such correlation demonstrates that thermal conduction happens in an indistin-guishable way from electrical conduction i.e. by lattice vibration and electrons as carriers. An audit in this paper is done to find the relationship between the electrical and thermal conductivity of di erent materials. The accessible information identified with elec-trical and thermal conduction is used to discover the empirical relationship utilizing EXCEL programming. Result demonstrates that the thermal conductivity of a material is firmly associated with electrical conductivity yet as the group (periodic table) and va-lency changes the relationship additionally changes. The study is related to discover best-fit models amongst electrical and thermal conductivity of the materials and make the utilization of these properties in relation to anticipate other properties of materials. The correlations may be further used to forecast the composite material properties.
Keywords: Quality, thermal conductivity, electrical conductivity, density, valency, linear etc.

I. INTRODUCTION

Power devices, electric powered engines, generators, and thermal exchangers represented a few exemplary packages of conductive composites. High thermal conductivity is desirable for heat to be correctly dissipated. Polymer shows a low ther-mal conductivity because of their pretty low atomic density, vulnerable interactions or chemical bonding, and complex crystal shape of their molecular vibrations.[1]

Up to now, the electrical properties of nanowires, particularly inert steel nanowires and nanowire bundles, arent hard to measure. But for thermal assets characterization, just a few experimental investigations were reported, because of the di culties in suspending a single nanowire, decreasing contact resistance and accurate thermal size.[2]

Thermal properties refer to the response of a material to the application of heat. As a solid absorbs strength inside the form of heat, its temperature rises and its size will increase. The electricity can be transported to cooler regions of the specimen if temperature gradients exist, and ultimately, the specimen may also soften. Heat potential, thermal enlargement, and thermal conductivity are residences which can be regularly essential in the practical use of solids.[3]

II. THEORY OF ELECTRICAL CONDUCTION

One of the maximum vital electric property of strong material is the ease with which it transmits an electric current. Ohms law relates I (current) or time rate of charge passage to the applied voltage V as follows: V = IR
Sometimes, electrical conductivity is used to specify the electrical characteristics of a material. It is merely the reciprocal of the resistance, or

$$\sigma = 1/\rho,$$

Ohms law may be expressed as,

$$J = \sigma\varepsilon$$

In which J is the current density per unit of specimen area I/A and is the electric field intensity, or the voltage di erence between two points divided by the distance separating them that is,

$$\varepsilon = V/I$$

$$\sigma = 1/\rho,\ \rho = RA/l,\ \varepsilon = V/l \text{ and } J = I/A$$

$$J = \sigma\varepsilon$$

$$I/A = 1/\rho(V/l) = (l/RA)(V/l)$$

$$I = V/R$$

An electric current consequences of the motion of electrically charged particles in reaction to forces that act on them from an externally applied electric field. Positively charged particles are accelerated within the field path, negatively charged particles in opposite direction. Within most solid substances a current arises from the flow of electrons, which is termed electronic conduction. In addition, for ionic substances, a total movement of charged ions is viable that produces a current; this is termed ionic conduction. [3][4]
There exist a relation between electric conductivity and thermal conductivity as both the properties are associated with the electron flow.

III. THEORY OF THERMAL CONDUCTION

To recognize thermal conductivity in materials, it is vital to be familiar with the concept of heat transfer, which is the movement of thermal energy from a hot to a cold body. It occurs in numerous situations:

1. When an object is at a distinct temperature from its environment;
2. When an object is at a distinctive temperature to every other item in touch with it.

When a temperature gradient exists within the object.
The direction of heat transfer is derived by the second law of thermodynamics, which states that the entropy of an isolated system which is not in thermal equilibrium will tend to increase over the year, approaching a maximum value at equilibrium. This means heat transfer always occurs from an object at a higher temperature to an object at a lower temperature and will retain till thermal equilibrium is reached.[3]
A transfer of thermal energy occurs via three modes: conduction, convection, and radiation. Each mode has a di erent mechanism and rate of heat transfer, and thus, in any specific state, the rate of heat transfer relies upon how much a certain mode is prevalent.

Conduction: The transfer of thermal energy by a combination of di usion of electrons and phonon vibrations. This kind of heat transfer mode is applicable to solids.

Convection: The transfer of thermal energy in a moving medium in the hot gas/liquid moves through the cooler medium (normally due to density di erences).

Radiation: Electromagnetic waves transfer thermal energy. The sun could be the example of energy transfer through a (near) vacuum.

Thermal conductivity is the materials property that indicates the capacity to conduct heat. Fouriers first law gives the heat flux is proportional to the temperature variation, surface area, and length of the sample:
$H=(\delta Q)/(\delta t)=K.A(\delta T)/l$

where $\delta Q=\delta t$ is the heat transfer rate, A is the area of the surface and l is the length of the object.

Mechanisms of Heat Conduction: Heat is transmitted in solid substances by both lattice vibration waves (phonons) and free electrons. Thermal conductivity is related to each of these ways of transfer, and the total conductivity is the sum of the two contributions, or k = kl + ke.[3][4]

where kl and ke is the lattice vibration and electron thermal conductivities, respectively; usually one or the other predominates. The thermal energy associated with phonons or lattice waves is transported in the path of their motion. The kl contribution outcomes from a net movement of phonons from high to low-temperature areas of a body across which a temperature gradient exists.[3]

The nice metallic thermal conductors are pure copper and silver. At room temperature, commercially pure copper typically has a conductivity of about 360 W/mK (although the thermal conductivity of a single crystal of copper was measured at 12,200 W/mK at a temperature of 20.8 K). In metals, the movement of electrons dominates the conduction of heat. [3][4]
The bulk substances with the highest thermal conductivity (aside from the superfluid helium II) is, perhaps quite, a non-metal: pure single crystal diamond, which has a thermal conductivity at room temperature of around 2200 W/mK. The high conductivity is even wont to test the credibility of a diamond. Strong covalent bonds within the molecule are accountable for the high conductivity even though there are no free electrons, heat is conducted by phonons. Most herbal diamonds also contain boron atoms that replace carbon atoms in the crystal matrix, which also have high thermal conductance. [3]
We can correlate the resistance behavior to the observed changes in the film structure of PrBaCo2O5+.[5]

IV. THEORETICAL RELATION BETWEEN ELECTRICAL AND THERMAL CONDUCTION

From Ohm's law of electricity,

$$I = V/R,$$
$$I=(V/\rho)(A/l)\text{—(as }R=\rho L/A)$$
$$I=(V/\rho)(A/l)$$
$$I=\sigma(V.A/l)$$
$$\sigma = I.l/V:A \quad (1)$$

From Fourier's Law,

$$H=K.A.(l/\delta T)$$
$$K = (H.\delta T)/(A.l) \quad (2)$$

Using equation (1) and (2),

$$K/\sigma = (H.\delta T /I.l)(V.A/A.l)$$
$$K=(V/I)(H.\delta T)\sigma$$
$$K=R.(H/\delta T)\sigma$$

Let, (H.R) = constant C

$$K/\sigma= \delta T.C \quad (3)$$

Where, K- Thermal conductivity, C - Thermal resistance, R - electrical resistance and - electrical conductivity.
The relation between thermal conductivity and the moisture content has an inflection point, and the values of the inflection points correspond nicely with each other for di erent soil types. The water dependencies of thermal conductivity and electrical resistibility have similar mechanisms.[6]
The study, the thermal and electrical conductivity of potato during storage under room conditions shows the relation with moisture, starch content and pH values.[7]

V. WIEDEMANNFRANZ LAW

The Wiedemann Franz law describes the relationship between the electrical conductivity and the thermal conductivity of a metal. It quantifies the concept that metals that are better electrical conductors are also better thermal conductors. The statement of the Wiedemann Franz law is,

$$k/\sigma=LT \quad (4)$$

L is the proportionality constant, known as the Lorenz number, theoretically, is equal to,

$$L =k/\sigma T=[(\pi)^2 /3](Kb/e)^2 = 2:44x10^8\ W/OhmK^2 \quad (5)$$

This law is named after Gustav Wiedemann and Rudolph Franz, who in 1853 mentioned that K /σ have approximately the same value for di erent metals at the equal temperature. The ratio K /σ is proportional to temperature was discovered by Ludvig Lorenz in 1872.

This relationship is based upon the fact that the heat and electrical conduction both contain the free electrons in the metal.
The thermal conductivity will increase with the average particle velocity since this will increase the forwarding transport of energy. The electrical conductivity, on the other hand, decreases while particle velocity increases because the collisions divert the electrons from forwarding transport of charge. [8] Limitations of concept

- Experiments have proven that the value of L (constant), is not exactly the same for all materials.
- Rosenberg notes that the Wiedemann Franz law is normally valid for high and occasional temperatures, but would not suitable at intermediate temperatures.
- In many high purity metals, both the electrical and thermal conductivities rise as the temperature is decreased.
- In degenerate semiconductors, the Lorenz number L has a strong dependency on certain system parameters: dimensional-ity, the strength of interatomic interactions and Fermi level.
- This law is not valid in the case of manipulating the electronic density of states, varying doping density and layer thickness in superlattices and materials with correlated carriers.[8]

Both thermal expansion coe cient and thermal conductivity reduce as silicon content increased because Si and Al2O3 dispersed in the Al matrix uniformly to suppress the high thermal expansion of Al to a big quantity as well as the interfacial thermal resistance which led to the decline in thermal conductivity. Electrical resistivity extended when silicon content was increased because low thermal expansion coe cient particles of Si and Al2O3 severely damaged the continuity of the Al matrix which hindered the movement of an electron in the matrix. [9]

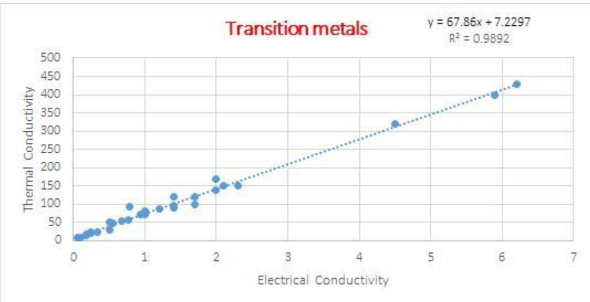

Figure 1: Transition Material

VI. DATA

Data is amassed from the sources listed below and analysis results are compared with known values,

- Periodic table
- Research papers
- Laboratory reports

The data is used to locate the relation between thermal conductivity and electrical conductivity by using excel software.
The relation is obtained for di erent materials of the following class,

- Transition material
- Alkali materials
- Alkali Earth material
- Post-transition metal
- Lathonoids
- Actinoids

The relationship is compared and a single relation is acquired for all materials.
Let T= thermal conductivity in W/mK and E= Electrical conductivity $(ohm)^{-1}$

VII. RELATIONS AND GRAPH

7.1. Transition material

The graph plotted among electrical and thermal conductivity as shown in fig.1
The relation for the best fit line –

$$T = 67.86(E) + 7.2297. \ldots\ldots.(R^2 = 0.9892) \quad (6)$$

7.2. Alkali materials

The graph plotted between electrical and thermal conductivity as shown in fig.2
The relation for the best fit line,

$$T = 65.082(E) + 6.6133\ldots.(R^2 = 0.9876) \quad (7)$$

7.3. Alkali Earth material

The graph plotted between electrical and thermal conductivity as shown in fig.3
The relation for the best fit line,

$$T = 71.3(E) + 1.6201\ldots.(R^2 = 0.9814) \quad (8)$$

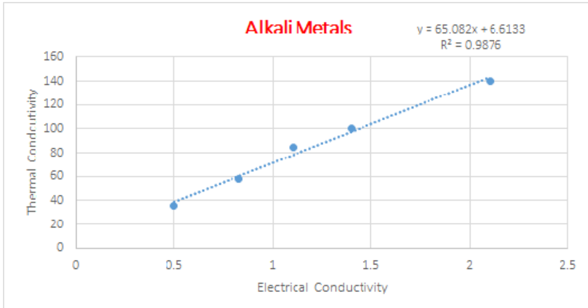

Figure 2: Alkali Material

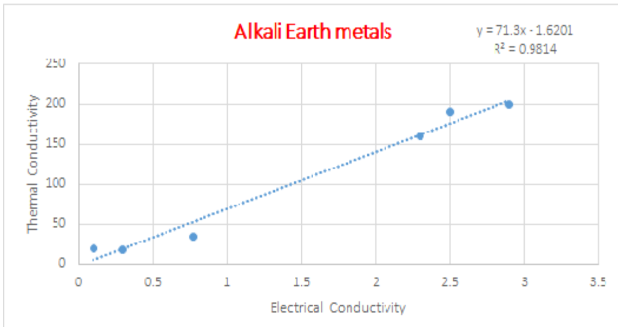

Figure 3: Alkali earth metals

7.4. Post-transition metal

The graph plotted between electrical and thermal conductivity as shown in fig.4
The relation for the best fit line

$$T = 61.362(E) + 2.9272\ldots\ldots(R^2 = 0.988) \quad (9)$$

7.5. Lathonoids

The graph plotted between electrical and thermal conductivity as shown in fig.5

The relation for the best fit line,

$$T = 96.136(E) + 1.8154……(R^2 = 0.8694) \quad (10)$$

7.6. Actinoids

The graph plotted between electrical and thermal conductivity as shown in fig.6

The relation for the best fit line,

$$T = 96.136\ (E) + 1.8154……..(R^2 = 0.8694) \quad (11)$$

VIII. RESULT

The average values of the coecients are calculated and best equation is, T=73.9385*(E)+2.744583

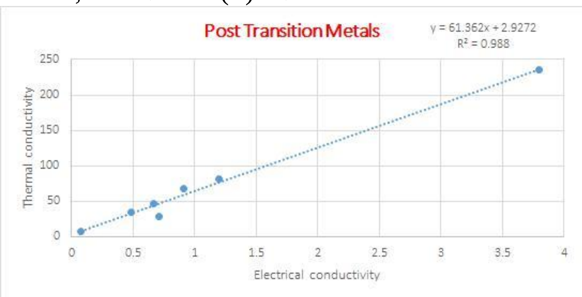

Figure 4: Post-Transition materials

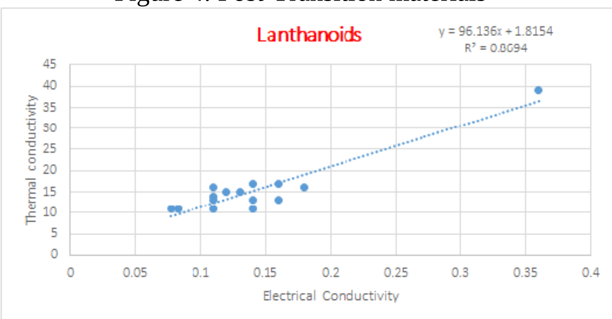

Figure 5: Lithonoid

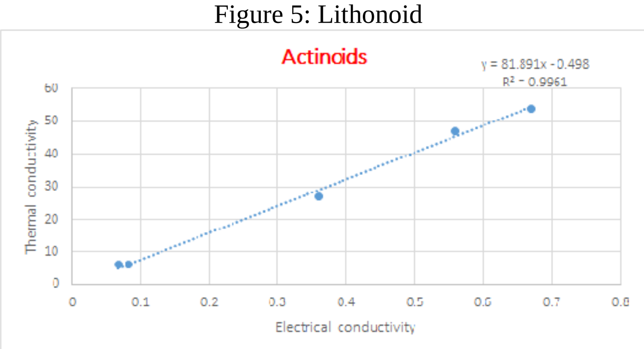

Figure 6: Actinoid

CONCLUSION

In this study, the thermal and electrical conductivity val-ues were taken from available sources and the relation is investigated. Selected materials and the related equations are summarized in Table 1. The following Table 2 gives the final concluding values, Error 1 and Error 2 are based on the equation error (Actual val-ues and calculated values from equation) and average error (ac-tual values and calculated values from equation (12)). All equa-tions were found to be statistically significant. For this reason, it is feasible to reliably estimate thermal and electrical conductiv-ity once the either of two is known. It is also observed that the best fit line is a linear relation. It is likewise discovered that; no exact relation between thermal and electrical conductivity, how-ever, it varies as per group, metallurgical and physical condition of the material. The materials crystal structure, atomic arrange-ment, temperature, impurities present, moisture content, heat treatments, cold/hot working on the material are some of the parameters a ecting the thermal and electrical conductivities. Whereas, the well-developed equation between these two pa-rameters (electrical and thermal conductivities) is useful to cal-culate the exact theoretical values and comparing it with prac-tical measurement to know the defects in modern materials.

Further work

Even thou the relation for di erent material is envisioned, the firm relation between the thermal and electrical conductivity is not acquired. The micro or atomic level study is necessary to understand the relationship between electrical and thermal conduction. Improper relation between the two parameters may lead to mistakes in measurements, wrong values selected for design calculations, acceptance and rejection of component in tests like NDT, laboratory measurements. A detailed investigation in this direction is needed at the atomic level.

Table 1: Result

Material	Equation
Transition material	T = 67.86*E + 7.2297
Alkali materials	T=65.082*E+6.6133
Alkali Earth material	T=71.3*E-1.6201
Post-transition metals	T=61.362*E+2.9272
Lathonoids	T=96.136*E+1.8154
Actinoids	T=81.891*E-0.498

Table 2: Summery

Material	Equation	R^2	Error1	Error2
Transi.	T=67.86*E+7.229	0.989	2.15	2.95
Alkali	T=65.082*E+6.613	0.988	1.988	4.56
Alka. Ea.	T=71.3*E-1.620	0.981	4.93	6.3
Post tran.	T=61.362*E+2.927	0.988	3.145	8.74
Lathon.	T=96.136*E+1.815	0.869	0.64	0.95
Actin.	T=81.891*E-0.498	0.996	0.63	3.11

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