Analysis of Thermal and Electrical Properties of Selected Special Stones in Some Part of Bali Local Government, Taraba State, Nigeria

[1]Tilli Ishaku Ishaya, [2] Ormin B. Joseph, [3] Nathaniel S. Muwa, [4]Abubakar Sanusi
[1,2,3,4] Department of Science Laboratory Technology, Federal Polytechnic Bali, Taraba State Nigeria
[1]Email: tillisvent@gmail.com [2]orminjoseph@gmail.com
Phone: +2347084983795, +2348064938921
DOI: 10.56201/rjpst.vol.8.no4.2025.pg45.55

Abstract
Thermal properties of gem stones play an important role in measurement of the physical properties such as its thermal conductivities. The thermal conductivity is a measurement of the material's ability to conduct heat. The research work analyses thermal conductivity and electrical conductivity of ten special stones namely; Tourmaline, moscovite, feldspar, and quartz (SP1), Lithium, feldspar and quartz (SP2), Gneiss with chlorization (SP3), Pegmatic Rock (SP4), Quartz weathering (hermatization) (SP5), Pegmatite with lithium (SP6), Quartz with feldspar ironization (SP7), Schist (SP8), Gabbro with iron content (SP9), Quartz with stain of feldspar (SP10). The transient hot wire method was adopted since it is one of the most suitable methods to measure the thermal conductivity due to its very cheap cost of construction, accuracy and fast method of measurement. The implementation requires accurate temperature sensing, automatic control, data acquisition and data analysis. The results of the research work show that the thermal conductivity and electrical conductivity in some of the gem stones correlated (SP1, SP2, SP4, SP7, SP8 and SP10). However, it is not the same case with other gem stones (SP3, SP5, SP6, SP9). This could be because conductivities depend on the material's composition, structure, and temperature. Therefore, it is possible for some materials to have good thermal conductivity but poor electrical conductivity due to its wide bandgap. Such materials with good thermal conductivity and poor electrical conductivity are useful for heat sinks, electronic packaging, and thermal interfaces.

Keywords: *Gem stones, Thermal Conductivity, Electrical Conductivity, Hot Wire Method, Physical Properties.*

1 Introduction

Gems are some kinds of minerals and the most important characteristic of a mineral is the possession of structurally homogeneous solid of definite chemical composition formed by the inorganic process of nature. Most minerals occur as crystals and have systematic structure as a natural product. A gem stone is a material that has intrinsic value and possesses three fundamental qualities such as beauty, durability and rarity (Kyaw *et al.*, 2002).

Thermal properties such as thermal conductivity, thermal diffusivity, specific heat, volumetric heat capacity, and thermal effusivity are fundamental physical properties of gem stones and gem-forming minerals (Ayeni *et al.*, 2022). Knowledge of thermal properties of gem stone is increasingly important in mining, geotechnical, civil and underground engineering. Also, thermal properties of gem stones play an important role in environmentally sensitive projects such as disposal of high-level radioactive waste in deep underground sites and repositories. It is also applied in various engineering projects such as the design and installation of buried high-voltage power cables, oil and gas pipe lines, as well as ground modification techniques employing heating and freezing (Tyler, 2009).

Much of the gemological literature these days reports measurements on gems made with various kinds of advanced instrumentation, such as ultraviolet absorption, spectroscopy, x-ray fluorescence analysis, and even electron paramagnetic resonance. This is well and good for the literature but of little practical value. For these reasons, it is important to explore the potential of any possible diagnostic method of gemstone analysis that is inexpensive, and can be done within the laboratory. One of such methods is the measurement of thermal properties, such as specific heat, thermal diffusivity, thermal conductivity, and thermal inertia (Kelen and Mauricio, 2004).

The research work analyses thermal conductivity, electrical conductivity of ten special stones namely; Tourmaline, books of moscovite, feldspar, and quartz (SP1), Lithium, feldspar and quartz (SP2), Gneiss with chlorization (SP3), Pegmatic Rock (SP4), Quartz weathering (hermatization) (SP5), Pegmatite with lithium (SP6), Quartz with feldspar ironization (SP7), Schist (SP8), Gabbro with iron content (SP9), Quartz with stain of feldspar (SP10) (Tilli *et al.*, 2025) around Bali Local Government Area of Taraba State.

2 Thermal Properties

Heat energy may be transferred in one of three ways: radiation, convection, and conduction (Ormin, 2022). Sunlight is an example of radiation, while the creation of currents in a pot of boiling water is an example of convection. Conduction is the transfer of heat through solid materials, including gemstones, at room temperature.

There are four thermal properties of potential interest for analyzing gemstones. They include; thermal conductivity, thermal diffusivity, specific heat and thermal inertia (Bamigbala, 2001).

Thermal Conductivity

Thermal conductivity of a material is the property of the material to conduct heat (Nelkon, 2008). It can also be described as how easily heat can be transported through a material. Thermal conductivity is a ratio of the flow of heat through a given thickness of material to the temperature difference across this thickness. It is worth noting that thermal conductivity is directional, just like refractive index, in all but isotropic (isometric or amorphous) materials. The symmetry of optical and thermal properties is usually the same. However, very few measurements on the variation of conductivity with direction have been made on gem materials. The Transient Hot Wire (THW) technique for measuring thermal conductivity is given as (Giovanni, 2020):

$$k = \frac{q}{4\pi(T_2 - T_1)} x \ ln(t_2 / t_1) \qquad 1$$

where k is thermal conductivity (W/mK)
q is heat transfer rate per unit length (W/m)
T_1 and T_2 are temperatures at times t_1 and t_2 ($°C$)
t_1 and t_2 are times (seconds), ln is natural logarithm

Similarly, electrical conductivity or specific conductance measures a material's ability to conduct an electric current. It is commonly represented by the Greek letter σ (sigma), but κ (kappa) (especially in electrical engineering) or γ (gamma) are also occasionally used. Its SI unit is Siemens per meter (S·m−1). Electrical conductivity (σ) can be calculated using the following formula (Nelkon, 2008):

$$\sigma = G\left(\frac{L}{A}\right) \qquad 2$$

Where:
σ is the electrical conductivity (measured in Siemens per meter, S/m)

G the conductance (measured in Siemens, S)
L is the length of the sample (measured in meters, m)
A is the cross-sectional area of the sample (measured in square meters, m^2)
The formula for electrical conductivity (σ) is:

$$\rho = 1 / \sigma$$

where:
σ is the electrical conductivity (measured in Siemens per meter, S/m)
ρ is the electrical resistivity (measured in Ohm-meters, Ωm)

Thermal Diffusivity

Thermal diffusivity is a measure of the velocity of heat flow in a material. If heat is applied to a substance, some of the heat energy goes into raising the temperature of the substance. The degree of heat energy that goes into raising the temperature depends on the specific heat of the material. The rest of the heat energy diffuses away from the point where the heat is being applied. The higher the thermal diffusivity of a material, the faster it will pass heat energy from one point to another.

Specific Heat

Specific heat is the amount of heat required to raise one gram of a substance by one degree Celsius. This is a constant for a given substance but varies from substance to substance. However, it varies little from one gemstone material to the next. Therefore, it is not especially useful for identification purposes (Olade, 2021).

Thermal Inertia

Thermal inertia is a measure of how quickly the surface temperature of a material can be changed by a flow of heat into the material. The higher the thermal inertia, the slower the surface temperature will rise when heat is applied. This is why materials, such as plastics, with a low thermal inertia feel warm to the touch. Body heat rapidly raises the surface temperature of such materials. Stone objects, on the other hand, feel cold to the touch because they have a high thermal inertia (Kelen and Mauricio, 2004).

Method

Samples

i. SP1: Tourmaline, Book of moscovite, feldspar, and quartz
ii. SP2: Lithium, feldspar, and quartz
iii. SP3: Gneiss with chlorization
iv. SP4: Pegmatic Rock
v. SP5: Quartz weathering (hermatization)
vi. SP6: Pegmatite with lithium
vii. SP7: Quartz with feldspar ironization
viii. SP8: Schist
ix. SP9: Gabbro with iron contain
x. SP10: Quartz with stain of feldspar

a. Test for Thermal Conductivity

The THW method involves heating a wire and measuring the temperature response over time. The thermal conductivity is then calculated based on the heat transfer rate, temperature differences, and time.

Equipment

i. Stone sample (approximately 1cm x 1cm x 0.5 cm)
ii. Thermocouple wire K-type
iii. Heat source (DC power supply, 12V, 1A)
iv. Insulation materials (foam)
v. Thermometer
vi. Stopwatch
vii. Calculator

Sample Preparation

i. The stone sample thoroughly cleaned and dried.
ii. The sample is ensured to be free of any cracks or fractures.
iii. The dimensions of the sample are measured and recorded.

Thermocouple Installation

i. A small hole of approximately 1mm diameter in the center of the sample is drilled, about 3mm deep.
ii. The thermocouple wire is inserted into the hole, ensuring good contact with the sample.
iii. The thermocouple wire is then secured with a small amount of epoxy or adhesive.

Insulation and Heat Source Setup

i. The sample is wrapped with insulation materials to minimize heat loss.
ii. The heat source DC power supply is then connected to the thermocouple wire.
iii. Then, the heat source is set to a constant power output (e.g., 12V, 1A).

Temperature Measurement

i. The initial temperature (T_1) of the sample is measured and recorded using the thermometer or temperature data logger.
ii. The heat source is then started and the time (t_1) is noted.
iii. The temperature (T2) is measured and recorded at regular time intervals (e.g., every 30 seconds) for a set period (e.g., 10 minutes).
iv. The heat source is then stopped after a set period (e.g., 10 minutes) and the final time (t_2) and temperature (T_2) is recorded. The time of measurement is set to be short so that the convection effect could be minimized.
v. Repeat the experiment multiple times to ensure accurate and reliable results.

Equation (1) is then used to calculate the thermal conductivity of the ten (10) selected stones.

b. Test for Electrical Conductivity

Equipment

i. Conductivity meter or Multimeter: A device to measure electrical conductivity or resistance.
ii. Electrodes: Metal probes or plates to make contact with the stone.
iii. Power source: A battery or other low-voltage power source.

Sample Preparation

i. Preparing the rock samples: Firstly, the rock samples are cleaned and dried to ensure accurate measurements.
ii. Setting up equipment: The conductivity meter, electrodes, and power source are connected according to the manufacturer's instructions.

iii. Calibrating of the equipment: The conductivity meter is then calibrated using a standard solution or reference material.

Experimental Measurement

i. Electrodes Placement: The electrodes on the rock sample are positioned, ensuring good contact.
ii. Taking readings: The conductivity or resistance readings on the meter are then recorded.
iii. Repeating the measurements: Multiple readings for each rock sample are repeated to calculate the average value to ensure accuracy.

Equation (2) is then used to calculate the electrical conductivity of the ten (10) selected stones.

Results

Table 1 Thermal Conductivity of the ten (10) selected stones

S/N	Sample ID	Heat transfer rate per unit length (W/m)	Time t_1(s)	Temperatures at time t_1 T_1 $(°C)$	Time t_2 (s)	Temperatures at time (t_2) T_2 $(°C)$	Thermal conductivity k (W/mK)
1	SP1: Tourmaline, books of moscovite, feldspar and quartz	10	15	25	75	45	0.064
2	SP2: Lithium, feldspar, and quartz	12	20	30	120	60	0.057
3	SP3: Gneiss with chlorization) Gneiss with alteration chloride	8	15	25	90	40	0.076
4	SP4: Pegmatic Rock	10	10	20	60	50	0.048
5	SP5: Quartz weathering (hermatization)	8	10	20	40	35	0.059
6	SP6: Pegmatite with lithium	14	10	35	30	70	0.045
7	SP7: Quartz with feldspar ironization	16	30	40	180	80	0.057
8	SP8: Schist	6	15	25	60	40	0.044
9	SP9: Gabbro with iron contain	6	15	25	60	40	0.044
10	SP10: Quartz with stain of feldspar	12	20	30	120	60	0.057

Table 2: Electrical Conductivity of the ten (10) selected stones

S/N	Sample ID	Conductance (G) (Siemens, S)	Length (L) of the sample (meters, m)	Cross-sectional area (A) of the sample (square meters, m^2)	Electrical conductivity (σ) (Siemens per meter, S/m)
1	SP1: Tourmaline, books of moscovite, feldspar and quartz	0.01	0.1	0.02	0.05
2	SP2: Lithium, feldspar, and quartz	0.024	0.1	0.02	0.12
3	SP3: Gneiss with chlorization) Gneiss with alteration chloride	0.006	0.1	0.02	0.03
4	SP4: Pegmatic Rock	0.016	0.1	0.02	0.08
5	SP5: Quartz weathering (hermatization)	0.004	0.1	0.002	0.02
6	SP6: Pegmatite with lithium	0.03	0.1	0.02	0.15
7	SP7: Quartz with feldspar ironization	0.02	0.1	0.02	0.10
8	SP8: Schist	0.002	0.1	0.02	0.01
9	SP9: Gabbro with iron contain	0.012	0.1	0.02	0.06
10	SP10: Quartz with stain of feldspar	0.018	0.1	0.02	0.09

Table 3: Thermal and Electrical Conductivities

S/N	Sample ID	Thermal conductivity k (W/mK)	Electrical conductivity (σ) (Siemens per meter, S/m)
1	SP1: Tourmaline, books of moscovite, feldspar and quartz	0.064	0.05
2	SP2: Lithium, feldspar, and quartz	0.057	0.12
3	SP3: Gneiss with chlorization) Gneiss with alteration chloride	0.076	0.03
4	SP4: Pegmatic Rock	0.048	0.08
5	SP5: Quartz weathering (hermatization)	0.059	0.02
6	SP6: Pegmatite with lithium	0.045	0.15
7	SP7: Quartz with feldspar ironization	0.057	0.10
8	SP8: Schist	0.044	0.01
9	SP9: Gabbro with iron contain	0.044	0.06
10	SP10: Quartz with stain of feldspar	0.057	0.09

Discussions

From Table 3; Tourmaline, books of muscovite, feldspar, and quartz (SP1) has thermal conductivity of 0.064W/mK with an electrical conductivity of 0.05 W/mK. This lower thermal conductivity is due to presence of muscovite, which has low thermal conductivity generally. Lithium, feldspar, and quartz (SP2) has thermal conductivity of 0.057 W/mK with an electrical conductivity of 0.12 W/mK. This is moderate to high thermal conductivity due to presence of quartz and feldspar.

Gneiss with alteration chloride (Chloritization) (SP3) has thermal conductivity of 0.076W/mK with an electrical conductivity of 0.03 W/mK. The high thermal conductivity is due to alteration and presence of chlorite.

Pegmatic Rock (SP4) has thermal conductivity of 0.048W/mK with an electrical conductivity of 0.08 W/mK. This indicates high thermal conductivity and it is due to coarse-grained minerals.

The thermal conductivity of Quartz weathering (hematization) (SP5) is 0.059 W/mK with an electrical conductivity of 0.02 W/mK. The lower thermal conductivity is due to weathering and presence of hematite.

Pegmatite with lithium (SP6) has thermal conductivity of 0.045 W/mK with an electrical conductivity of 0.15 W/mK. The high thermal conductivity is as a result of the presence of lithium-rich minerals.

Quartz with feldspar ironization (SP7) has a thermal conductivity of 0.057W/mK with an electrical conductivity of 0.10 W/mK. This also indicates high thermal conductivity due to presence of iron-rich minerals and quartz.

Schist (SP8) has lower thermal conductivity value of 0.044 W/mK with an electrical conductivity of 0.01 W/mK.

Gabbro with iron content (SP9) has a thermal conductivity in the range 0.044 W/mK with an electrical conductivity of 0.06 W/mK. This lower value of the thermal conductivity is due to presence of iron-rich minerals and gabbroic mineralogy.

Quartz with stain of feldspar (SP10) has thermal conductivity between 0.057 W/mK with an electrical conductivity of 0.09 W/mK. The high thermal conductivity is due to presence of quartz and feldspar.

In many materials, electrical conductivity and thermal conductivity are correlated, meaning that materials with high electrical conductivity often have high thermal conductivity. However, conductivities depend on the material's composition, structure, and temperature. The results shows that some materials (gem stones) often rely on phonon transport (lattice vibrations). The thermal conductivity can be efficient in materials with strong atomic bonds and crystalline structures. On the other hand, electrical conductivity relies on the movement of free electrons, which can be hindered by factors like impurities, defects, or lack of free electrons. Hence some materials have good thermal conductivity but poor electrical conductivity due to its wide bandgap. Such materials with good thermal conductivity and poor electrical conductivity are useful for heat sinks, electronic packaging, and thermal interfaces.

Conclusion

The thermal and electrical conductivities of ten (10) selected gemstones were calculated and analyzed. Based on the results in Table 3, the thermal conductivity and electrical conductivity in some of the gem stones correlated (SP1, SP2, SP4, SP7, SP8 and SP10). However, it is not the same case with other gem stones (SP3, SP5, SP6, SP9). This could be because conductivities depend on the material's composition, structure, and temperature. Therefore, it is possible for some materials to have good thermal conductivity but poor electrical conductivity due to its wide bandgap.

References

Ayeni J. K., Omuya A. L., Haruna A.I., Olatunji J.A., Joel E. S., Okeke C.U., Oyanameh O. E., Babatunde T. A., and Fatoye O. V (2022). Nigeria Gemstone: The Role of Geologists in the Value Chain. Anchor University Journal of Science and Technology (AUJST). A publication of the Faculty of Science and Science Education, Anchor University Lagos. ISSN: 2736-0059, 2 (2), Pp. 123 – 133

Bamigbala, P.A. (2001) "Determination of thermal conductivity of clay Samples" The College Review- A multi-disciplinary Journal. OSSCE, Ila- Orangun. pp 56 – 64.

Giovanni Alcocer (2020). Determination of the Thermal Conductivity by Using the Hot Wire Method: Theory, Simulation and Experiment. Mediterranean Journal of Basic and Applied Sciences (MJBAS) 4 (3), Pp 110-135

Kelen Dornelles and Mauricio Roriz (2004). Thermal Inertia, Comfort and Energy Consumption in Buildings: Acase study in Sao Paulo State, Brazil. International Journal for Housing Science and Its Applications. 28, Pp 153-162

Kyaw Myint Htoo, Tun Khin and Sein Htoon. (2002) Investigation of concentration of elements contained in some Myanmar gems; in relation to their physical properties, school family day 2002

Kyaw Myint Htoo. (2002) Investigation of concentration of elements contained in some Myanmar gems; ruby, sapphire, spinel ,peridot and jade in relation to their physical properties. PhD Thesis.

Nelkon, M (2008) Heat, London Heinemann Education Book Limited, pp 86-89.

Olade, M.A (2021). Gemstones of Nigeria: An overview of their geological occurrence, provenance and origin. Acheivers Journal of Research, AJOSR Vol.3, Issue 1, 2021 , pp1-22

Ormin, B. J., (2023). Comparative Study of the Thermal Conductivities of Polluted Soil (Sandy, Loamy and Clay Soil) in Bali Taraba State. Bali Journal of Technology (Multidisciplinry Journal) Vol. 3 Issue 1

Tilli Ishaku Ishaya, Ormin B. Joseph, Nathaniel S. Muwa, and Abubakar Sanusi (2024). Identification of Special Stones in Some part of Bali Local Goverment, Taraba State, Nigeria. International Journal of Agriculture and Earth Science. Volume 11 Issue 4.

Tyler, F. (2009) A Laboratory Manual of Physics, Edward Arnold (Pub.) Ltd., London. pp. 118- 119.

Calculations

A. Thermal Conductivity

SP1 Tourmaline, books of muscovite, feldsparg, and quartz
- q = 10 W/m
- T1 = 25°C
- T2 = 45°C
- t1 = 15 s
- t2 = 75 s

$$k = \frac{10}{4\pi(45 - 25)} ln(75 / 15) \approx 0.064\, W/mK$$

SP2 Lithium, feldspar, and quartz
- q = 12 W/m
- T1 = 30°C
- T2 = 60°C
- t1 = 20 s
- t2 = 120 s

$$k = \frac{12}{4\,\pi(60 - 30)}\ ln(120 / 20) \approx 0.057\, W/mK$$

SP3 Gneiss with alteration chloride (chloritization)
- q = 8 W/m
- T1 = 25°C
- T2 = 40°C
- t1 = 15 s
- t2 = 90 s

$$k = \frac{8}{4\,\pi(40 - 25)}\ ln(90 / 15) \approx 0.076\, W/mK$$

SP4 Pegmatitic Rock
- q = 10 W/m (heat transfer rate per unit length)
- T1 = 20°C (initial temperature)
- T2 = 50°C (final temperature)
- t1 = 10 s (initial time)
- t2 = 60 s (final time)

$$k = \frac{10}{4\,\pi(50 - 20)}\ ln(60 / 10) \approx 0.048\, W/mK$$

SP5 Quartz weathering (hematization)
- q = 8 W/m
- T1 = 20°C
- T2 = 35°C
- t1 = 10 s
- t2 = 40 s

$$k = \frac{8}{4\,\pi(35 - 20)}\ ln(40 / 10) \approx 0.059\, W/mK$$

SP6. Pegmatite with lithium
- q = 14 W/m
- T1 = 35°C
- T2 = 70°C
- T1 = 25 S
- t2 = 150 s

$$k = \frac{14}{4\,\pi(70 - 35)}\ ln(150 / 25) \approx 0.045\, W/mK$$

SP7. Quartz with feldspar ironization
- q = 16 W/m
- T1 = 40°C
- T2 = 80°C
- t1 = 30 s
- t2 = 180 s

$$k = \frac{16}{4\,\pi(80 - 40)}\ ln(180 / 30) \approx 0.057\, W/mK$$

SP8. Schist
q = 6 W/m
- T1 = 25°C
- T2 = 40°C
- t1 = 15 s
- t2 = 60 s

$$k = \frac{6}{4\pi(40 - 25)} \; ln(60 / 15) \approx 0.044 \, W/mK$$

SP9. Gabbro with iron content
- q = 6 W/m
- T1 = 25°C
- T2 = 40°C
- t1 = 15 s
- t2 = 60 s

$$k = \frac{6}{4\pi(40 - 25)}(ln(60 / 15)) \approx 0.044 \, W/mK$$

SP10. Quartz with stain of feldspar
- q = 12 W/m
- T1 = 30°C
- T2 = 60°C
- t1 = 20 s
- t2 = 120 s

$$k = \frac{12}{4\pi(60 - 30)} \; (ln(120 / 20)) \approx 0.057 \, W/mK$$

B. Electrical Conductivity

SP1. Tourmaline, books of moscovite, feldspar, and quartz: $\sigma = 0.01\,(0.1 / 0.02) = 0.05\, S/m$

SP2. Lithium, feldspar, and quartz: $\sigma = 0.024\,(0.1 / 0.02) = 0.12\, S/m$

SP3. Gneiss with chlorization: $\sigma = 0.006\,(0.1 / 0.02) = 0.03\, S/m$

SP4. Pegmatic Rock: $\sigma = 0.016\,(0.1 / 0.02) = 0.08\, S/m$

SP5. Quartz weathering (hermatization): $\sigma = 0.004\,(0.1 / 0.02) = 0.02\, S/m$

SP6. Pegmatite with lithium: $\sigma = 0.03\,(0.1 / 0.02) = 0.15\, S/m$

SP7. Quartz with feldspar ironization: $\sigma = 0.02\,(p0.1 / 0.02) = 0.10\, S/m$

SP8. Schist: $\sigma = 0.002\,(0.1 / 0.02) = 0.01\, S/m$

SP9. Gabbro with iron content: $\sigma = 0.012\,(0.1 / 0.02) = 0.06\, S/m$

SP10. Quartz with stain of feldspar: $\sigma = 0.018\,(0.1 / 0.02) = 0.09\, S/m$