ESTIMATION OF THE RESISTIVITY OF GRAPHITE PENCILS

Molua O.C,[1] Ighrakpata F.C[2] and Igherighe E.C[3]
Physics Dept. College of Education, Agbor
Physics Dept. College of Education, Warri

Abstract

The graphite pencils are an instrument made of a mixture of graphite and clay, coated with oil or wax for finer quality. There are arrays of graphite pencils categorized by hardness (F), and blackness or softness (B), with each type of pencil giving different textures and shades when used to draw or write. Length (l) and cross-sectional area of graphite pencils determine the amount of electricity allowed to flow through it, affecting its conductivity. The greater the length, the greater the resistance, however the greater the cross-sectional area, the resistivity of the pencil will be smaller. Eight graphite pencils, 6H, 5H, 2H, 3H, HB, 5B, 2B and 3B, which were tested. The hardest of all the investigated samples 6H produced a resistivity of 3.6 x $10^{-5}\Omega m$*, while the softest 5B produced the least resistivity of 3.1 x 10 Ωm leading to the conclusion that the resistivity of a hard graphite pencil is higher than that of a soft graphite pencil. The quantity of clay in a hard graphite pencil is its main property accountable for this theory and suggests the association that its resistivity is dependent on the percentage composition of clay in graphite pencils; the more clay composed within graphite pencil the higher its resistivity.*

Introduction

A pencil is a writing implement or art medium usually constructed of a narrow, solid pigment core inside a protective casing. The case prevents the core from breaking, and also from marking the users hand during use. Pencils create marks via physical abrasion, leaving behind a trail of solid core material that adheres to a sheet of paper or other surface. They are noticeably distinct from pens, which dispense liquid or gel ink that stain the light color of the paper. Most pencil cores are made of graphite mixed with a clay binder, leaving grey or black marks that can be easily erased. Graphite pencils are used for both writing and drawing, and the result is durable: although writing can usually be removed with an eraser, it is resistant to moisture, most chemicals, ultraviolet radiation and natural ageing. Other types of pencil core are less widely used. Charcoal pencils are mainly used by artists for drawing and sketching. Colored pencils are sometimes used by teachers or editors to correct submitted texts but are more usually regarded as art supplies, especially those with waxy core binders that tend to smear on paper instead of erasing. Grease pencils have a softer crayon -like waxy core that can leave marks on smooth surfaces such as glass or porcelain. The most common type of pencil casing is a thin wooden cylinder permanently bonded around the core. Similar permanent casings may be constructed of other materials such as plastic or paper. In order to use the pencil, the casing must be carved or peeled off to expose the working end of the core as a sharp point. Mechanical pencils have more elaborate casings that support mobile pieces of pigment core, which can be extended or retracted through the casing tip as needed.

The graphite pencils are an instrument made of a mixture of graphite and clay, coated with oil or wax for finer quality. There are arrays of graphite pencils categorized by hardness (F), and blackness or softness (B), with each type of pencil giving different textures and shades when used to draw or write. As shown in fig 1, below.

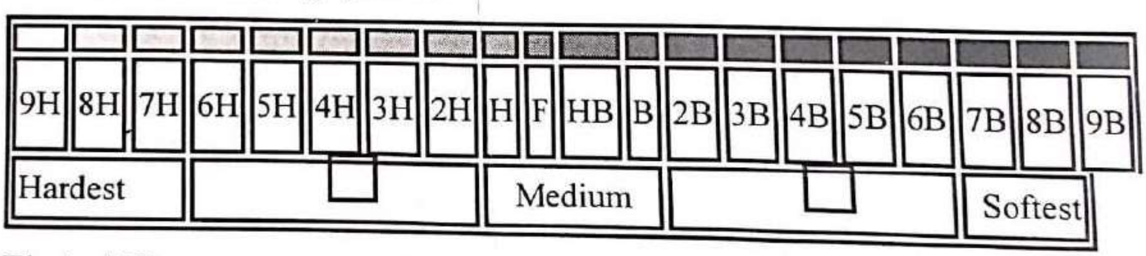


Fig 1: different textures and shades of pencils

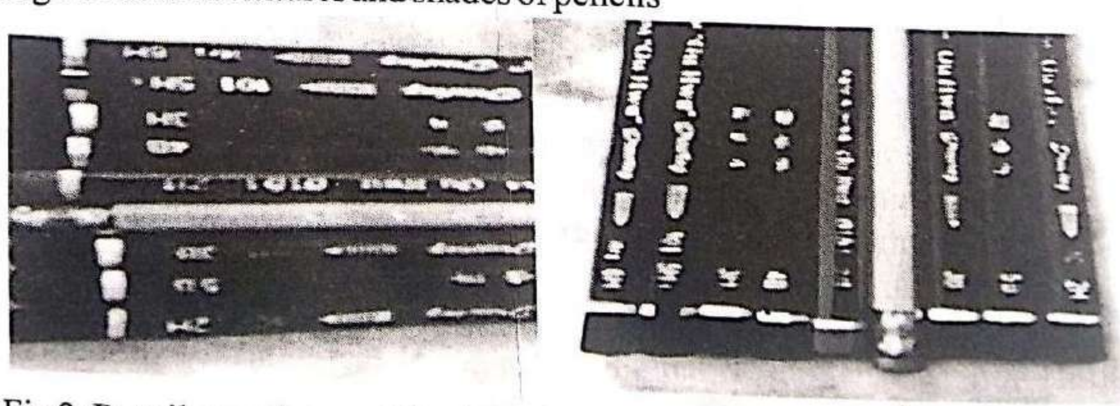


Fig 2: Pencil samples used for the study

Graphite or lead is a form of carbon that is a good conductor of electricity. Whereas clay composed of minerals, is an insulator of electricity. It is right to state that the quantity of clay, hence the hardness of graphite pencils, is the material within graphite, responsible for resisting the flow of electricity or electrons.

Length (l) and *cross-sectional area* of graphite pencils determine the amount of electricity allowed to flow through it, affecting its conductivity. The greater the length, the greater the resistance, however the greater the cross-sectional area, the resistivity of the pencil will be smaller. Three different pencils were tested within three minute periods, to help determine the effects of clay to the resistivity of a graphite pencil.

The parameters which influenced minor errors include: the time duration in conducting the experiment temperature of the pencil, as it increased within the circuit. There was no time to allow the each sample to cool down for the next experiment.

Theory

Resistance can be defined as the extent to which a material prevents the flow of electricity. Silver, aluminum, iron and other metals have a low resistance (and a high conductivity). Wood, paper, and most plastics have a high resistance (and a low conductivity).

The unit of measurement for electrical resistance is called the ohm (?). The ohm was named after the German Physicist Georg Simon Ohm (17891854), who first expressed the mathematical laws of electrical conductance and resistance in detail. Interestingly enough, the unit of electrical conductance is called the mho.

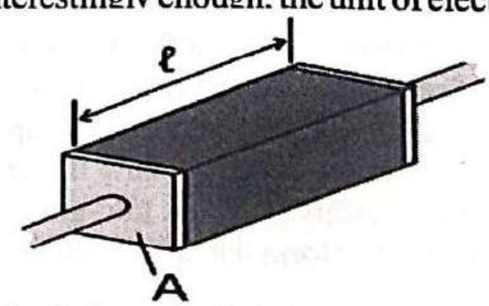


Fig 3: Model for the calculation of resistivity

Electrical resistivity ρ (Greek: rho) is defined by,

$$\rho = \frac{E}{J}$$

where

ρ is the static resistivity (Ù-m)
E is the magnitude of the electric field (V/m);
J is the magnitude of the current density (A/m²).

Many resistors and conductors have a uniform cross section with a uniform flow of electric current and are made of one material. In this case, the above definition of ρ leads to:

$$P = R\frac{A}{\ell}$$

where

R is the electrical resistance of a uniform specimen of the material (measured in ohms, Ω)

ℓ is the length of the piece of material (measured in metres, m)

A is the cross-sectional area of the specimen (measured in square metres, m²).

$$P = R\frac{\ell}{A}$$

The resistance of a given sample will increase with the length, but decrease with greater cross-sectional area. Resistance is measured in ohms. Length over area has units of 1/distance. To end up with ohms, resistivity must be in the units of "ohms × distance" (SI ohm-metre)

Materials and Methods

The different kinds of graphite accounts for the range in resistivities. Some graphite is manufactured while some is mined from the above locations. Because of its layered molecular structure, graphite has parallel and perpendicular resistivities, depending on how the graphite is oriented in a circuit. There is also high-density graphite, low-density graphite, granulated, coarse, grease, and every other form that affects the resistivity.

The materials used in this work include 2 digital Multi Meter (one acted as a volt meter and the other ammeter),4v-16v ac convertor , connecting wires,5H,5B,6H,2H,2B,HB,3H and 3B respectively. The Voltage and current across the different types of pencils were measured and recorded, while the lengths were measured and recorded. The various diameters were also measured with a micrometer screw gauge and recorded. The results were tabulated and the graph of Voltage against current plotted.

Results

The Results obtained from the use of the different pencils are shown in Tables 1-8, while their graphs are shown in figures 4-11.

Table 1: Data obtained for 2B pencil

V0ltage(v)	Current(A)
3.60	0.05
5.12	0.11
6.76	0.14
7.42	0.17
10.12	0.24
12.09	0.28

Other Parameters for 2B: Length-17.8cm, Diameter-0.20cm, Radius-1.0×10^{-3}m, Area-$3.14 \times 10^{-8}m^2$,

List Plot [{{0.05,3.60}, {0.11,5.12}, {0.14,6.75}, {0.17,7.42}, {0.24,10.12}, {0.28,12.09}}]

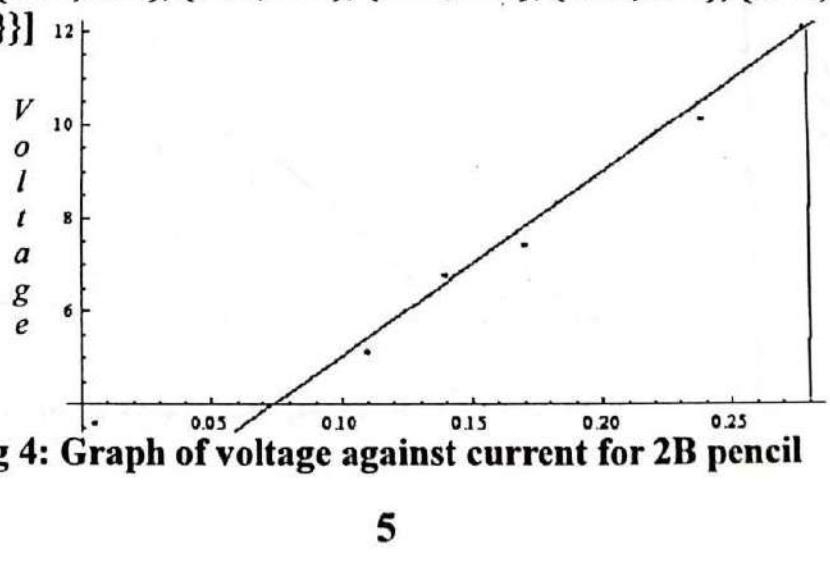


Fig 4: Graph of voltage against current for 2B pencil

$$Slope = \frac{12 - 4}{0.28 - 0.075} = \frac{8}{0.205} = 39.024\,\Omega$$

$$R = \frac{\rho L}{A}$$

$$Therefore\,\rho = \frac{RA}{L} = \frac{39.024x3.14x10^{-8}}{0.178} = \frac{0.0000012254}{0.178} = 0.0000068843\Omega m$$

Table 2: Data obtained for HB Pencil

Voltage(v)	Current(A)
2.26	0.25
3.12	0.49
3.88	0.59
4.39	0.60
6.68	0.74
6.68	0.75

Other Parameters for HB: Length-17.9cm, Diameter-0.33cm, Radius-$1.7x10^{-3}$m, Area-$9.08x10^{-8}m^2$,

List Plot [{{0.25,2.26}, {0.49,3.12}, {0.59,3.88},{0.60,4.39}, {0.74,6.68}, {0.75,(

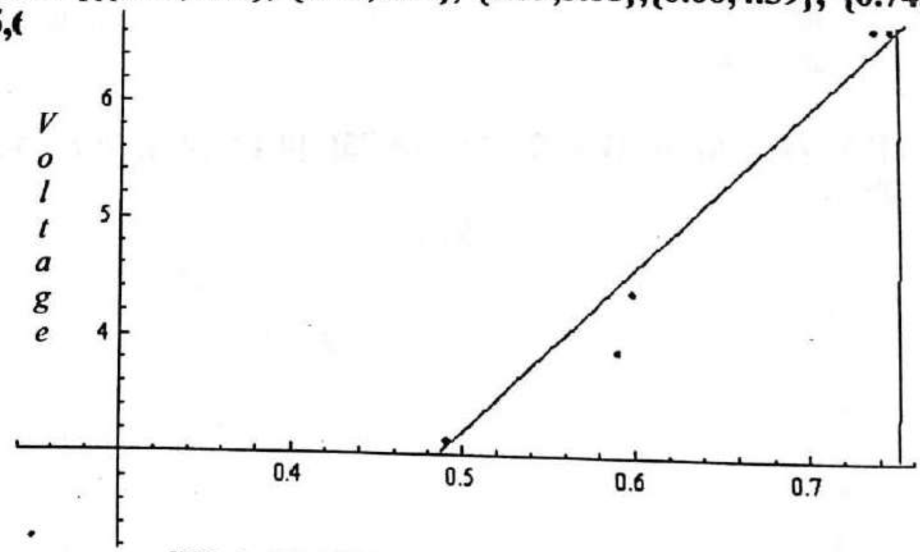


Fig 3. Graph of voltage against current for HB pencil

$$Slope = \frac{6.6-3}{0.745-0.484} = \frac{3.6}{0.261} = 13.793\Omega$$

$$R = \frac{\rho L}{A}$$

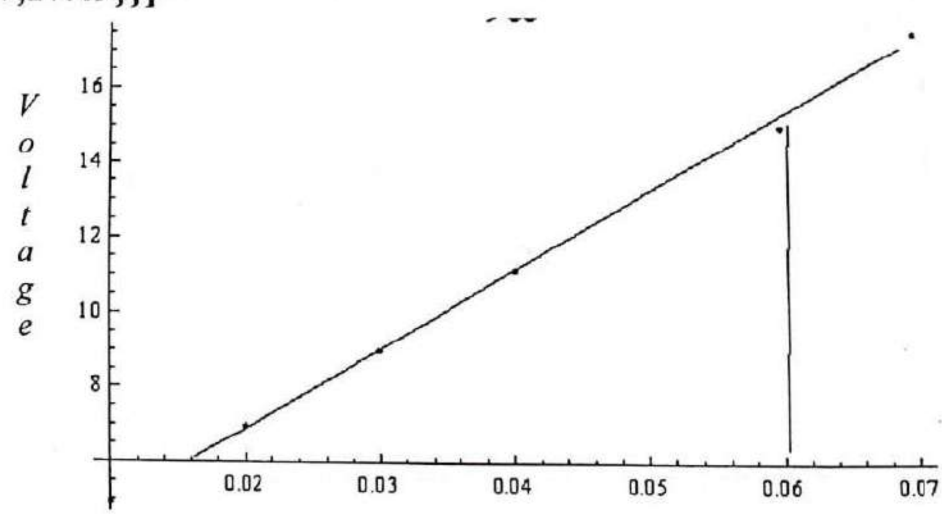
$$Therefore\, \rho = \frac{RA}{L} = \frac{13.793x9.08x10^{-8}}{0.179} = \frac{0.0000012524}{0.179} = 0.0000069966\Omega m$$

Table 3: Data obtained for 6H Pencil

Voltage(v)	Current(A)
4.94	0.01
6.97	0.06
8.97	0.04
11.09	0.03
14.92	0.02
17.49	0.07

Other Parameters for 6H: Length-17.7cm, Diameter-0.20cm, Radius-$1.0x10^{-3}$m, Area-$3.14\,x10^{-8}m^2$,

List Plot [{{0.01,4.94}, {0.02,6.97}, {0.03,8.97}, {0.04,11.09}, {0.06,14.92}, {0.07,17.49}}]



Current

Fig 6: Graph of voltage against current for 6H pencil

$$Slope = \frac{15-6}{0.06-0.016} = \frac{9}{0.044} = 204.545\,\Omega$$

$$R = \frac{\rho L}{A}$$

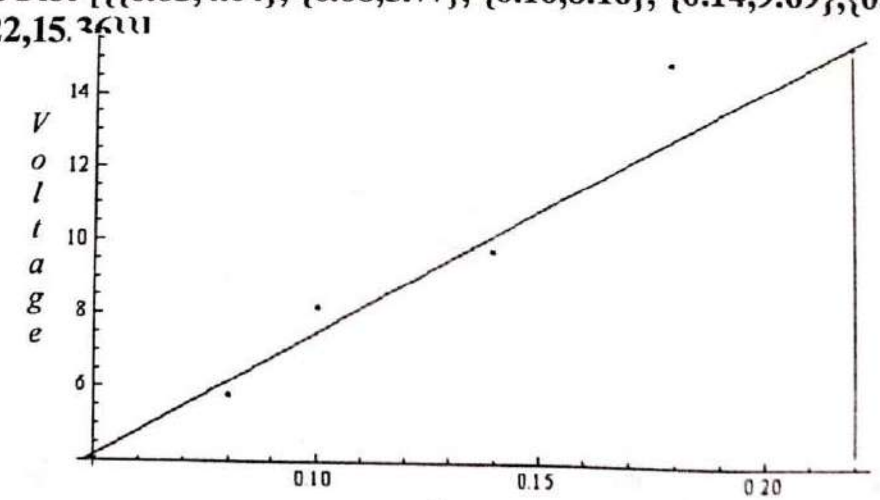
$$Therefore\,\rho = \frac{RA}{L} = \frac{204.545x3.14x10^{-8}}{0.177} = \frac{0.0000064227}{0.177} = 0.0000362864\Omega m$$

Table 4: Data obtained for 3B Pencil

Voltage(v)	Current(A)
4.04	0.05
5.77	0.18
8.16	0.14
9.69	0.10
15.36	0.08
14.86	0.22

Other Parameters for 3B: Length-17.6cm, Diameter-0.20cm, Radius-$1.0x10^{-3}$m, Area-3.14 $x10^{-8}m^2$,

List Plot [{{0.05,4.04}, {0.08,5.77}, {0.10,8.16}, {0.14,9.69},{0.18,14.86}, {0.22,15.36}}]



Current

Fig 7: Graph of voltage against current for 3B pencil

$$Slope = \frac{15-4}{0.22-0} = \frac{11}{0.22} = 50.00\Omega$$

$$R = \frac{\rho L}{A}$$

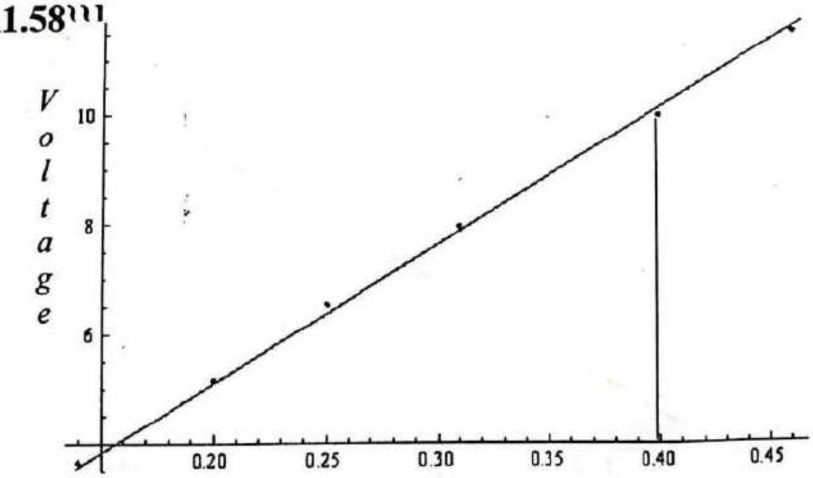
$$Therefore\,\rho = \frac{RA}{L} = \frac{50.0x3.14x10^{-8}}{0.176} = \frac{0.00000157}{0.176} = 0.0000089205\Omega m$$

Table 5: Data obtained for 5B Pencil

Voltage(v)	Current(A)
3.64	0.14
5.16	0.20
6.52	0.25
7.96	0.31
9.99	0.40
11.58	0.46

Other Parameters for 5B: Length-17.7cm, Diameter-0.20cm, Radius-$1.0x10^{-3}$m, Area-3.14 $x10^{-8}m^2$,

List Plot [{{0.14,3.64}, {0.20,5.16}, {0.25,6.52}, {0.31,7.96}, {0.40,9.99}, {0.46,11.58}}]



Current

Fig 8: Graph of voltage against current for 5B pencil

Slope=10-4/0.4-0.16 =6/0.34 =1.7647= Resistance

$$R = \frac{\rho L}{A}$$

$$Therefore\,\rho = \frac{RA}{L} = \frac{1.7647x3.14x10^{-8}}{0.177} = \frac{0.0000000554}{0.177} = 0.000000313\Omega m$$

Table 6: Data obtained for 3H Pencil

Voltage(v)	Current(A)
4.36	0.04
6.28	0.05
7.98	0.07
9.68	0.08
12.95	0.11
15.68	0.14

Other Parameters for 3H: Length-17.5cm, Diameter-0.20cm, Radius-$1.0x10^{-3}$m, Area-3.14 $x10^{-8}m^2$,

List Plot [{{0.04,4.24}, {0.06,5.99}, {0.08,7.69}, {0.10,9.25}, {0.14,12.58}, {0.16,15.29}}]

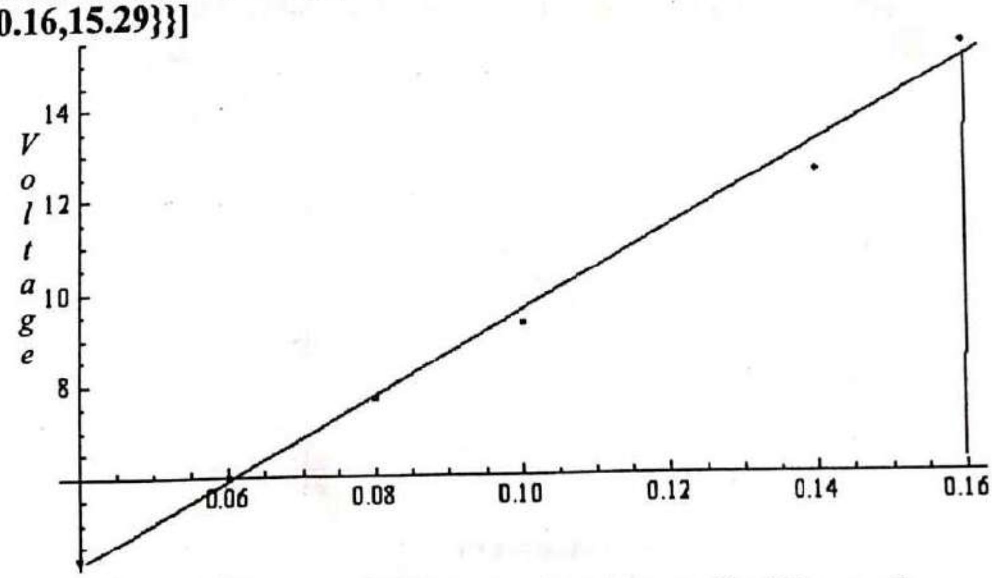


Fig 9: Graph of voltage against current for 3B pencil

Slope = 15-6/0.16-0.06=9/0.10 =90

$$R = \frac{\rho L}{A}$$

$$Therefore\ \rho = \frac{RA}{L} = \frac{90.0x3.14x10^{-8}}{0.175} = \frac{0.000012826}{0.175} = 0.0000161486\Omega m$$

Table 7: Data obtained for 5H Pencil

Voltage(v)	Current(A)
4.24	0.04
5.99	0.06
7.69	0.08
9.25	0.10
12.58	0.14
15.29	0.16

Other Parameters for 5H: Length-17.5cm, Diameter-0.20cm, Radius-$1.0x10^{-3}$m, Area-3.14 $x10^{-8}m^2$,

List Plot [{{0.04,4.36}, {0.05,6.28}, {0.07,7.98}, {0.08,9.68}, {0.11,12.95}, {0.14,15.68}}]

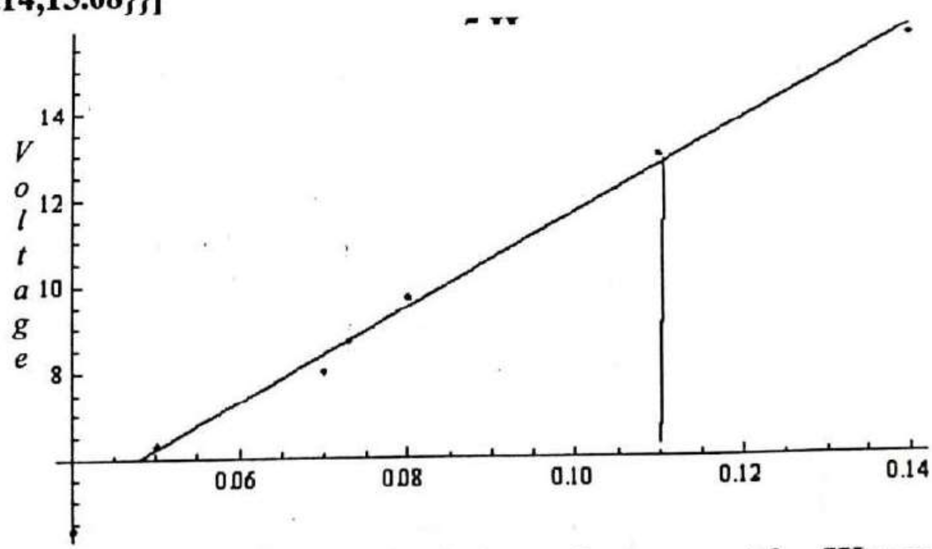


Fig 10 : Graph of voltage against current for 5H pencil

Slope = 12.5-6/0.11-0.048 =6.5/0.062=104.8387

$$R = \frac{\rho L}{A}$$

$$Therefore\,\rho = \frac{RA}{L} = \frac{104.8387x3.14x10^{-8}}{0.175} = \frac{0.0000032919}{0.175} = 0.0000188109\Omega m$$

Table 8: Data obtained for 2H Pencil

Volt age(v)	Current(A)
2.06	0.27
2.84	0.38
3.47	0.47
4.09	0.56
4.86	0.66
5.36	0.73

Other Parameters for 2H: Length-17.5cm, Diameter-0.20cm, Radius-$1.0x10^{-3}$m, Area-3.14 $x10^{-8}m^2$,

List Plot[{{0.27,2.06}, {0.38,2.84}, {0.47,3.47}, {0.56,4.09}, {0.66,4.86}, {0.73,5.36}}]

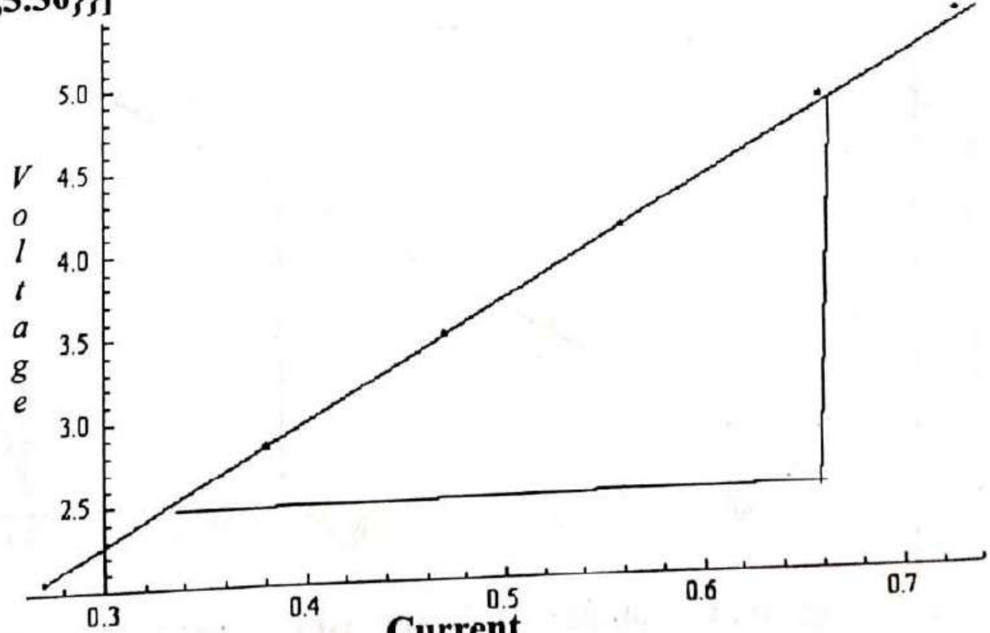


Fig 11: Graph of voltage against current for 2H pencil

Slope = 4.8-2.5/0.66-0.33=2.3/0.33 = 6.9697

$$R = \frac{\rho L}{A}$$

$$Therefore\ \rho = \frac{RA}{L} = \frac{6.9697x6.16x10^{-8}}{0.178} = \frac{0.0000004293}{0.178} = 0.0000024118\Omega m$$

Discussion of results and conclusion

Many pencils across the world, and almost all in Europe, are graded on the European system using a continuum from "H" (for hardness) to "B" (for blackness), as well as "F" (for fine point). The standard writing pencil is graded **HB**. According to Petroski,1990 this system might have been developed in the early 20th century by Brookman, an English pencil maker. It used "B" for black and "H" for hard; a pencil's grade was described by a sequence or successive Hs or Bs such as **BB** and **BBB** for successively softer leads, and **HH** and **HHH** for successively harder ones.

A hard graphite pencil has a higher resistance than a soft graphite pencil. The results from the eight pencil samples analysed supports this assertion. The hardest (fig 1) of all the investigated samples 6H produced a resistivity of $3.62864 \times 10^{-5}\Omega m$. Other results obtained include HB with a resistivity of $6.9 \times 10^{-6}\Omega m$, 3H with a resistivity of $1.6 \times 10^{-5}\Omega m$, 2H with a resistivity of $2.4 \times 10^{-5}\Omega m$, 2B with a resistivity of 6.8×10^{-6} , 3B with a resistivity of $8.9 \times 10^{-6}\Omega m$, 5B with a resistivity of $3.1 \times 10^{-7}\Omega m$ and 5H with a resistivity of $1.88 \times 10^{-5}\Omega m$.

We Conclude therefore from results obtained, after investigating the resistivity of the eight different pencil types of the same length and cross-sectional area, that resistivity is strongly dependent on hardness of the pencils-as the resistivity of a hard graphite pencil is higher than that of a soft graphite pencil. Thus, the harder the pencil, the higher the resistivity and vice-versa.

REFERENCES

Petroski, Henry (1990). /The Pencil: A History of Design and Circumstance/. New York: Alfred A. Knopf. ISBN 0-394-57422-2

http://en.wikipedia.org/wiki/Pencil.

http://en.wikipedia.org/wiki/Carbon.

Http://en.wikipedia.org/wiki/Graphite.