ISSN 2063-5346

THERMAL BEHAVIOUR OF TUNGSTEN FILMENT AND VERFICATION OF EMPIRICAL FORMULA

Jagannadha Sastry.V [1], S.Suresh [2], K. Suryanarayana [2], Dr.M.Ratnaraju [2], G.Anand [2], T.Sravan Kumar [2]

1. Assistant Professor, Department of Physics,
MAHARAJAH'S Colleg0e (AUTONOMOUS), Affiliated to Andhra University
Vizianagaram, A.P, India-535002. Email Id: sastry.physics@gmail.com

2. Assistant Professor, Department of Physics,
MAHARAJAH'S College (AUTONOMOUS), Affiliated to Andhra University
Vizianagaram, A.P, India-535002..

Article History: Received: 12.05.2023 **Revised:** 25.05.2023 **Accepted:** 05.06.2023

Abstract

The aim of this work, proposed for undergraduate students and teachers is the Calibration of temperature of tungsten filament bulb from electric measurements that are simple and precise and also the power dissipated across the filament under considerable limitations by following a simple heat transfer model.

Most of the filament- bulbs exhibit resistivity and yield a high temperature at the burning point. In this scenario, an experiment is performed by using available low power incandescent bulbs. The experimental results obtained, at higher temperature of the filament using empirical formula, were compared with those of resistivity of the material, in terms of linear expansion relation. The melting and boiling points of Tungsten is 3683 Kelvin and 5933 Kelvin respectively

I.INTRODUCTION:

There is number of methods to estimate the temperature of the Tungsten filament (Ref. 1, 2, 3, 4, 5, 6, 9). The following is the significant observations from the systematic review of literature, regarding the Tungsten filament.

1. A power law exists between the resistances R versus temperature T of the Tungsten filament. (Ref.1)

2. A transfer of input power predominantly into the Planck's radiation channel through Stephan's law occurs. (Ref.2)

3. The life time of the filament is governed by the rate of thermal evaporation of the metal.(Ref. 3)

4. The Current - Voltage characteristics of the filament lamp is found to exhibit hysteresis. (Ref. 5 , 6)

5. An experiment is conducted for verification of the Stefan's Boltzmann law by using a low power incandescent bulb. (Ref. 9)

In this present work, commercially available low power tungsten filament bulbs of 2 watts-12 volts and 21 watts-24 volts were used. Experimental data plots of Resistance versus Voltage and Temperature versus Voltage for the tungsten filament were done and also the behavior of Temperature and Resistance with respect voltage as well as current are similar under the limitations of experiment. Verification of Stefan's – Boltzmann law is done experimentally observed and at low intensity of currents it was observed that the temperature is not uniform. The results obtained are indicative of the transfer of electrical power predominantly into the Planck's radiation channel, through Stefans – Boltzmannlaw. Also the empirical relation of temperature of the filament as a function of its resistivity has been considered, (Ref no. 6). But it linear expansion coefficient (=0.0045 /K) and emissivity of the filament (= 0.3, on average) have been taken to be constant value within this limitation of low intensity of currents and this emissivity could be taken so, because of its spectral dependence (CRC Hand Book of Chemistry and Physics), corresponding to the Temperatures, with in the data we have.

II.**EXPERIMENT**:

In the present experiment 12 Volt (2 Watt), 24 Volt (21 Watt) commercial bulbs were used. The Current – Voltage measurements were doneby using a variable DC power supply and Multi meters. To determine the voltage across the filament and current in the series circuit, millimetersare made to operate as a voltmeter and ammeter respectively. The Resistance of the filament is obtained by using Ohm's law and the power dissipation is obtained from the Voltage and Current characteristics.

The temperature of the filament at different voltages were measured fromthe empirical relation derived from the Stefan's – Boltzmann law as,

$T = 3.05 \times 10^{8} \, (\rho_t)^{0.83}$Kelvin. (since: $\rho_t = \rho_0 \times \frac{R_f}{R_0}$) (Ref . 6)

From the thermal expansion property, the filament temperature is

$T = T_0 + \{ [(R_f - R_0) / \alpha] - 1 \}$, where α is the linear expansion coefficient of the material of the filament.

In terms of Resistivity,

$T = T_0 + \{ [(\rho_t - \rho_0) / \alpha] - 1 \}$ K

From the above mentioned relations of temperature, it was observed that their values at low intensity of currents coincide approximately (for 2 watts bulb error is below 2-5% from following given experimental data and analysis of the Plots.

With the help of Travelling Microscope we counted the no.of helical turns and by geometry procedure we evaluated the length and radius of the filament:

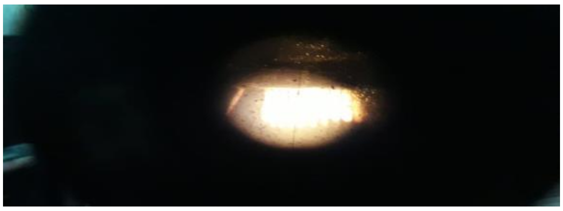
1.For 2 watts bulb:

Length and Radius of the filament are 2.5 cm and 10µm, surface area = 2πrL

2.For 21 watts bulb:

Length and Radius of the filament are 23 cm and 120µm, surface area = 2πrL

Filaments observed through Travelling Microscope :



III.MODELING:

The Stefan–Bolzmann law establishes a relation for the energy flux (heat radiation emitted per unit area and unit time) corresponding to anybody of finite absolute temperature ($T \neq 0$) placed in an environment at room temperature To(293 K), giving a radiated energy increasing with the fourth power of the temperature.

The electrical power input to the lamp is represented as the sum of the dissipated power by the filament due to conduction, convection and radiation processes respectively.

$$V^2 / R = K (T – T_0) + e\sigma A_s (T^4 – T_0^4)$$

K – The conduction and convection losses of the system

T and $T_0$are the temperatures in Kelvin for the filament and the surrounding ambient, respectively

σ - Stefan's – Boltzmann constant

At higher temperatures $T^4 >> T_0^4$ and for low power electrical bulbs (Ref. 2), such as those used in present work, the literature survey indicate that convention and conduction losses are very negligible in comparison with the radiation loss. Therefore $V^2 = e\ \sigma\ A_s\ T^4 R$

Usually, resistance of the metal increases with temperature due to disruption of free electron path in the crystal, and a drift dislocation of atoms and increase in the lattice phonon vibrations.

The increase in the temperature of the Tungsten in the range 300 K to 3655 K can be represented in terms of Resistivity as,

$$T = 3.05 \text{ x } 10^8 (\rho_t)^{0.83}$$

For higher temperature of the filament conduction, convention and the Newton laws of cooling heat energy for low power bulbs negligible.

Here calculating temperatures from the temperature coefficient of resistance approximately equal to the semi empirical relation temperatures and also from the logT versus logP graph the slope of a line indicates Stefan Boltzmn law accepting.

$$T = 3.05 \times 10^8 (\rho_t)^{0.83} \text{ K}$$

In this method we are using simple laboratory equipments and the obtained values from this experiment gives us less than 2% - 5% of the mean error in these values.

In the present work we have measured R and T both as function of voltage V and these have been shown in the Results and Discussions.

IV.**RESULT AND DISCUSSIONS**:

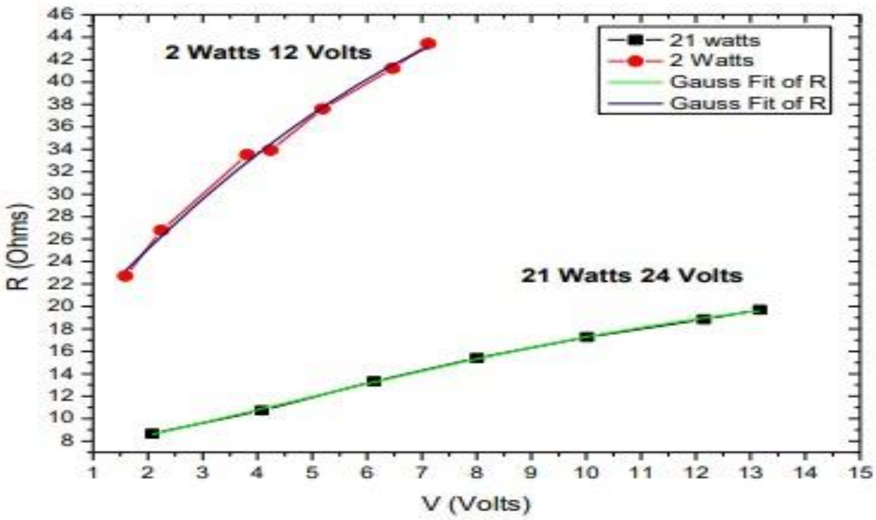
The experimental data is as mentioned below

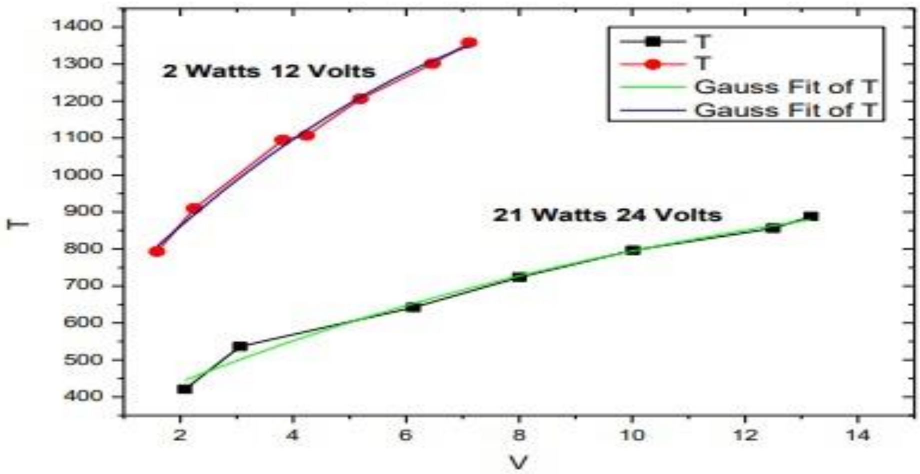
Voltage (volts)	Current (I) (Amperes)	$T = 3.05 \times 10^8 (\rho_t)^{0.83}$	$T = T_0 + \{ [(R_f - R_0) / \alpha] - 1 \}$ Kelvin
1.59	0.070	793.2	809.71
2.25	0.084	909.7	917.43
3.82	0.114	1095	1134.9
4.24	0.125	1106.5	1148.2
5.19	0.138	1205.7	1267.6
6.47	0.157	1300.7	1384
7.12	0.164	1358.3	1455

Voltage (volts)	Current (I) (Amperes)	$T = 3.05 \times 10^8 (\rho_t)^{0.83}$	$T = T_0 + \{ [(R_f - R_0) / \alpha] - 1 \}$ Kelvin
2.08	0.24	421	421.1
3.06	0.28	536.6	509.58
6.13	0.46	642.02	620.26
8.01	0.52	724.04	709.02
10.02	0.58	796.36	789.02
12.50	0.63	856.02	856.16
13.17	0.67	888.09	892.65

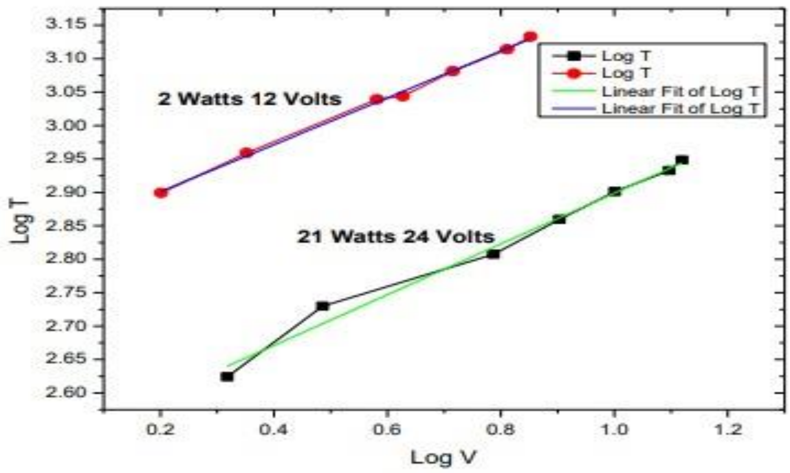
The above taking and variable values are mostly readout from standard positioning values for digital multimeter.

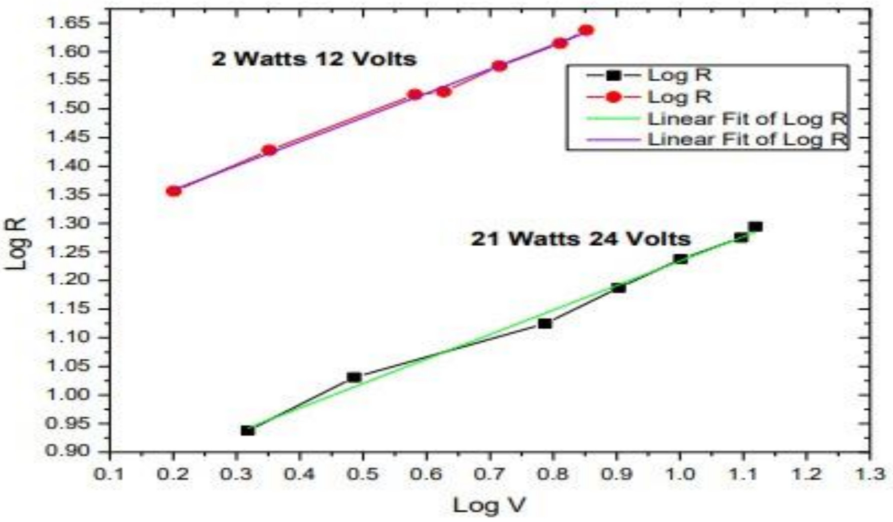
GRAPHS:



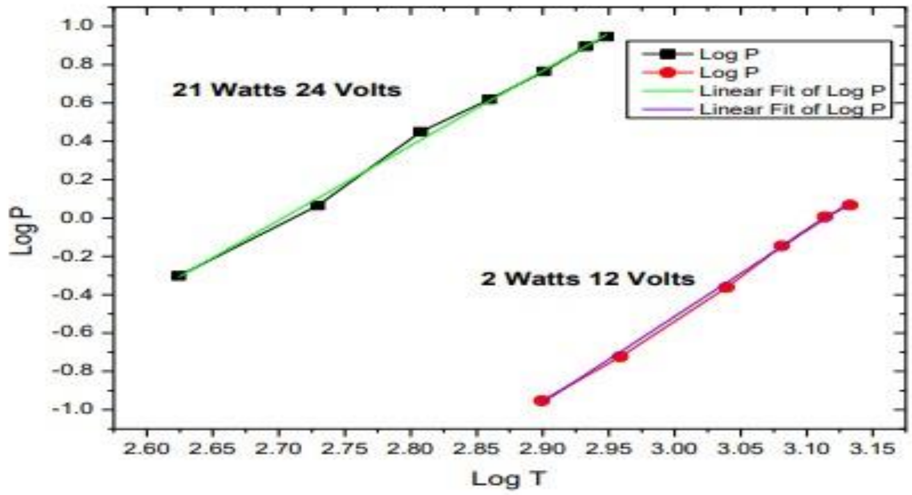


Resistance versus voltage, Temperature versus voltage curves obtained with 21watts and 2 watts incandescent filament bulb. These curves indicate the approximate proportionality relation between temperature and Resistance.





Log R versus Log V and Log T versus Log V curves obtained with 21watts and 2 watts incandescent filament bulb. These curves indicate the approximate proportionality relation between temperature and Resistance.



Log P versus Log T curve obtained with 21watts and 2 watts incandescent filament bulb. This curves indicates the result of Stephan's Boltzmann law.

The experimental data and the straight line represent least square fit to the data generated by a computer.

Plot a graph between Voltage versus Resistance gives us a non-linear curve and logV versus logR gives us a straightline represents least square fit to the data generated by system.

Plot a graph between Voltage versus Temperature also gives us a non-linear curve and logV versus logT gives us straight line for those considering bulbs.

Analysis of the given experimental data from the graph known us the resistance of the conductor variable with temperature in non ohmic region. When we consider total power converting to burning temperature of the filament then the slope of the logT versus logP graph gives experimental evidence of Stefans Boltzmann law. Which is giving the slope 3.892 to 4.01.

V.REGRESSION ANALYSIS OF GRAPHS:

From the analysis of the 21 watt bulb, the relation between log V vs Log R, implies : $R=5.29\ V^{0.5106}$ ohms the relation between log V vs Log T, implies : $T=261.8\ V^{0.436}$ ohms therefore, $R/T = 0.02\ V^{0.0734} \approx 0.02\ V^{0}$ i.e implies R is proportional to T

From the analysis of the 2 watt bulb, the relation between log V vs Log R, implies : $R=18.793\ V^{0.4223}$ ohms the relation between log V vs Log T, implies : $T= 275.04\ V^{0.3722}$ ohms therefore, $R/T = 0.06\ V^{0.0501} \approx 0.02\ V^{0}$ i.e implies R is proportional to T.

From the above verification of two bulbs, the resistance of the filament is variable with the temperature in the proportionality manner.

1.For 2 watts bulb:

Length and Radius of the filament are 2.5 cm and 10μm, surface area = 2πrL

$P = (2.398X10^{-14})T^{4.368}$

$= A\varepsilon\sigma\ T^{4.368}$

$\sigma = 5.0912 \times 10^{-8}$ watt/m^2/K^4

2.For 21 watts bulb:

Length and Radius of the filament are 23 cm and 120μm, surface area = 2πrL

$P = (2.684X10^{-12})T^{4.2}$

$= A\varepsilon\sigma T^{4.368}$

$\sigma = 5.1616 \times 10^{-8}$ watt/m^2/K^4

VI.CONCLUSION:

An experiment using two low power incandescent bulbs for the verification of Stefans Boltzmann law and the Empirical relation (T vs ρ_t) ---- (Ref.6)

Two separate sets of measurements were made on the filament bulbs included filament resistance versus applied voltage and filament temperature applied voltage results compared. Overall satisfactory results were obtained with negligible errors. (Ref.10,11,12,13,14,15,16)

Measurement of the filament temperature to confirm theoretical results is expected to give some confidence in theory to the student. To measurement of filament temperature by using the Pyrometer. (Ref.17,18,19,20,21,23)

When some conducting materials added(doped) to Tungsten, due to changes in resistance properties, then burning temperature of the filament can be controlled. May be by the Annealing process, the filament changes more heat-resistant and the internal structure of the tungsten filament changes and deform. The filament can become extra soft and flimsy.

VII.ACKNOWLEDGEMENTS:

The author gratefully acknowledge to management of MANSAS trust as well as Principal of M.R College (A), Vizianagaram also extend the acknowledgements towards the colleagues of Department of Physics, M.R College(A). Convey my sincere thank to our lab assistant Sri. Ch. V.S.V.V.Prasad for his continuous supporting towards experimental arrangements.

REFERENCES :

1. Agarwal, D.C and Menon V.J, Lifetime and temperature of incandescent lamps, phys, Educ. 33, 55-58. (1998)

2. Clauss D.A, Ralich, R.M and Ramsier R.D,. Hysteresis in a light bulb: connecting electricity and thermodynamics with simple experiments and simulations Eur. J.Phy,22,385-394 (2001)

3. Zanetti, V., Temperature of incandescent lamps, Am.J.Phys.53, 546-548 (1985)

4. Edmonds, I.R., Stefan-Boltzmann Law in laboratory, Am.J.Phys.36, 845-846 (1968)

5. Prasad, B.S.N and Mascarenhas, R.A., laboratory experiment on the application of Stefan’s law to tungsten filament electric lamp, Am.J.Phys. 46, 420-423 (1978)

6. Imtiaz Ahmad, Sidra Khalid and Ehsan E. Khawaja., Lat Am. J.phys Educ. Vol.4,No.1, jan.2010

7. Leff, H.S, illuminating Physics with light bulbs, the phys, Teacher 28, 30-35 (1990)

8. Denardo, B., Temperature of a light bulb filament, the phys, teacher 40, 101-105 (2002)

9. Marcello Carla, Am, J.Phys. 81(7), July 2013.

10. E.M.Wray, “A simple test of Stefan’s Law”, Phy, Educ.(U.K) 10, 25-27(1975)

11. Boston University Undergraduate Physics Laboratories, The Stefan Boltzmann law is available at <http://physics.bu.edu/ulab/modern/ . .

12. R. W. Ellsworth, Stefan-Boltzmann radiation law is available at at <http://physics.gmu.edu/~ellswort/p263/steboltz.pdf>.

13. A.R. Carter, Stefan-Boltzmann law is available at <http://www3.wooster/edu/physics/jris/files/carter.pdf>

14. M. Wellons, The Stefan-Boltzmann law is available at at <http://physics.bu.edu/ulab/modern/Stefan_Boltzmann.pdf>.

15. H. A. Jones, "A temperature scale for tungsten," Phys. Rev. 28, 202–207 (1926).

16. CRC Handbook of Chemistry and Physics, edited by R. C. Weast, 58th ed. (CRC Press, 1977), p. E-230.

17. W. W. Coblentz, "Emissivity of straight and helical filaments of tungsten," Bull. Bur. Stand. 14, 115–131 (1918).

18. W. E. Forsythe and A. G. Worthing, "The properties of tungsten and the characteristics of tungsten lamps," Astrophys. J. 61, 146–185 (1925).

19. J. C. De Vos, "A new determination of the emissivity of tungsten ribbon," Physica 20, 690–714 (1954).

20. Pyrometer Instrument Company,< http://www.pyrometer.com/ribbon_lamp.html>

21. Linux GPIB Package Homepage, . http://linux-gpib.sourceforge.net/>

22. Gnuplot homepage, . http://www.gnuplot.info/

23. Langmuir, "The melting-point of tungsten," Phys. Rev. 6, 138–157 (1915).