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Study on Emitted Radiations from Filament Bulb of Different Power

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Abstract

The research work is carried out to find spectrum of wavelength of the emitted radiations from filament bulb. Both temperature and wavelength measurement are based on theoretical model. The temperature finding formula for tungsten filament is obtained by using blackbody radiation approach. The peak wavelength of the emitted radiation is obtained 1.461 μm and 1.125 μm for 6 and 500 watt bulb respectively by using Wein's displacement law which depends upon temperature of the filament. The wavelength obtained by using Wein's displacement law, is just an index, which helps to investigate, "how the radiation energy density is distributed" so as to give rise to an electromagnetic spectrum. The results obtained from the applied methodologies show that the accuracy of a model is quite good. Some mathematical techniques and probability theory are used to verify the work. The work is followed by both classical and quantum analysis to justify the results. Temperature only is not the key factor that deserves power of the bulb. The value of resistance plays a vital role in fixing power of the bulb. At least one factor is important in the calibration of the power of the bulb, "either temperature or surface area" of the filament.

Keywords

Filament, Electromagnetic Spectrum, Probability Distribution, Spectral Emittance

1. Introduction

Tungsten is a chemical element with the symbol **W**. Its atomic number is 74. Tungsten has melting point of 3422˚C and boiling point is 5930˚C. Its density is 19.3 gm/cm^3 at room temperature and 17.6 gm/cm^3 when liquid is at melting point. Its heat of fusion is 52.31 kJ/mol and heat of vaporization is 774 kJ/mol.

The value of molar heat capacity of tungsten is 24.27 J/(mol·K). Its density is about 1.7 times than that of lead. It lies in the d-block of the periodic table. Its group and period in the periodic table is "6". Tungsten is named by Torbern Bergman in 1781. It is paramagnetic substance [1].

Its phase at STP is solid. Pure single crystalline tungsten is more ductile. The strategic value of tungsten came to notice in the early 20th century. Tungsten desirable properties such as resistance to high temperatures, its hardness and density, and its strengthening of alloys made it an important raw material for the arms industry [1].

1.1. Characteristics of Tungsten

Tungsten is a metal which presents many points of particular interest both from the practical and the scientific point of view. From the time when tungstic acid was first prepared by Scheele in 1781 and Bergmann separated the metal, tungsten remained a rare metal, and it only began to assume industrial importance as the result of the work of Oxland in 1847-57 [2]. Tungsten is a very hard, dense, silvery-white, lustrous metal that tarnishes in air, and forms a protective oxide coating. In powder form tungsten is gray. Tungsten is ductile in pure form and has a very high tensile strength, even a very small diameter [3]. Tungsten filaments are used in incandescent lamps and radio tubes. The high temperatures at which the tungsten filament can be operated render it especially suitable for these purposes [4]. Light of an accurately defined color and brilliancy can be found by heating a tungsten filament to a particular temperature. Temperature, voltage, dependence of current, voltage, etc., upon filament dimensions; wire weight, life of lamps; gas losses; end losses; temperature, brightness, and efficiency of some commercial lamps are characteristics of tungsten lamps [5].

1.2. Background of Incandescent Bulb

A great deal of research has been undertaken to investigate the optical, electrical, chemical and thermal properties of tungsten materials; as well as the characteristics of tungsten light bulbs [6]. Incandescent bulb is shown in **Figure 1**. The most modern light bulbs use argon as the inert fill gas, with a small amount of nitrogen to block the electrical conduction through a gas in an applied electric field. A solid must be heated red hot to over 800 K to emit visible light [7]. Incandescent lamps have lives, typically 1000 to 2000 hours of use. Incandescent lights remain popular because they produce a pleasant color which is similar to natural sunlight. Incandescent lightbulbs are the least expensive to buy. Incandescent lamps come in different shapes and sizes with different characteristics [8]. The incandescent light bulb, incandescent lamp, or incandescent light globe emits light when a filament wire is heated to a high temperature until it glows. These are manufactured in a wide range of sizes, light outputs, and voltage ratings, from 1.5 V to about 300 K. The light bulbs, in the early days, were vacuum-filled. The result will be the same, but the bulb's seals need to hold under a

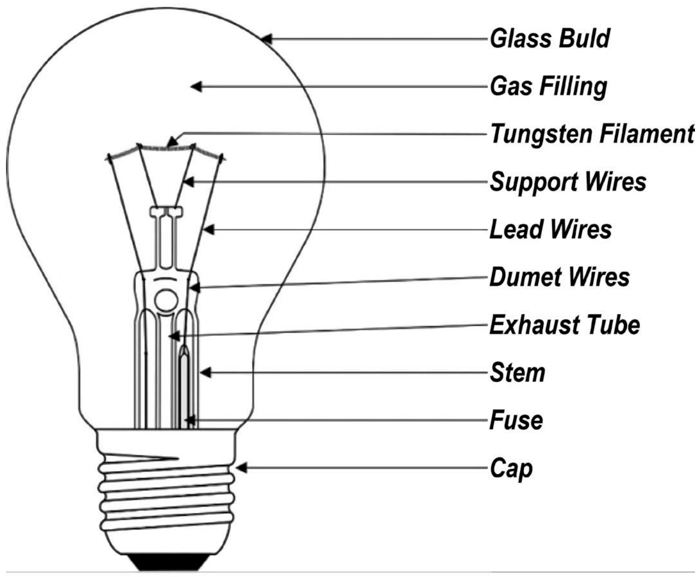

Figure 1. Incandescent bulb (Ref. [11]).

greater pressure difference than that of the outer air. The incandescent lamp is widely used in household and commercial lighting, for portable lighting such as table lamps, car headlamps, flashlights, and for decorative and advertising lighting [9].

The temperature of the filament increases due to Joule heating on biasing electrical current. An inert gas like argon is normally used to fill inside the bulb which prevents the tungsten filament from oxidizing, otherwise results in the catastrophic failure of the transducer [6]. The resistance of the straight wire tungsten filament R_{Wire} will depend on the operating temperature T of the filament [10].

1.3. Principle of Production of Electromagnetic Spectra in Filament Bulb

The radiation in the filament bulb is emitted by a process called incandescence. The electrical resistive heating creates thermally excited atoms. Some of the thermal kinetic energy is transferred to electronic excitations within the solid. The photonic emission occurs when the atoms from the excited states jump to the lower state [12]. When sufficient of the emitted radiation is in the visible spectrum, we can see an object by its own visible light; we say it is incandescing [12]. There is a near-continuum of electron energy levels in a solid. These result in a continuous non-discrete spectrum of radiation. All bodies emit electromagnetic radiation over a range of wavelengths. A cooler body radiates less energy than a warmer body. When a body is heated and its temperature rises, the perceived wavelength of its emitted radiation changes from infrared to red, then from red to orange, and so forth [12]. As the temperature rises, the body glows with the colors corresponding to even-smaller wavelengths of the electromagnetic spectrum. This is the underlying principle of the incandescent light bulb. A black body doesn't exist and is theoretical [13].

1.4. Electromagnetic Radiation Spectra

A hot metal filament glows red, and when heating continues, its glow eventually covers the entire visible portion of the electromagnetic spectrum. The temperature (T) of the object that emits radiation, determines the wavelength at which the radiated energy is at its maximum [14].

There are no sharp, well defined boundaries in the electromagnetic spectrum. Conventionally; the optical radiation range is defined as extending from 1 mm at the bottom end of the infrared to 100 nm at the upper end of the ultraviolet. In **Table 1** different types of radiations with their wavelength range are given. The main mechanisms that produce optical radiation are incandescence, electrical discharge, and lasing [14].

The colour of the radiations depends upon the wavelength of the emitted radiations. Emitted wavelength and temperature of the heating body are inversely proportional to each other [15].

The filament lamp will shine a reddish light at 2000 K because it emits the visible light of longer wavelength. At 3000 K, the filaments shine brighter and emit a yellow light of shorter wavelength [16].

Stefan-Boltzmann and Wein's displacement laws explain respectively, the intensity and color of light emitted by a body [15]. A continuum spectrum of light is emitted by a black body.

Visible light is a form of electromagnetic radiation which can be perceived by our eyes. Different visible colours of light with their wavelength limit have been shown in **Table 2**. The wavelength of visible radiations (Light) varies from 380

Table 1. Radiations with their wavelength [14].

Radiations	Wavelength range
Ultraviolet	100 - 400 nm
Light	380 - 400 to 760 - 780 nm
Infrared	760 - 780 nm to 1 mm

Table 2. The visible light spectrum [17].

Color	Wavelength (nm)
Red	625 - 740
Orange	590 - 625
Yellow	565 - 590
Green	520 - 565
Cyan	500 - 520
Blue	435 - 500
Violet	380 - 435

nm to 740 nm. Various spectral color bands make up light. The band from 100 nm to 400 nm is called ultraviolet radiation. The band from 710 nm to 1.5 micrometers is called near infrared and the band from 1.5 to 4.0 micrometers is called far infrared [15].

1.5. Planck's Law on Blackbody Radiation

The monochromatic radiant emittance and wavelength λ are related by the conventional spectrum curve of the blackbody thermal radiations [18] which is shown in **Figure 2**.

Planck found an empirical formula to explain the experimentally observed distribution of energy in the spectrum of a black-body [19].

Planck's formula is given by

$$E\mathrm{d}\lambda = \frac{8\pi hc}{\lambda^5} \cdot \frac{1}{\mathrm{e}^{\frac{hc}{\lambda kT}} - 1} \mathrm{d}\lambda \tag{1}$$

For Shorter wavelength $\mathrm{e}^{\frac{hc}{\lambda kT}}$ becomes large compared to unity and hence the Planck's law reduces to

$$E\mathrm{d}\lambda = \frac{8\pi hc}{\lambda^5} \cdot \frac{1}{\mathrm{e}^{\frac{hc}{\lambda kT}}} \mathrm{d}\lambda = \frac{8\pi hc}{\lambda^5} \cdot \mathrm{e}^{\frac{-hc}{\lambda kT}} \mathrm{d}\lambda$$

This is Wein's law [19].

For longer wavelength $\mathrm{e}^{\frac{hc}{\lambda kT}}$ may be approximated to $\left(1 + \frac{hc}{\lambda kT}\right)$ and hence the Planck's law reduces to

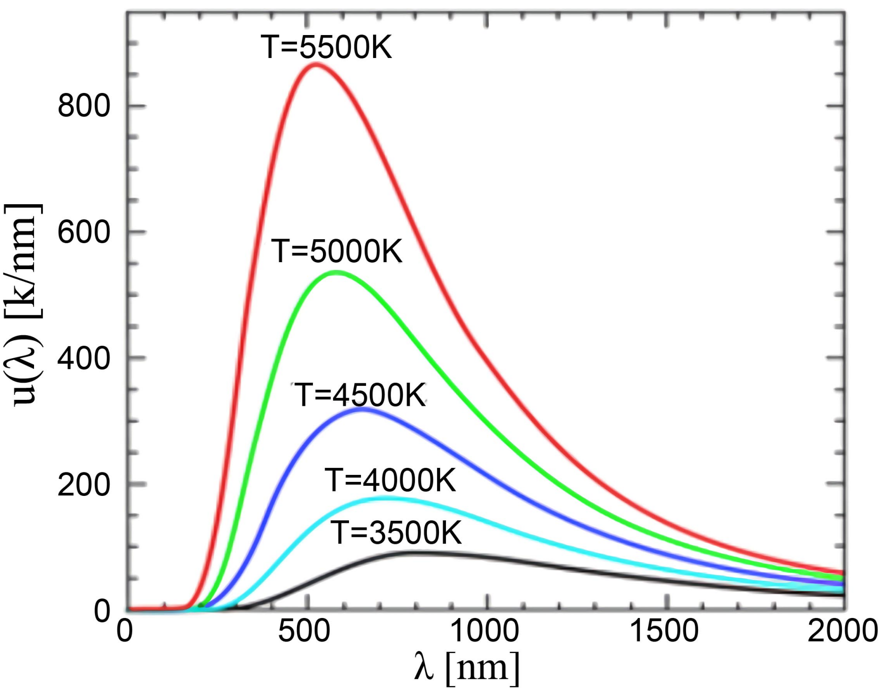

Figure 2. The traditional spectrum curve of the blackbody radiation [18].

$$E\mathrm{d}\lambda = \frac{8\pi hc}{\lambda^5}\frac{1}{1+\frac{hc}{\lambda kT}-1}\mathrm{d}\lambda = \frac{8\pi hc}{\lambda^5}\frac{1}{\frac{hc}{\lambda kT}}\mathrm{d}\lambda = \frac{8\pi hc}{\lambda^5}\frac{\lambda kT}{hc}\mathrm{d}\lambda = \frac{8\pi kT}{\lambda^5}\mathrm{d}\lambda \quad (2)$$

This is Rayleigh's Jeans law [19].

Thus we see that Wein's displacement law holds for shorter wavelengths while the Rayleigh's Jein's law holds for longer wavelength [19].

1.6. Resistance and Temperature Relation

For a temperature ranging from room to about 2500 K, tungsten filament obeys a linear relation between its resistance and temperature,

$$R(T) = R_0\left[1+\alpha(T-T_0)\right] \quad (3)$$

Where R_0 represents ambient resistance measured at temperature T_0 and α is temperature coefficient of resistivity. $R(T)$ is the resistance at temperature T [20].

1.7. Electromagnetic Spectrum

Electromagnetic radiation is a form of energy that is all around us and takes many forms, such as radio waves, microwaves, x-rays and gamma rays. The electromagnetic waves are divided into different ranges, depending on wavelength and corresponding frequency [21]. Electromagnetic waves have a vast range of practical everyday applications that includes such diverse uses as communication by cell phone and radio broadcasting, Wi-Fi, cooking, vision, medical imaging, and treating cancer [21].

2. Literature Review

2.1. Temperature and Emissivity

The emissivity of tungsten wire filaments in incandescent lamps change with wavelength. Tungsten wire is the key component of the incandescent lamp. The lamp shows better performance if the emissivity of the filament is higher [22]. The emissivity of tungsten filament lies above the 0.375 and below the 0.400 for the range of the wavelength between 550 nm above and 1000 nm below. Different values of spectral emissivity at different temperatures have been shown in **Table 3**. The maximum value of the emissivity is 0.400 for the color of light whose wavelength ranges between 650 nm and 700 nm [22].

The energy emitted per unit area per unit time depends upon the emissivity of the material. The total emissivity can be calculated by using the relation as below:

$$P = \varepsilon\sigma AT^4 \quad (4)$$

where ε is the total emissivity, σ is Stefan's Constant, A is the area of the tungsten, T is the temperature [5].

The bulb filament is not efficient at emitting blackbody radiation. The emissivity is defined as the ratio of energy radiated by a material to that radiated by

Table 3. Variation in spectral emissivity with temperature (Ref. [5]).

Temperature Degrees K (T)	Spectral Emissivity (ε)
2100	0.433
2200	0.431
2300	0.429
2400	0.427
2500	0.425
2600	0.423
2700	0.421
2800	0.419
2900	0.417
3000	0.415
3100	0.413

an ideal blackbody at the same wavelength and temperature. The emissivity and temperature of the filament has the relation of $\frac{1}{\varepsilon_{\text{filament}}\left(T_{\text{filament}}\right)}$ [6]. The body which has greater emissivity gets heated with a lower temperature. Temperature and emissivity of the material of the body are inversely proportional to each other. **Table 4** shows different values of resistivity at different temperatures. From a pure energy viewpoint, the heated filament is the place of the conversion of electrical energy into heat and electromagnetic radiation [22].

The performance of lamp depends upon the emissivity of filament. There is direct correlation between emissivity and illumination. The life of the filament depends strongly on the burning temperature. The key in measuring the filament temperature is the emissivity [22].

2.2. Stefan's Boltzmann Constant

The Stefan-Boltzmann constant σ has been evaluated by using an absolute radiometer of the electrical substitution type to measure the radiance of a cavity radiator at the freezing point of gold. The value obtained for σ is (5.6644 ± 0.0075) × 10^{-8} W·m^{-2}·K^{-4} [24].

2.3. Emission/Absorption Lines

An atom may be excited to a higher level due to the presence of sufficient energy. If this excited atom transits back to its ground state, this energy is then released at a characteristic frequency related to these two energy levels as shown in **Figure 3**. If E_0 is the energy of the ground state and E_1 is the energy of the first excited state then the atom in the first excited state releases energy when drops to the ground state. The released energy is equal to the difference in energy between these two levels [25]. The frequency of the emitted energy is given below:

Table 4. Value of resistivity of the filament with temperature (Ref. [23]).

Temperature (K)	Resistivity (μΩ·cm)
2100	60.06
2200	63.48
2300	66.91
2400	70.39
2500	73.91
2600	77.49
2700	81.04
2800	84.70
2900	88.33
3000	92.04

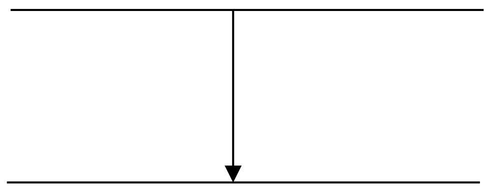

Figure 3. Basic energy level diagram showing emission energy.

$$E = hf = h\frac{c}{\lambda} = E_1 - E_0 \tag{5}$$

where h is the Planck's constant, f is the frequency, c is the velocity of light and λ is the wavelength of the emitted radiation.

2.4. Wavelength and Temperature

A blackbody can be described as an enclosed body which absorbs all the incident radiations upon it. When the blackbody is at equilibrium, it will emit radiation at the same rate as it absorbs radiation from the surrounding medium. Sometimes a blackbody is referred to as a complete absorber [25].

At a particular wavelength λ, the radiation emitted by a perfect blackbody radiator is described by Planck radiation law

$$I(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{\frac{-hc}{\lambda kT}-1}} \quad [7] \tag{6}$$

Yang X., Wei, B. studied the local spectrum characteristics of the blackbody thermal radiation based on the traditional spectrum curve. **Figure 4** describes how the wavelength of the emitted radiation varies with the temperature. On higher temperature of the black body, the wavelength of the emitted radiations is lower and vice-versa [18].

The wavelength of maximum emission of any body is inversely proportional to its absolute temperature. In this way, higher the temperature, the wavelength

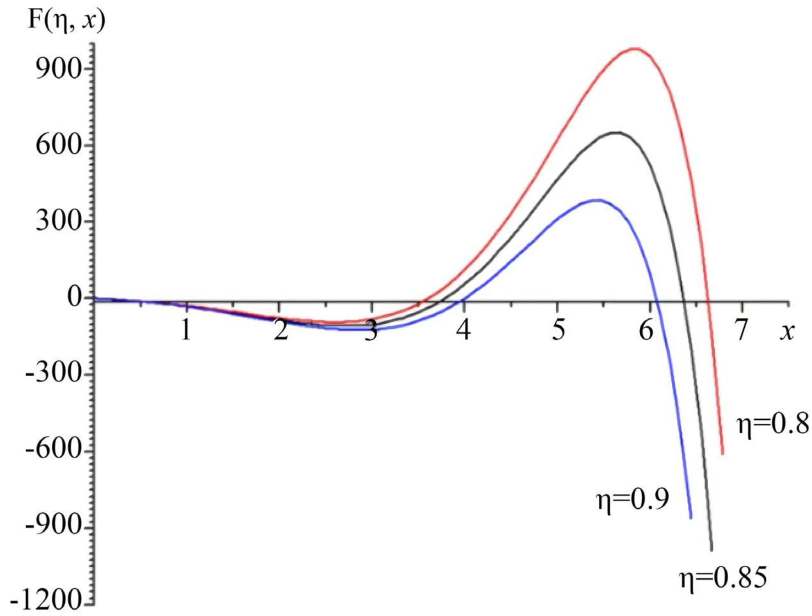

Figure 4. Spectrum curve of the blackbody thermal radiation [18].

of maximum emission is shorter. This condition is called Wein's law. Wein's law tells that if the temperature of a body increases, the wavelength of maximum emission becomes smaller [15].

The following equations describe this law;

$$\lambda_{\max} = \frac{b}{T} \tag{7}$$

where b is a constant equal to 2897 μm and T is the temperature in Kelvin.

3. Materials and Methods

Nine theoretical filament bulbs have been taken in this research work. These bulbs are chosen considering, they are the more frequently used bulbs in our daily life. The filament in the tungsten lamps has been assumed to be essentially a single-coil straight wire. The parameters length L, emissivity ε, and resistivity ρ are the functions of temperature shown in Equation (14). The 60 and 100 W lamps are basically coiled coil types [10]. Here the calculations are done under the assumption that they are coiled only once. The data produced are numerical, and they are analysed using mathematical and statistical methods. The research methods are based on quantitative techniques.

There are different techniques to determine the temperature of the filament bulb. In this work, the power of the filament bulb has been calculated in terms of voltage, radius of the filament wire, its length and resistivity using Equation (12). The relation between power and intensity is shown in **Figure 5**. The relation between resistance and current has been tabulated and its plot is shown in **Figure 6**. The temperature and wavelength relation is shown in **Figure 7**. The power and surface area relation is shown in **Figure 8**. The plot between spectral emittance and wavelength in **Figure 9** represents the nature of the classical blackbody

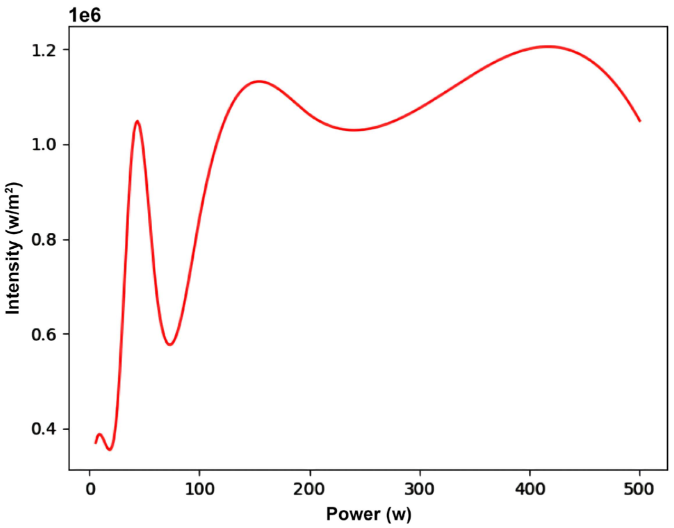

Figure 5. Dependence of intensity of radiations on power of the bulb.

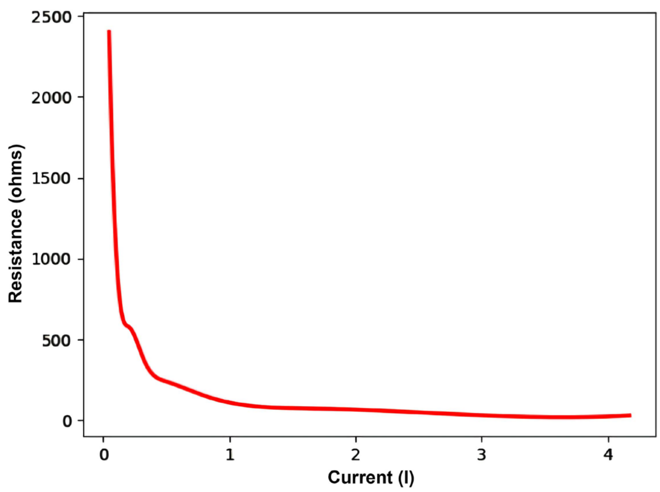

Figure 6. Dependence of current flowing through the filament with respect to the resistance of the wire.

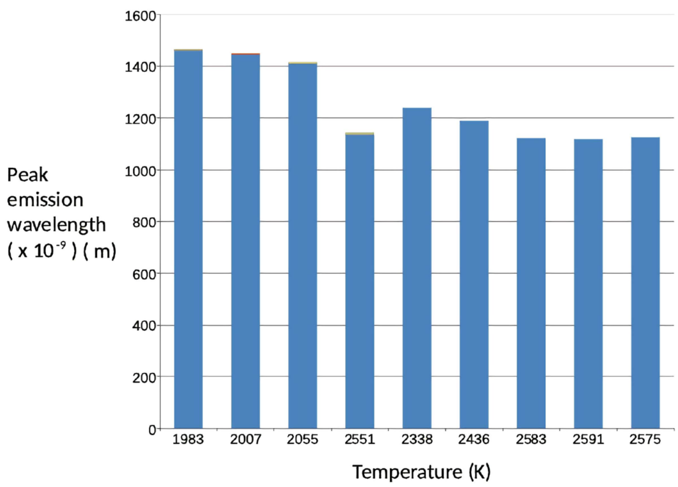

Figure 7. Dependence of peak emission wavelength on temperature.

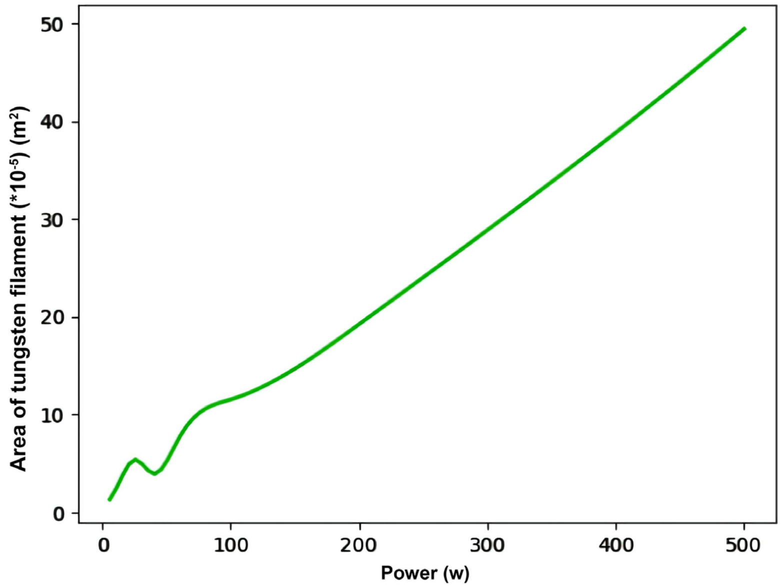

Figure 8. Dependence of power of bulb with surface area of the filament.

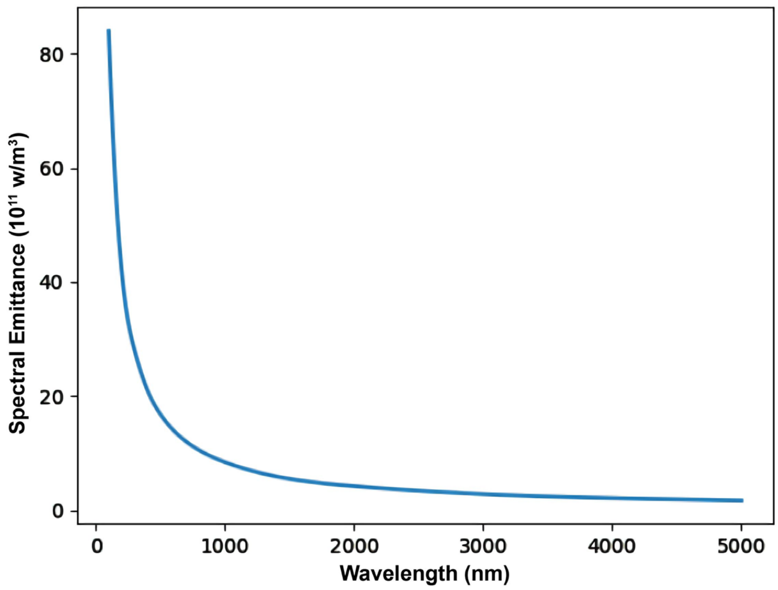

Figure 9. Dependence of spectral emittance on the wavelength.

radiation curve. Microsoft Power Excel 2010, and python programming has been used to plot the graphs. The different graphs at different temperatures, between spectral emittance and wavelength are plotted with the help of high resolution blackbody radiation calculator [26]. The radiation curve between spectral emittance and wavelength, have been shown only for three different wattage bulb, considering the radiation curve of other different wattage bulbs lie within the area of these curves. The radiation curve of 6 watt bulb, 100 watt bulb, and 500 watt bulb has been shown in Figures 10-12 respectively. The peak value of wavelength, at different particular temperature, has been calculated using Wein's displacement law. The different physical quantities like spectral radiance,

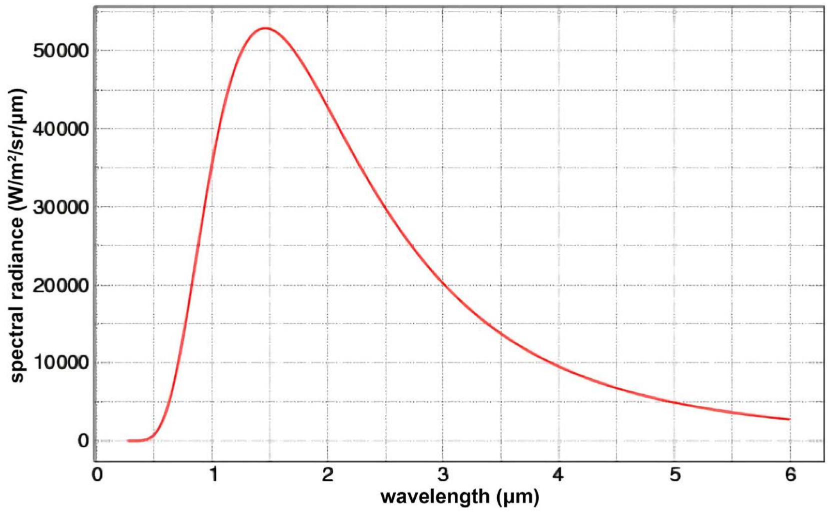

Figure 10. Probability distribution of the radiations emitted from 6 watt filament bulb.

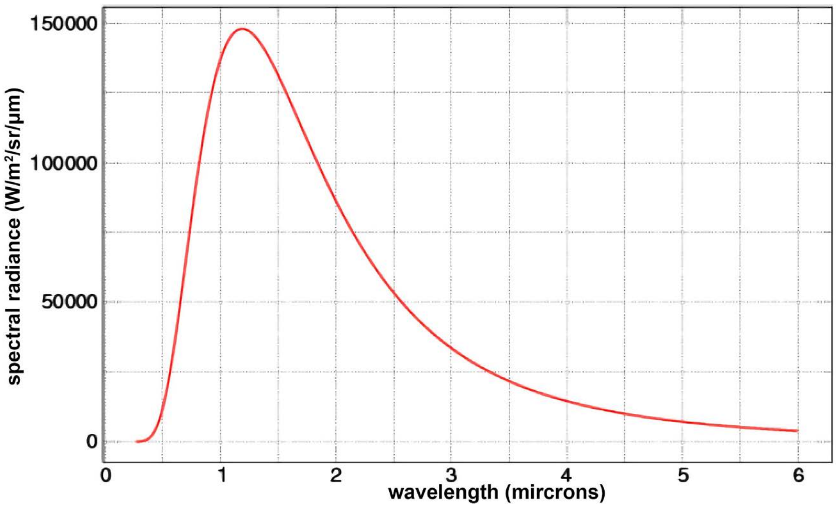

Figure 11. Probability distribution of the radiations emitted from 100 watt filament bulb.

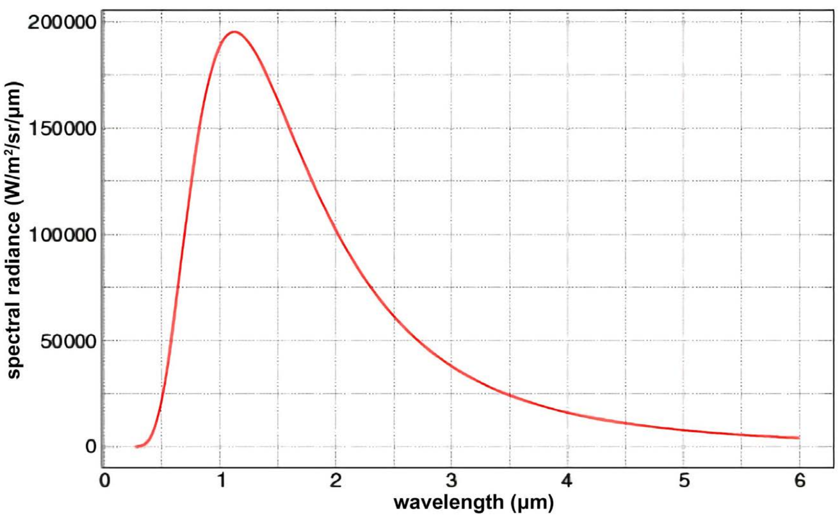

Figure 12. Probability distribution of the radiations emitted from 500 watt filament bulb.

radiant emittance, peak spectral radiance, band radiance, and wavelength of peak are calculated by using blackbody spectral calculator [26]. The lower limit and upper limit of wavelength, has been taken as 2.7×10^{-7} m and 6×10^{-6} m respectively. The model of choosing lower value and upper value of wavelength is based on the probability distribution (probability occurrence) of the spectrum of emitted radiations from filament bulb. The graph generated by using Hi-resolution spectral calculator [26] gives the Planck's blackbody radiation curve which has been shown in **Figures 10-12**. The statistical data between spectral emittance and wavelength has been shown for power curve fit. These data are obtained using "vernier spectral analysis software" [27].

3.1. Statistical Analysis Methods

Mean value, standard deviation, minimum value, maximum value, difference between extreme values of wavelength, difference between extreme values of spectral emittance, have been calculated using vernier spectral analysis software [27]. The wavelength has been plotted along x-axis, and the spectral emittance has been plotted along y-axis which is shown in **Figure 9**. The purpose of calculating standard deviation is to understand "how spread out a data set is". Curve fitting (Regression analysis) equation has been shown to find best fit line or curve for a series of data points. The equation obtained for curve fit can be used to find points anywhere along the curve. The graph between spectral emittance and wavelength shown in **Figure 9** satisfies the equation $y = ax^b$. Thus **Figure 9** satisfies power curve fit. Normal distribution is used for the probability of finding the wavelength in the certain wavelength limit. Normal distribution of 400 nm, 500 nm and 600 nm wavelength radiations are shown in **Figures 13-15** respectively.

Provided whole digits after decimal (of length and diameter) are included into research work. The provided value of length of filament used is in three decimal places, diameter of filament is in 6 decimal places. Calculated radius, from the

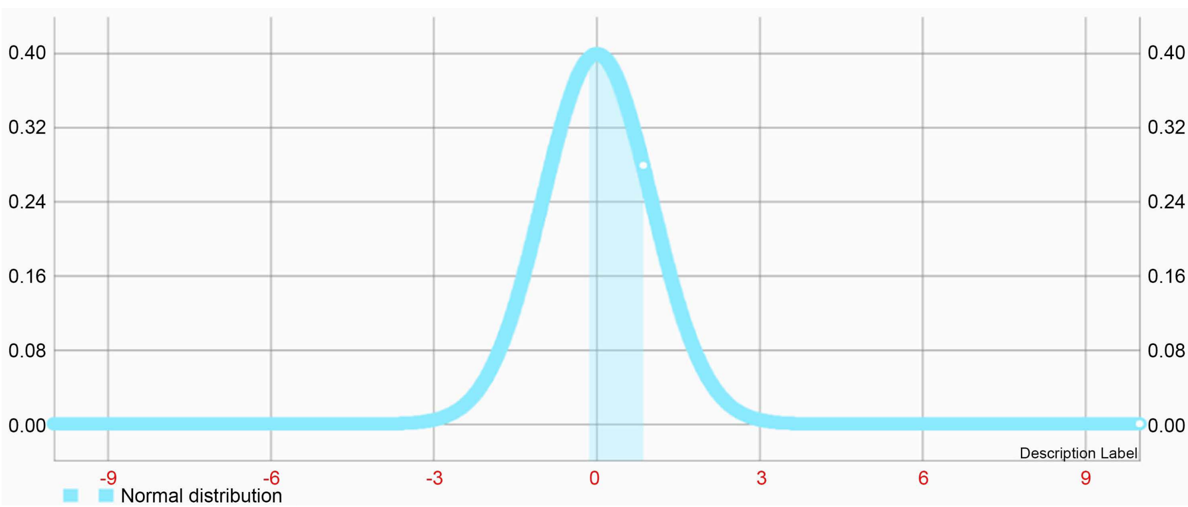

Figure 13. Normal distribution of 400 nm wavelength radiations.

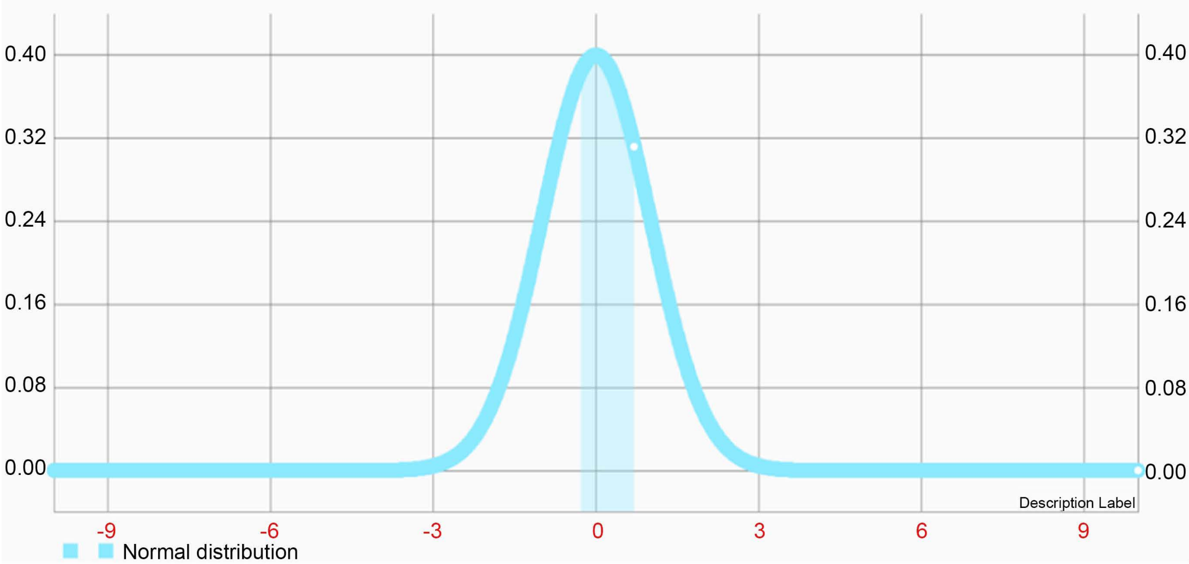

Figure 14. Normal distribution of 500 nm wavelength radiations.

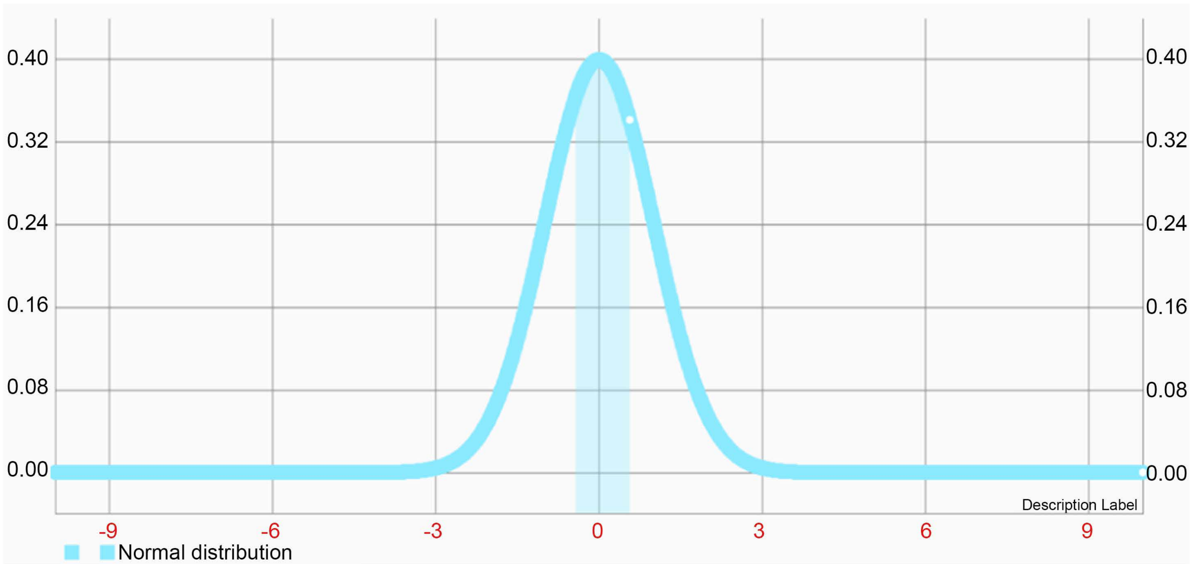

Figure 15. Normal distribution of 600 nm wavelength radiations.

provided value of diameter, has been kept in seven decimal places. The purpose of including almost all digits after decimal, of these physical quantities, is to minimize the possible error that may occur during calculation. Scientific calculator has been used to calculate radius of tungsten filament, current flowing in filament, power dissipated in filament, and surface area of filament. Normal distribution application is used to plot the distribution curve.

3.2. Temperature Calculation Methods

When a light bulb is turned on using a switch, a constant (ac) voltage V of 120 V is applied across the filament. Since the filament has a high resistance, because of its fine diameter and long length (see Equation (11)), a small amount of current flows through the filament according to Ohm's law

$$V = IR \tag{8}$$

where I is current, V is voltage across the filament and R is resistance of the filament [28]. The filament then becomes hot, since amount of power P produced in the filament is

$$P = \frac{V^2}{R} \tag{9}$$

Since voltage is a constant in our electrical distribution system, the form of equation for the power dissipated in a resistor should be that shown in Equation (9), and should not be $P = I^2 R$. Since V is a constant, Equation (9) relates one variable R to another variable P. If the equation $P = I^2 R$ was used, then P, I and R would all be variables. The filament is compared to a theoretical blackbody radiator. The total power emitted per unit surface area (A) of a hot object at temperature T (in Kelvin) is given by the Stefan-Boltzmann law [24]:

$$\frac{P}{A} = \varepsilon \sigma T^4 \tag{10}$$

where, σ is called Stefan-Boltzmann constant, and has the value 5.67 × 10^{-8} W/(m^2-K^4). The emissivity ε is a material dependent quantity. For tungsten, value of ε is taken as 0.421 assuming that the temperature of filament reaches to about 2700 K [5]. For a long cylindrical filament of radius r and length L, the cross sectional area A is πr^2 and the surface area S is $2\pi rl$. End effects are ignored in surface area of the tungsten filament. The electrical resistance R of material is given by

$$R = \frac{\rho L}{A} \tag{11}$$

Combining Equation (9) and Equation (11), the power dissipated in the filament can be written as

$$P = \frac{V^2 \pi r^2}{\rho L} \tag{12}$$

Since voltage in our houses is fixed, it is apparent from Equation (9) that for higher wattage bulbs, electrical resistance of the filament must decrease as bulb wattage increases. From Equation (11), R can be decreased by increasing A (*i.e.* r^2) or by decreasing L. Therefore, for higher wattage bulbs, it is necessary to either increase r or decrease L. From the Stefan-Boltzmann law [29], the power emitted by the filament can also be written as

$$P = \varepsilon \sigma T^4 \left(2\pi rL\right) \tag{13}$$

From Equation (13), we can see that the bulb wattage (brightness), filament temperature (life time), filament radius and length are all interdependent. The surface area of the filament can be maximized by increasing r. From Equation (13), if the power is increased, it is desirable to increase r and L to minimize increase in temperature T. Equation (12) and Equation (13) can be equated and we get

$$T^4 = \frac{V^2 r}{2\varepsilon\sigma\rho L^2} \tag{14}$$

The Equation (14) shows interdependence of filament temperature, radius and length. Tungsten filament emissivity directly affects relationship between surface temperature of a filament and its thermal radiation spectrum.

3.3. Secondary Data Acquisition

Table 5 is the operating data on standard lamps. All lamps quoted here are single coiled except 60 and 100 watts lamps which are double coiled. Table 5 shows length and diameter of the filament of different watts.

All digits after decimal are taken, to calculate the surface area of the filament. The obtained digits after decimal are 10 in 6, 10, 25, 40, 60, 100, 200, 300 watt bulb and nine digits in 500 watt bulb. So, the error in the calculation is expected to minimum. The temperature of glass that surrounds the filament is taken to be very small in compared to the temperature of the tungsten filament. So the energy emitted per unit area per unit time (Intensity of the radiations) is supposed to be dependent upon the temperature of the tungsten filament.

3.4. Wavelength Calculation Methods

There is no any theoretically derived direct equation, to calculate the wavelength of the emitted radiations from the filament bulb. So since the filament bulb acts as a source of black body, Wein's displacement law in Equation (15) is used to calculate the peak wavelength of the emitted radiation. Although, Wein's displacement law in Equation (15) is used only for higher energy and shorter wavelengths, the law is used, considering the spectrum of the radiations from the filament bulb that may consist of very few fraction of visible light at the shorter wavelengths. The ultraviolet radiation (320 - 340 nm), lie in shorter wavelength [30]. Some authorities extend the short wavelength limit to 400 nm which falls upon visible range.

Table 5. Different wattage bulb with their filament length and diameter (Ref. [10]).

Lamp watt P	Length L cm	Diameter D cm
6	37.084	0.001143
10	43.180	0.001626
25	56.388	0.003048
40	38.100	0.003302
60	53.340	0.004572
100	57.912	0.006350
200	63.500	0.009652
300	72.390	0.012700
500	87.376	0.018034

The wavelength of the emitted radiation has been calculated by using the following relation.

$$\text{Wavelength}(\lambda) = \frac{hc}{4.965kT} \tag{15}$$

where h is the Planck's constant, c is the velocity of light, k is the Boltzmann's constant, and T is the temperature of the body.

3.5. Wavelength Selection Method

There is a distribution of different photons of various different energies. The peak of the distribution tells us that which of these photons occurs at the greatest amount at the given temperature. The traditional spectrum curve in **Figure 2** and spectrum curve of black body radiation in **Figure 4** are used to find the probability distribution of the entire spectrum in varying wavelength range. For example, wavelength of the most of the emitted radiation from the filament bulb has the value of the order of 10^{-6}. This means maximum of the emitted radiations lie in the near infrared region. The work is also based on the model that, "Probability occurrence of the visible light is the quantum result".

The work is based on the fact that, "No radiations have actual value of wavelength". They are all approximate. There is no any strong evidence that could be justified by theoretical and experimental procedure on the validity of the provided value of the wavelength which we are using on these days. Thus the various values of the wavelength (which I have mentioned above in the introduction and in the literature review) fall within certain particular range are only probabilistic.

To find the percentage of the wavelength range of the emitted radiations from the filament bulb, the total number of square divisions on the graph was counted. The total numbers of square divisions are supposed as 100%. Since the curve does not occupy exactly integral square division; Fractional divisions are also taken into calculation. Calculation was done manually. Even, one fifth of a square division has been included in counting.

4. Results and Discussion

The value of emissivity is taken as 0.421 assuming the filament temperature reaches to about 2700 K. The value of resistivity is taken to be about 8.104×10^{-7} ohm-m. The current passed depends upon the resistance of the filament. The resistance can be varied by varying the length and diameter of the filament. The only constant parameter is applied voltage.

4.1. Temperature Measurement Calculation

The temperature of the filament depends upon the applied voltage, emissivity, radius, length, resistivity of the filament, and the value of Stefan's constant. The temperature of the filament, when the bulb is on, is calculated by using Equation (14). The supplied voltage is constant. In **Table 6** the calculated value of temperature is shown.

Table 6. Calculation of temperature.

Length L cm	Diameter D cm	Radius r cm	Temperature in Kelvin (K) $T^4 = \frac{V^2 r}{2\varepsilon\sigma\rho L^2}$	Bulb Power P watt
37.084	0.001143	0.0005715	1983	6
43.180	0.001626	0.0008130	2007	10
56.388	0.003048	0.0015240	2055	25
38.100	0.003302	0.0016510	2551	40
53.340	0.004572	0.0022860	2338	60
57.912	0.006350	0.0031750	2436	100
63.500	0.009652	0.0048260	2583	200
72.390	0.012700	0.0063500	2591	300
87.376	0.018034	0.0090170	2575	500

The temperature of the heating filament depends upon its length and the diameter. So the power of the bulb depends upon the length and diameter of the filament. The volume of the material of the filament and the surface area of the filament increases, if the power of the bulb increases, except for 25 watt and 40 watt bulb. The volume and surface area of 25 watt bulb is greater than the 40 watt bulb. But the interesting factor is that the temperature of 40 watt bulb is greater than the 25 watt bulb. Thus in the above result from Table 6, it can be concluded that at least one factor should exceed for the power to be fixed.

4.2. Resistance, Current, Power, and Surface Area Measurement Calculation

At constant voltage, the value of resistance depends upon the power of the bulb. So the current flowing through the filament varies with resistance. The power of the bulb in column (5) of Table 7 is the calculated value. This value is similar to the calibrated power in the bulb. The voltage supplied is constant.

The resistance is maximum in the lower wattage bulb and minimum in the higher wattage bulb which can be observed in Table 7. The resistance varies inversely with the power of the bulb. The current passing through the filament increases if the power of the bulb increases which can be known from Table 7. So the current flowing through the filament must be greater for higher wattage bulb.

4.3. Intensity Measurement Calculation

The calculated values of energy emitted per unit area per unit time (Intensity) from each wattage bulb are shown in Table 8. The values are obtained by using Equation (13). The intensity of the radiations depends upon the temperature of the filament as shown in Equation (13). The value of intensity is used to find the spectral emittance (energy density). The different values of intensity at different power are given in Table 8.

Table 7. Calculated resistance, area, current, and power of the filament.

Bulb Wattage (P)	Resistance $R = \frac{V^2}{P}$	Operating voltage (V)	Current (I)	Power dissipated in the filament (P) = I^2R	Area of the tungsten filament (A) = $2\pi rl$ in m^2
6	2400	120	0.05	6	0.0000133095
10	1440	120	0.0833	10	0.0000220462
25	576	120	0.20833	25	0.0000539674
40	360	120	0.33333	40	0.0000395031
60	240	120	0.5	60	0.0000765753
100	144	120	0.8333	100	0.0001154707
200	72	120	1.67	200	0.0001924512
300	48	120	2.5	300	0.0002886768
500	29	120	4.17	500	0.0004947820

Table 8. Calculation of intensity (total radiant flux) from power.

Power (P) in watt	Intensity (I) in W/m^2
6	369,110
10	387,306
25	425,709
40	1,010,897
60	713,252
100	840,571
200	1,062,583
300	1,075,808
500	1,049,480

The result of the intensity for each wattage bulb, shown here in **Table 8**, is of unit meter square. There is fluctuation in the value of intensity of the emitted radiation in the sense that they are not in ascending order with respect to the power. But the intensity calculated for each wattage bulb from their actual surface area follows ascending order with respect to their power.

The illuminating areas of the surface from which the radiations are emitted depend upon the length and diameter of the tungsten filament of the incandescent bulb. Here in **Table 6**, the illuminating surface of the 60 watt bulb has greater length and diameter, than the 40 watt bulb although the temperature of the heating filament is greater in case of 40 watt bulb than 60 watt bulb. Intensity per meter square is greater in 40 watt bulb than in 60 watt bulb but in real, intensity is greater in 60 watt bulb than in 40 watt bulb because the surface area of 60 watt bulb is 0.0000765753 m^2 (see **Table 7**) and the surface area of 40 watt bulb is 0.0000395031 m^2 (see **Table 7**). Similar fact is observed in case of 300 watt bulb and 500 watt bulb. The temperature of 300 watt bulb is greater than

500 watt bulb but the surface area of the filament in 500 watt bulb is greater than the 300 watt bulb. So temperature only does not keep importance in the total intensity determination but also the surface area of the heating filament.

4.4. Resistance and Current

The resistance and current variation is shown in **Table 7**. From **Table 7**, it can be concluded that resistance and current satisfies inverse relation. The current is along x-axis, and the resistance is along y-axis which is shown in **Figure 6**.

Lower the value of filament resistance, greater is the flow of electric current. The higher wattage bulb has lower resistance filament and maximum current flow. The fall in resistance with respect to the lower wattage bulb is greater than the fall in resistance for higher wattage bulb. The change between any two resistances is greater for lower wattage bulbs than higher wattage bulbs as shown in **Figure 6**. The resistance and current has inverse graphical nature. There is sharp fall in resistance from 6 watt bulb to 40 watt bulb. The fall in resistance is low if the power increases. The graph tends to show the asymptotic behavior after 200 watt bulb which can be seen in **Figure 6**. Since, the difference between two resistances goes on decreasing on increasing power of the bulb; the curve seems to be shifted from its discrete nature to continuous nature. The slope of the curve decreases. The graphical behavior in **Figure 6** is asymptotic.

$\frac{\Delta R}{\Delta P}$, cannot be zero, because ΔR cannot be made zero. This means that power of the filament bulb cannot be increased by lowering the resistance after certain limit.

4.5. Temperature and Wavelength

The value of emissivity does not largely affect the value of the temperature. The Wein's displacement law is considered to verify the statement and is preceded as below:

$$\text{Wavelength}(\lambda) = \frac{hc}{4.965kT}$$

For $\varepsilon = 0.421$, $T = 1983\ \text{K}$

$$\text{Wavelength}(\lambda) = \frac{6.62\times10^{-34}\times3\times10^{8}}{4.965\times1.38\times10^{-23}\times1983} = 1.46\times10^{-6}\ \text{m}$$

Similarly, when $\varepsilon = 0.386$, (which is effective emissivity and is equal to the 90% of the 0.421), the value of temperature found to be 2027 K. So, on using

$$\text{Wavelength}(\lambda) = \frac{6.62\times10^{-34}\times3\times10^{8}}{4.965\times1.38\times10^{-23}\times2027} = 1.43\times10^{-6}\ \text{m}.$$

The wavelength, on two different values of emissivity is not largely affected. The percentage error in the two values of the temperatures with different emissivity (% error) = 2.2 {the two temperatures taken here for the calculation are 1983 K and 2027 K}.

The value of the emissivity lies within the range of 0.413 to 0.470, depending on the temperature of the heating filament [given in Table 3].

The temperature and peak emission wavelength relation is illustrated in Figure 7.

It can be observed from Table 9, the peak emission wavelength of radiations emitted from filament lamp lies in the order of 10^{-6} m. From this point of view, it can be estimated that the emitted radiations from the filament bulb carries few visible radiations and most infrared radiations. Shorter wavelengths are emitted when the temperature of the heated filament goes on increasing. The peak emission wavelength is greatest for 6 watt bulb heated at temperature 1983 K which is shown in Table 9. Most of the emitted radiations from 6 watt bulb lie in infrared radiations.

4.6. Power, Volume and Surface Area Profile

In this section, the bulb power is discussed on the basis of surface area, and volume of the material of tungsten filament. The surface area of the filament affects its temperature. Table 10 shows how the surface area and volume of the material of filament are related to power of the bulb. Table 10 shows volume of the material of the filament and the surface area of the tungsten filament for different power of the bulb.

The relation between the power of the bulb and the surface area of the filament is illustrated in Figure 8.

Higher the power of the bulb, higher is the surface area of the filament as calculated in Table 7. But the case is different in 25 watt and 40 watt bulb which can be found in Table 7. The 40 watt bulb's filament has lower surface area than 25 watt bulb's filament but the temperature of the heating filament in 40 watt bulb is highly greater than that of 25 watt bulb as found in Table 6. At least one factor is important in fixing the power of the bulb, "either temperature or surface area" of the filament.

Table 9. Evaluation of peak emission wavelength from temperature.

Temperature (T) in Kelvin	Peak emission wavelength $\lambda_{\max} = \frac{hc}{4.965kT}$ (in meter)
1983	1.461×10^{-6}
2007	1.444×10^{-6}
2055	1.410×10^{-6}
2551	1.136×10^{-6}
2338	1.239×10^{-6}
2436	1.189×10^{-6}
2583	1.122×10^{-6}
2591	1.118×10^{-6}
2575	1.125×10^{-6}

Table 10. Power, volume and surface area profile.

Power dissipated in the filament (P) = I^2R (in watt)	Volume of the material of the filament (v) = $\pi r^2 l$ (in m^3)	Surface area of the tungsten filament (A) = $2\pi rl$ (in m^2)
6	3.8032×10^{-11}	0.0000133095
10	8.9620×10^{-11}	0.0000220462
25	4.0000×10^{-10}	0.0000539674
40	3.0000×10^{-10}	0.0000395031
60	9.0000×10^{-10}	0.0000765753
100	1.8000×10^{-9}	0.0001154707
200	4.6000×10^{-9}	0.0001924512
300	9.2000×10^{-9}	0.0002886768
500	2.2300×10^{-8}	0.0004947820

4.7. Wavelength and Spectral Emittance

In this section I have discussed the behavior of the radiations emitted from the filament bulb on the basis of the parameters: wavelength and spectral emittance. The value of spectral emittance of radiations for different value of wavelength can be calculated by taking the ratio of the intensity of the emitted radiations (at a particular temperature) and wavelength. The plot between spectral emittance and wavelength in **Figure 9** are shown only for 100 watt bulb. The radiations emitted from different wattage bulbs exhibit similar behavior. The different values of spectral emittance at different wavelength are given in **Table 11**.

Spectral Emittance and Wavelength Plot

Figure 9 shows the variation of spectral emittance with wavelength. The extreme values of wavelength along x-axis are 100 nm and 2500 nm. Similarly, the extreme values of spectral emittance along y-axis are 1.68×10^{11} W/m^3, and 84×10^{11} W/m^3.

The spectral emittance and wavelength plot fits more accurately in power curve. The power curve equation is satisfied by the form $y = ax^b$. The root mean square error in power curve fitting is 0.002996. The value of power b in x^b, is −0.9999, which is constant. The value of co-efficient a is 8397.

Statistics for the plot between spectral emittance, and wavelength, in power curve fitting

x-Range = 100 - 2500 nm

$y = ax^b$

$a = 8397$

$b = -0.9999$

RMSE = 0.002996

Standard deviation = 21.959

Mean = 14.632×10^{11} W/m^3

Minimum = 3.360×10^{11} W/m^3@2500.000 nm

Maximum = 84.000×10^{11} W/m^3@100 nm

Table 11. Dependence of spectral emittance with wavelength.

Wavelength (nm)	Spectral Emittance (W/m^3)
100	8.4×10^{12}
200	4.2×10^{12}
300	2.8×10^{12}
400	2.1×10^{12}
500	1.68×10^{12}
700	1.2×10^{12}
1000	8.4×10^{11}
2000	4.2×10^{11}
3000	2.8×10^{11}
4000	2.1×10^{11}
5000	1.68×10^{11}

The root mean square error is less in power curve fitting. The power curve equation is $y = ax^b$. The spectral emittance and wavelength curve is satisfied by the power curve equation.

The above curve in **Figure 9** obeys Rayleigh's jeans law of blackbody. The nature of the curve does not mean to tell anything about the spectrum of the emitted radiations. The curve does not give any idea about the presence of visible radiations. But the radiations from the filament bulb form an electromagnetic spectrum. So modeling a concept "the probability distribution of radiation energy density", the radiations from the bulb are explained on the basis of the radiated power density plank law which is discussed below.

4.8. Filament Lamp Emission Curves

Here I have discussed the blackbody radiation curve for 6, 100, 500 watt bulb. The value of radiant emittance, radiance, peak spectral radiance, wavelength of peak, spectral radiance, band radiance, are calculated for these bulbs. These values show the probability distribution of the radiation energy density. The value of lower limit and upper limit of wavelength are taken respectively 0.27 μm and 6 μm respectively. These values are chosen because they contain all possible wavelengths (both shorter and longer) that may emit from the bulb.

4.8.1. Blackbody Radiation Curve for 6 watt Bulb

The results obtained in this section are for 6 watt bulb. The 6 watt bulb filament gets heated at temperature 1923 K. The value of peak wavelength obtained is 1.4613 μm. The value of radiance per m^2 per steradian is 117,502 watt. About 7.35485e+18 photons are required for one joule of energy in 6 watt bulb.

Inputs	Results
Temperature: 1983 K	Radiant emittance: 369,144 w/m^2
Emissivity: 0.421	Radiance: 117,502 w/m^2/sr

Continued

Wavelength: 1.461×10^{-6} m	Peak Spectral radiance: 52873.2 w/m^2/sr/μm
Lower limit: 2.7×10^{-7} m	Wavelength of peak: 1.4613 μm
Upper limit: 6×10^{-6} m	Spectral Radiance: 52873.2 w/m^2/sr/μm
	(7.35485e+18 photons/J)
	Band Radiance: 110907 w/m^2/sr

In 6 wattage bulb, no radiations exist 0.5 μm below which can be concluded from Figure 10. Since the wavelength, of cyan colour is 500 - 520 nm , of blue colour is 435 - 500 nm, and of violet colour is 380 - 435 nm, no wavelength of these colors are observed in the spectrum of the radiations emitted from the 6 watt bulb. The negligible amount of green and yellow colour of light is observed. The emitted red colour of light exists comparatively in greater amount which can be observed from Figure 10.

4.8.2. Blackbody Radiation Curve for 100 Watt Bulb

The results obtained in this section are for 100 watt bulb. The 100 watt bulb filament gets heated at temperature 2436 K. The value of peak wavelength obtained is 1.18955 μm. The value of radiance per m^2 per steradian is 267,587 watt. About 5.98557e+18 photons are required for one joule of energy in 100 watt bulb.

Inputs	Results
Temperature: 2436 K	Radiant emittance: 840,649 w/m^2
Emissivity: 0.421	Radiance: 267,587 w/m^2/sr
Wavelength: 1.189×10^{-6} m	Peak Spectral radiance: 147,914 w/m^2/sr/μm
Lower limit: 2.7×10^{-7} m	Wavelength of peak: 1.18955 μm
Upper limit: 6×10^{-6} m	Spectral Radiance: 147,914 w/m^2/sr/μm
	(5.98557e+18 photons/J)
	Band Radiance: 258,694 w/m^2/sr

In 100 wattage bulb, all the radiations beyond peak value of wavelength (*i.e.* 1.189×10^{-6} m) lie in the infrared region which can be seen from Figure 11. No radiations exist below 0.4 μm. This means radiations having wavelength below 0.4 μm which fall in ultraviolet regions do not exist. Extremely small quantity of radiations having wavelength 0.5 μm, and below are noticeable. The probability of finding ultraviolet radiations cannot be expected. The probability of finding radiations having wavelength equal to red light is maximum. Most of the radiations emitted are invisible. About 13 percentages of the emitted radiations has wavelength 1×10^{-6} m below. About 5 percentages of the emitted radiations exists within wavelength range 0.5 μm and 0.75 μm. In total, about 8% of the emitted radiations fall in visible range.

Violet colour of light is not emitted in 100 watt bulb. Blue colour is found in extremely negligible amount in the spectrum of the visible radiations. The spectrum of other colour of light including negligible amount of blue colour, is observed in 100 watt bulb.

4.8.3. Blackbody Radiation Curve for 500 Watt Filament Bulb

500 watt bulb filament gets heated at temperature 2575 K. The value of peak wavelength obtained is 1.12534 μm. The value of radiance per m^2 per steradian is 334,091 watt. About 5.66338e+18 photons are required for one joule of energy in 500 watt bulb. The intensity of the emitted radiations is 1.04958e+06 watt in 500 watt bulb.

Inputs	Results
Temperature: 2575 K	Radiant emittance: 1.04958e+06 w/m^2
Emissivity: 0.421	Radiance: 334,091 w/m^2/sr
Wavelength: 1.125×10^{-6} m	Peak Spectral radiance: 195,213 w/m^2/sr/μm
Lower limit: 2.7×10^{-7} m	wavelength of peak: 1.12534 μm
Upper limit: 6×10^{-6} m	Spectral Radiance: 195,213 w/m^2/sr/μm
	(5.66338e+18 photons/J)
	Band Radiance: 324,483 w/m^2/sr

In 500 wattage bulb, all the radiations beyond peak value of wavelength (*i.e.* 1.125×10^{-6} m) lie in infrared region which can be known from **Figure 12**. No radiations exist towards left from 0.4 μm. This means radiations having wavelength below 0.4 μm which fall in the ultraviolet region does not exist. Extremely small quantity of radiations having wavelength 0.5 μm, and below are noticeable. The probability of finding ultraviolet radiations cannot be expected. The probability of finding radiations having wavelength equal to red light is maximum. Most of the radiations emitted are invisible. About 18.5 percentages of the emitted radiations has wavelength below 1×10^{-6} m. About 13 percentage of the emitted radiations, fall between 0.75 μm and 1 μm. About “6” percentage of the emitted radiations, fall in the wavelength range, between 0.5 μm and 0.75 μm.

About 11% of the emitted radiations fall within the spectrum of the visible range. Extremely negligible amount of the wavelength of violet colour can be expected in the spectrum of the radiations of the 500 watt bulb. About 89% of the emitted radiations fall in infrared and other higher wavelength region.

When the radiation curves in **Figures 10-12**, of 6, 100, and 500 watt respectively are compared, the amount of infrared radiations emitted is seen greatest in 500 watt bulb and least in 6 watt bulb. The radiation curve is more flattened in 6 watt bulb and less flattened in 500 watt bulb. This is due to the lower value of peak emission wavelength in 500 watt bulb than 6 watt bulb.

The radiant emittance depends upon the intensity of the emitted radiations. Here, the 500 watt bulb has the greatest radiant emittance than the lower wattage bulb (6 watt) bulb. The spectral radiance also goes on increasing with increase in the power of the bulb. More clearly, the energy emitted by a surface into a solid angle, in a specific direction, in a unit time interval, by a unit projected area, over a unit wavelength interval is greater in higher wattage bulb (500 watt) than the lower wattage bulb (6 watt bulb). The number of photons per joule is greater in 6 wattage bulb than the 500 wattage bulb. The number of photons required for one joule for lower wattage bulb (6 watt) is greater than the higher wattage bulb (500 watt) bulb. Since, number of photons per joule (or per energy) depends directly on the wavelength of the emitted radiation, more numbers of photons are required for one joule of energy in 6 watt bulb than in 500 watt bulb. More strictly, comparatively few amounts of shorter wavelength radiations are emitted in lower wattage bulb than in higher wattage bulb. The higher value of spectral radiance in 6 watt bulb indicates that there is more distribution of longer wavelength radiations than shorter wavelength distribution. The lower value of spectral emittance in 500 watt bulb indicates that there is more distribution of shorter wavelength radiations than longer wavelength distribution.

5. Statistical Analyses

The error between two values of the resistance for the same wattage bulb is due to the value of the resistivity. The value of resistivity of the tungsten filament varies with the temperature, but we have taken same particular value of resistivity for different wattage bulbs, which gets heated at different temperatures after passing current. For example, the difference in the value of resistance for 6 wattage bulb (obtained by two ways) is greater in comparison to the higher wattage bulb. That is because the 6 wattage bulb gets heated at a lower temperature than higher wattage bulbs. So the value of the resistivity taken in the calculation (on using $R = \frac{\rho L}{A}$) is to be lowered.

The root mean square error (RMSE) is less in power curve fitting than inverse curve fitting. The root mean square error in power curve fitting is 0.002996, and in inverse curve fitting, the root mean square error is 0.003218. The points fit more exactly in power curve. The equation for power curve is $y = ax^b$. The value of a is 8397 and b is −0.9999. The value of x varies from 100 - 2500 nm.

In inverse curve fitting, the points are justified by the equation $y = \frac{a}{x}$, where $a = 8400$ and RMSE is 0.003218.

Normal Distribution

The probabilities of finding the particular wavelength in the certain range are calculated below. The probabilities of finding the wavelength 400, 500, and 600 nm wavelengths of visible radiations are only discussed here and are shown in **Figures 13-15** respectively. The lower and upper limits are taken 0.3 μm and 1 μm respectively. The probability depends upon the mean value, standard deviation, value of lower limit and value of upper limit. The parameters taken to calculate the probability of obtaining the mean value satisfies the result. Other results can also be verified in a similar way by varying the parameters, since all parameters (value of lower limit, value of upper limit, standard deviation, and mean value) can be taken as variables. The area under the curve represents the total probability "1". The highlighted area under the curve represents the probability occurrence of the particular wavelength within certain range.

1) 400 nm Wavelength

Here, probability of finding 400 nm wavelengths in the range between 0.3 μm, and 1 μm is discussed. The spread value is 0.7 μm.

Lower limit (a) = 0.3×10^{-6} m

Upper limit (b) = 1×10^{-6} m

Standard deviation (σ) = 0.7×10^{-6}

Mean value (μ) = 400 nm

Probability = 0.35801

The blue colour area under the curve in **Figure 13** is located around mean which represents occurrence of maximum probability. Narrow distribution implies that the probabilities are higher that values won't fall far from the mean. The probability of finding radiations of wavelength 400 nm in the limit between 0.3 μm, and 1 μm is 0.35801. About 35.801 percentages of the radiations having wavelength 400 nm exists in the range between 0.3 μm, and 1 μm.

Total probability = probability of finding 400 nm wavelength + probability of finding other wavelength except 400 nm wavelength.

Probability of finding other wavelength except 400 nm wavelength = Total probability − probability of finding 400 nm wavelength = 1 − 0.35801

= 0.64199

= 64.199%

The probability of finding other wavelengths between 0.3 μm and 1 μm except 400 nm wavelength is 64.119%.

2) 500 nm Wavelength

Here, probability of finding 500nm wavelength in the range, between 0.3 μm, and 1 μm is discussed. The spread value is 0.7 μm.

Lower limit (a) = 0.3×10^{-6} m

Upper limit (b) = 1×10^{-6} m

Standard deviation (σ) = 0.7×10^{-6}

Mean value (μ) = 500 nm

Probability = 0.37141

Bluer colour areas under the curve in **Figure 14** cluster around the central peak than in **Figure 13** which signifies the maximum probability occurrence of 500 nm wavelength in the specified wavelength range. The probability of finding the radiations of wavelength 500 nm in the limit between 0.3 μm, and 1 μm is 0.37141. About 37.141 percentages of the radiations having wavelength 500 nm exists in the range between 0.3 μm, and 1 μm.

Total probability = probability of finding 500 nm wavelength + probability of finding other wavelength except 500 nm wavelength.

Probability of finding other wavelength except 500 nm wavelength = Total probability − probability of finding 500 nm wavelength = 1 − 0.37141

= 0.62859

= 62.859

The probability of finding other wavelengths between 0.3 μm and 1 μm except 500 nm wavelength is 62.859%.

3) 600 nm Wavelength

Here, probability of finding 600 nm wavelengths in the range between 0.3 μm, and 1 μm is discussed. The spread value is 0.7 μm.

Lower limit (a) = 0.3×10^{-6} m

Upper limit (b) = 1×10^{-6} m

Standard deviation (σ) = 0.7×10^{-6}

Mean value (μ) = 600 nm

Probability = 0.37842

The probability of finding radiations of wavelength 600 nm in the limit between 0.3 μm, and 1 μm is 0.37842. About 37.842 percentages of the radiations having wavelength 600 nm exists in the range between 0.3 μm, and 1 μm.

Total probability = probability of finding 600 nm wavelength + probability of finding other wavelength except 600 nm wavelength.

Probability of finding other wavelength except 600 nm wavelength = Total probability − probability of finding 600 nm wavelength = 1 – 0.37842

= 0.62158

= 62.158%

This shows that probability of finding other wavelengths between 0.3 μm and 1 μm except 600 nm wavelength is 62.158%.

The clustered around the central peak is greatest in 600 nm wavelength and least in 400 nm wavelength. This signifies that the probability occurrence of 600 nm wavelength radiation is greatest among the 400 nm, 500 nm, and 600 nm wavelengths. White region under the curve indicates the probability occurrence of other wavelengths except those whose probability occurrence is to be determined.

6. Significance of Research

The temperature measurement equation released in this work, can be used for all heated solid body (having resistance that depends upon its length and area) due to applied voltage. The peak value of wavelength obtained by using Wein's displacement law is only an indicator which helps to investigate, "how the energy of the emitted radiations is distributed". So, Wein's displacement law can be used if we have to find the probability distribution of radiation energy density in filament bulb. Only about small fraction of the emitted radiations (that may vary on the power of the bulb) fall in visible region, remaining fraction may be useful in heat production. So the filament bulb is useful for both light and significant heat.

7. Overview of Research

Wein's displacement law is applicable in interpretation of electromagnetic spectrum radiated by the filament bulb. The Wein's displacement equation that had been used is $(\lambda_{\max}) = \frac{hc}{4.965kT}$. If we suppose the constant value in the right hand side, different than the value (4.965), keeping others parameters constant, there will be two probability of getting the value of wavelength. The two probable values are either greater, or less than the value of wavelength obtained by using the equation $(\lambda_{\max}) = \frac{hc}{4.965kT}$. Suppose, if we lower the constant value 4.965, the value of maximum wavelength $\lambda_{\max}$, is higher. On higher value of maximum wavelength, the black body radiation curve does not give probability of obtaining wavelength in the visible region which is against the practical behavior of the filament bulb. Similarly, if we increase the constant value 4.965, the maximum wavelength is lower. On lower value of maximum wavelength, the black body distribution curve is such that there is probability of finding the smaller wavelength in the ultraviolet region which is also against the practical behavior of the filament bulb. So the equation $(\lambda_{\max}) = \frac{hc}{4.965kT}$ can be used to analyze the electromagnetic spectrum emitted from the filament bulb.

8. Conclusions

Filament bulb follows blackbody radiation curve. Only very small fractions of radiation fall in visible region. The curve is followed by radiated power density Planck law. Ultraviolet radiations are not emitted from the filament bulb of the observed watt. In "6" wattage bulb, spectrum of the emitted radiations does not contain cyan, blue and violet colour of light. In 100 watt bulb, violet colour is absent in the spectrum of the emitted visible light. In 500 watt bulb, spectrum of all colours of light is observed. Maximum intensity of red colour of light is emitted in the filament bulb. The intensity of emitted radiations goes on decreasing with decrease in wavelength of the radiations. This signifies that less number of radiations or photons of higher energy is emitted in higher wattage bulb and more number of radiations with lower energy is emitted in lower wattage bulb. For example, in **Figures 10-12**, the intensity of emitted red colour of light is greater than other visible colours of light (when compared among the visible colour radiations). Power of bulb depends directly on radius of the filament. Greater the radius of the filament is, greater the power of the bulb is. The calculated value of power suggests that, length and diameter of the filament which has taken in the work are quite correct.

Temperature is not the key factor for power of the bulb. The higher temperature filament may also have lower power. Radius is an important factor that determines power of the bulb. Resistance of filament has also indirect relationship with power of the bulb. Resistance for higher wattage bulb is lower, so the current flowing through higher wattage bulb is greater. The current passing through the bulb goes on increasing if power of the bulb increases.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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