# PHYSICS EXTENDED ESSAY

## THE RELATIONSHIP BETWEEN THE POWER OF VISIBLE RADIATION OF INCANDESCENT TUNGSTEN AND ITS TEMPERATURE

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# Abstract

This essay is an examination of *how the power of visible radiation depends on the temperature*. An experiment was carried out to measure the relationship between the temperature and the emitted radiant power of incandescent tungsten. The experiment enables me to collect data to reach a conclusion between these two variables. Also, bearing in mind that resistor does not obey ohm's law generally, due to the change of temperature, it is investigated that if the total emitted power would be changed due to this effect. A system was set up to collect data and a "TI-84 Plus" Graphic Display Calculator was used to calculate quantitative values obtained from the experiment. Also a computer programme (Logger Pro 3.8) was used to plot graphs which are derived from the data and calculations of the experiment. As a result of the experiment I found that there is a direct correlation between the emitted radiant power and temperature. The results were compared with the law governing the radiant power of an ideal black body, which is called Stefan-Boltzmann Law, to obtain the accuracy of the experimental values. Finally, I evaluated the sources of error and offered reasonable improvements for the experiment.

(*Word Count: 197)*

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# Introduction

Josef Stefan observed in his experiment that the total energy emitted by a black body per unit surface area is directly proportional to the fourth power of its absolute temperature. A similar relationship was derived by the Ludwig Boltzmann in 1884, by the use of Maxwell's theory and classic thermodynamics. Therefore the relationship derived is named as "Stefan-Boltzmann Law" referring to the contribution of both scientists.

The relationship observed by Josef Stefan suggested that;

$$j^* = \varepsilon\sigma T^4$$

Where $j^*$ is total energy radiated per area (or known as blackbody irradiance, radiant flux, energy flux density or the emissive power) in watts per square meter, $\varepsilon$ is emissivity of the body, $\sigma$ is a constant and $T$ is absolute temperature in Kelvin. The constant $\sigma$ is equal to $5.67 \times 10^{-8}\ watt\ m^{-2} K^{-4}$.

A more general approach to the relationship suggests that grey body, which does not emit full amount of radiative flux, has an emissivity variable, $\varepsilon$. Since our experiment involves an ideal black body which emits full amount the emissivity, $\varepsilon$ is thought to be equal to *1*.

To find the absolute power of energy which is emitted by a black body, the surface area has to be taken into account.

Since,

$P = Aj^*$ and $\varepsilon - 1$

We can derive the total power of energy radiated by the object by this equation,

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

Where $P$ is the total power emitted in *watts*, $A$ is the surface area in $m^2$, $\sigma$ is a constant and $T$ is the absolute temperature in *Kelvin*.

Ohm's Law suggests that voltage of a circuit is directly proportional with the current and total resistance of a circuit.

$$V = IR$$

However as current flows in a circuit, the temperature of the resistor would increase. Increase in temperature causes the resistance of the resistor to increase.

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

Where $T$ is temperature, $T_0$ is a reference temperature, $R_0$ is the resistance at $T_0$ and $\alpha$, which depends on the material, is the percentage change in resistivity per unit time.

Therefore resistance likely to change in the circuit if there is a current flow. If a resistor obeys Ohm's Law then it is called ohmic, otherwise non-ohmic.

In this experiment the relationship between the absolute power of energy and temperature is to be investigated. The main purpose is to try observing the dependence of the power of visible radiation depends on temperature.

Stefan-Boltzmann law can be used to determine a total power of an object is emitting. It's applications are used in obtaining a temperature relation between a planet and its star, radiation emitted by a human body, temperature of stars and also with the help of the law, astronomers can easily infer the radii of the stars. For example via the relationship between temperature and its absolute power astronomers can predict a space object's temperature without an actual contact with the object. Therefore in astronomy and quantum physics this law is very significant due to these various applications. This law helps many important scientific calculations as listed above and that is why this law is worthy of investigation.

# Experiment

Purpose: To observe and measure the relationship between the temperature and the emitted radiant power of incandescent tungsten.

Hypothesis: The total emitted power of the tungsten would increase as its temperature increases.

Independent Variable: Voltage of the circuit and the light bulb

Dependent Variable: Power output of the tungsten

## Apparatus

Power Supply (Voltage Interval: 0-80 Volts)

Multimeter (Uncertainty: ±0.001) (Output unit: 200mV)

Pyrometer (Coefficient: $11.17 \times 10^{-3}\ mV/\frac{W}{m^2}$) (indirect output via multimeter)

Voltmeter (Uncertainty: ±0.001) (Output unit: Volts)

Ammeter (Uncertainty: ±0.001) (Output unit: Amperes)

Tungsten Light Bulb (Resistance of the filament: 14.300 Ω)

Circuit Breaker

Light Bulb Socket

Black Cardboard

Non-transparent Tape

Foam Box

# Method

In order to observe a relation between the total energy emitted by a blackbody and the temperature of the tungsten a system was constructed.

The foam box represents the medium in which the light emitted from a blackbody travels. The box was placed on the pyrometer, from what the data to reach the emitted power is to be obtained. The foam box's surface is white and white color is known to reflect the light. In such case, the reflected rays from the surface will also fall on the pyrometer and therefore manipulate the measurements of the total energy radiated per area. To prevent such a systematic error, the inner surface of the foam box is covered with a black cardboard, which would not reflect the light.

A tungsten light bulb was used to represent a blackbody. The light bulb was screwed on a socket and the socket was taped on the upper side of the box from inside, so that the bulb faces the sensor of the pyrometer, which rests on the bottom. After isolating the edges of the foam box with a non-transparent tape to prevent any light from the environment to leak inside the box, the socket was connected to a circuit through tiny holes, only where the wires can fit.

An ammeter and a rheostat (in other words alternating resistance) were connected to the circuit in series. The potential difference applied on the light bulb is the independent variable of the experiment, therefore a voltmeter was connected in parallel to the bulb to measure the potential difference applied on the tungsten filament.

Also it is known that resistance depends on temperature, which increases when there is a current flowing in the resistor. A circuit breaker was added to the circuit to prevent the bulb from heating up and distorting the values which would be applied to ohm's law. The circuit breaker functions to decrease the effect of temperature on the resistance.

The multimeter was connected to the output wires of the pyrometer to measure the potential difference created within the instrument due to light.

Lastly, the variable resistance is connected to the circuit to simplify changing the potential difference applied on the light bulb.

Six different measurements were made to decrease the error and to reach a more accurate result.

*Figure 1 displays the setting of the system. (The front of the box was displayed open on the picture to reveal the system inside). From left to right in the first picture, there are variable resistance, ammeter, circuit breaker, voltmeter, multimeter (at the background), and foam box on the pyrometer. In the second picture there is a closer look at the box. Light bulb and blue socket are on the upper side of the box, whereas pyrometer sensor is at the bottom.*

# Raw Data

The data were collected from six different experiments[1] and the average of each measurement was written on the table 1.1. The following calculations were followed to reach the average data.

Sample calculation: taking the average measurements of electric current,

$$\frac{(R_1 + R_2 + R_3 + R_4 + R_5 + R_6)}{6} = R_{average}$$

Where R is the result of electric current measurement obtained from the experiment. The numbers indicate the chorological order of the experiments[1].

| Potential difference (V) (±0.001) | Electric Current (A) (±0.001) | Voltage output of the Pyrometer (200mV) (±0.001) | Resistance in Temperature of the Medium (Ω) (±0.001) |
|---|---|---|---|
| 1.000 | 0.067 | 0.012 | 14.300 |
| 2.000 | 0.125 | 0.015 | 14.300 |
| 3.000 | 0.175 | 0.018 | 14.300 |
| 4.000 | 0.224 | 0.020 | 14.300 |
| 5.000 | 0.263 | 0.023 | 14.300 |
| 6.000 | 0.289 | 0.032 | 14.300 |
| 7.000 | 0.328 | 0.035 | 14.300 |
| 8.000 | 0.345 | 0.046 | 14.300 |
| 9.000 | 0.372 | 0.049 | 14.300 |
| 10.000 | 0.397 | 0.059 | 14.300 |
| 11.000 | 0.418 | 0.065 | 14.300 |

*Table 1.1 shows the average of raw data collected via the instruments. It shows how the values of electric current, voltage output of the pyrometer and resistance of the medium is changed with respect to the potential difference applied on the light bulb.*

In this table the values which were measured via the ammeter and multimeter per voltage applied on the light bulb. Also voltage of the light bulb is measured via a voltmeter.

[1] See appendix for more information about the data of each six experiment

To begin with, the current passing through the tungsten filament was measured per volt. These values are used for determining the temperature of the tungsten filament (*for more information see page 14)*

Secondly, the voltage output of the pyrometer is measured via a multimeter. This voltage output values is converted into power output values by a pre-determined coefficient provided by the instrument. With the help of this value, I reached values of the total power emitted per area by the light bulb. (*for more information see page 17)*

Also, the resistance of the resistor is the constant, because there is no change in the temperature of the room.

# Data Calculation

There are four significant elements, which we could not obtain by simply obtaining via instruments. A set of calculation and process has to be followed to reach those values, which includes resistance of the filament while a current is flowing therefore when it is hot, relative resistance, temperature of the filament and total power emitted by the filament. The following calculations explain how those values are obtained or calculated.

*i.* **Resistance of the filament ($R_T$):**

It known that the resistance of a resistor depends on its temperature. The relationship between the resistance and temperature is,

$$R = R_0\,[a(T - T_0) + 1]$$

Where $T$ is temperature, $T_0$ is a reference temperature, $R_0$ is the resistance at $T_0$ and $\alpha$, which depends on the material, is the percentage change in resistivity per unit time.

It is known that if there is a current flowing in the resistor, the temperature increases and the resistance changes. Therefore the resistance of the filament would be different than the resistance measure in the room temperature.

The value of current and the voltage is known, so the resistance of the resistor could be derived using the Ohm's Law which suggests that voltage of a circuit is directly proportional with the current and total resistance of a circuit.

$$V = IR$$

Sample calculation; calculating the resistance of the filament when there is a 2.000 volts of potential difference and 0.125 amperes of flowing current:

$$(2.000 \pm 0.001)volts = (0.125 \pm 0.001)amperes \times R_T$$

$$R_T = 16.000 \pm 0.136\Omega$$

| Potential difference (V) (±0.001) | Electric Current (A) (±0.001) | Resistance of the Filament ($R_T$) (Ω) |
|---|---|---|
| 1.000 | 0.067 | 14.925 ± 0.238 |
| 2.000 | 0.125 | 16.000 ± 0.136 |
| 3.000 | 0.175 | 17.143 ± 0.104 |
| 4.000 | 0.224 | 17.857 ± 0.084 |
| 5.000 | 0.263 | 19.011 ± 0.076 |
| 6.000 | 0.289 | 20.761 ± 0.075 |
| 7.000 | 0.328 | 21.341 ± 0.068 |
| 8.000 | 0.345 | 23.188 ± 0.070 |
| 9.000 | 0.372 | 24.194 ± 0.068 |
| 10.000 | 0.397 | 25.189 ± 0.066 |
| 11.000 | 0.418 | 26.316 ± 0.065 |

*Table 2.1 shows the resistance of the filament in ohms, electric current flowing through the filament in amperes and potential difference applied to the filament in volts*

*ii.* **Relative Resistance:**

The relative resistance is obtained by dividing the resistance of the filament when it is hot and there is a potential difference applied, by the resistance of the filament in room temperature.

$$Relative\ Resistivity = \frac{R_T}{R_{room}}$$

| **Resistance of the Filament when it is hot ($R_T$) (Ω)** | **Resistance in Temperature of the Medium ($R_{room}$)(Ω) (±0.001)** | **Relative Resistance of the Filament ($\frac{R_T}{R_{room}}$)** |
|---|---|---|
| 14.925 ± 0.238 | 14.300 | 1.044 ± 0.017 |
| 16.000 ± 0.136 | 14.300 | 1.119 ± 0.010 |
| 17.143 ± 0.104 | 14.300 | 1.199 ± 0.007 |
| 17.857 ± 0.084 | 14.300 | 1.249 ± 0.006 |
| 19.011 ± 0.076 | 14.300 | 1.329 ± 0.005 |
| 20.761 ± 0.075 | 14.300 | 1.452 ± 0.005 |
| 21.341 ± 0.068 | 14.300 | 1.492± 0.005 |
| 23.188 ± 0.070 | 14.300 | 1.622 ± 0.005 |
| 24.194 ± 0.068 | 14.300 | 1.692 ± 0.005 |
| 25.189 ± 0.066 | 14.300 | 1.762 ± 0.005 |
| 26.316 ± 0.065 | 14.300 | 1.840 ± 0.005 |

*Table 2.2 shows the relative resistance of the filament.*

*iii.* **Temperature of the filament:**

It known that the resistance of a resistor depends on its temperature. The relationship between the resistance and temperature is,

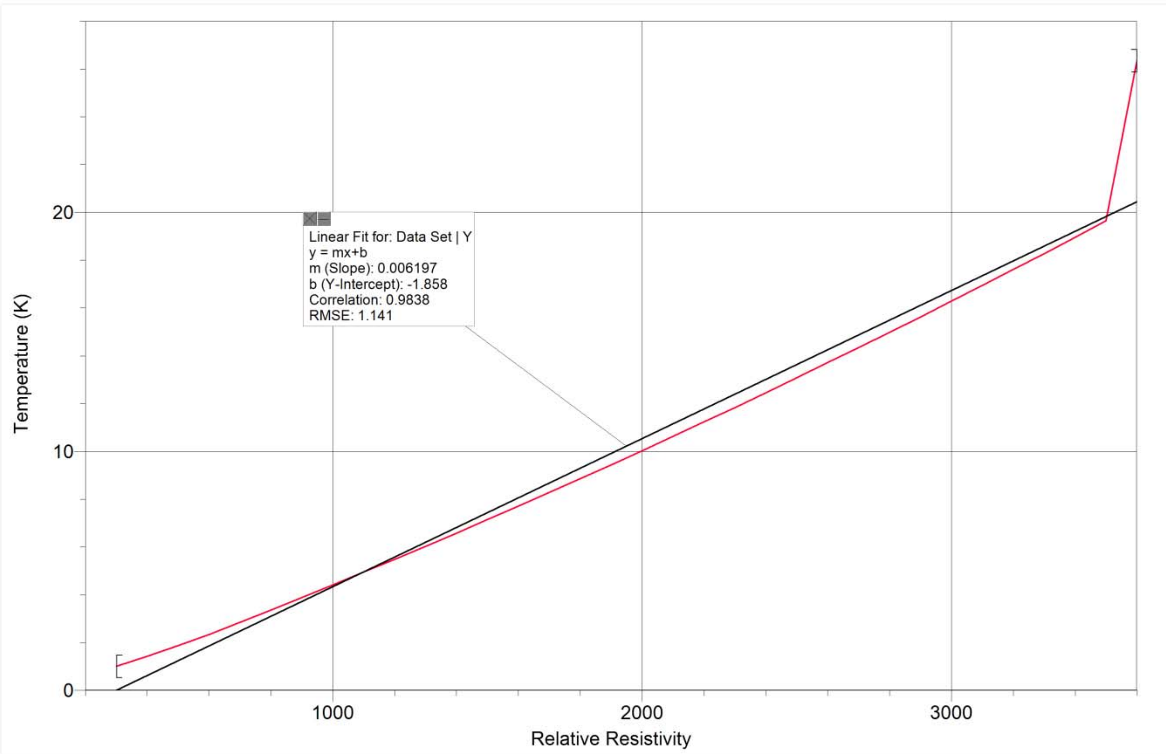
$$R = R_0 [a(T - T_0) + 1]$$

Where *T* is temperature, $T_0$ is a reference temperature, $R_0$ is the resistance at $T_0$ and *α,* which depends on the material, is the percentage change in resistivity per unit time.

However the equation above is functional for small temperature changes. That relation does not explain the relation between temperature and resistance when the change in temperature is not small. Therefore, in experiments containing big change of temperatures, the temperature of the filament can be estimated using experimental data on resistivity of tungsten, via a graph.

| R/$R_{300K}$ | Temp [K] | Resistivity □□ cm | R/$R_{300K}$ | Temp [K] | Resistivity □□ cm | R/$R_{300K}$ | Temp [K] | Resistivity □□ cm | R/$R_{300K}$ | Temp [K] | Resistivity □□ cm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 300 | 5.65 | 5.48 | 1200 | 30.98 | 10.63 | 2100 | 60.06 | 16.29 | 3000 | 92.04 |
| 1.43 | 400 | 8.06 | 6.03 | 1300 | 34.08 | 11.24 | 2200 | 63.48 | 16.95 | 3100 | 95.76 |
| 1.87 | 500 | 10.56 | 6.58 | 1400 | 37.19 | 11.84 | 2300 | 66.91 | 17.62 | 3200 | 99.54 |
| 2.34 | 600 | 13.23 | 7.14 | 1500 | 40.36 | 12.46 | 2400 | 70.39 | 18.28 | 3300 | 103.3 |
| 2.85 | 700 | 16.09 | 7.71 | 1600 | 43.55 | 13.08 | 2500 | 73.91 | 18.97 | 3400 | 107.2 |
| 3.36 | 800 | 19.00 | 8.28 | 1700 | 46.78 | 13.72 | 2600 | 77.49 | 19.66 | 3500 | 111.1 |
| 3.88 | 900 | 21.94 | 8.86 | 1800 | 50.05 | 14.34 | 2700 | 81.04 | 26.35 | 3600 | 115.0 |
| 4.41 | 1000 | 24.93 | 9.44 | 1900 | 53.35 | 14.99 | 2800 | 84.70 | | | |
| 4.95 | 1100 | 27.94 | 10.03 | 2000 | 56.67 | 15.63 | 2900 | 88.33 | | | |

Table 2.3 shows the experimental data on resistivity of tungsten.[2]




*T*

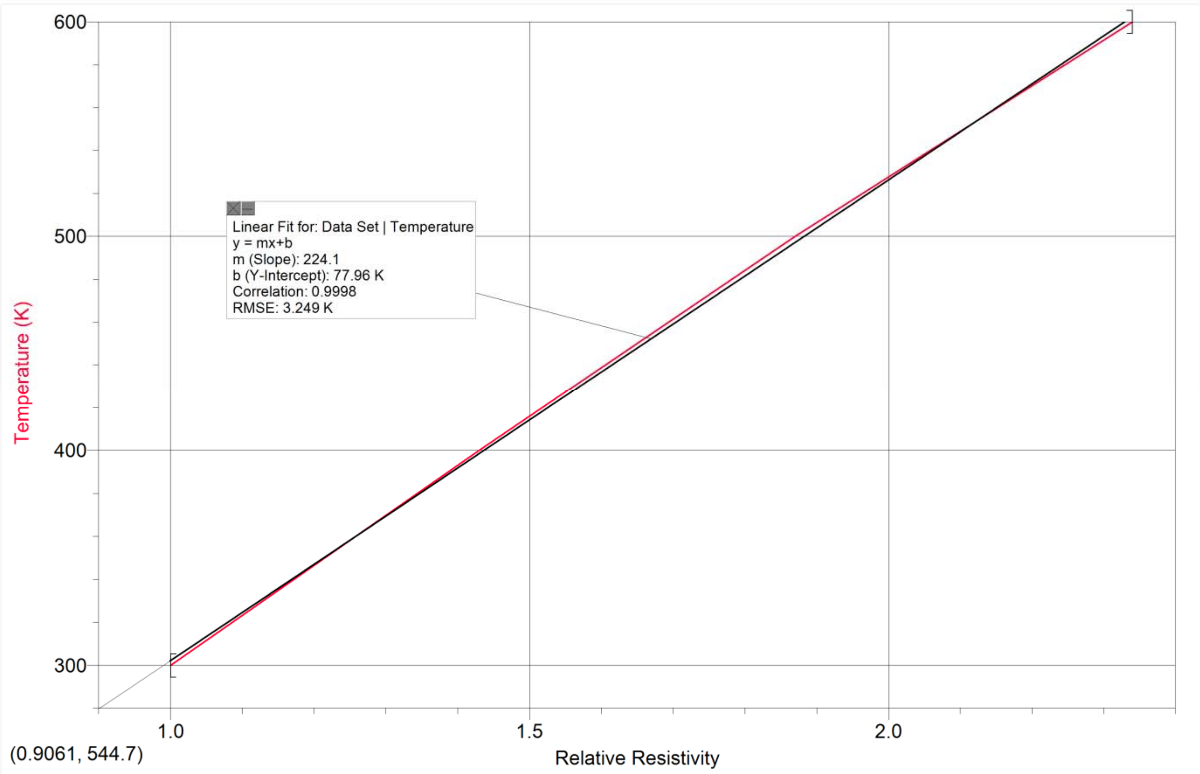
*he graph 2.1 is the graph of the table 2.1 and it shows the relative resistivity versus temperature.*

[2] Source: Texas Christian University; http://personal.tcu.edu/~zerda/manual/lab22.htm
Accessed in Feb. 06, 2010

It is seen that the increase is not linear, therefore a more focused graph would be more appropriate to estimate the temperature of tungsten. It is known that the relative resistance never exceeds "2.000" in our experiment. Therefore a graph with a more focused graph interval would be more appropriate to estimate the temperature of the tungsten filament.

| **Relative Resistance of the Filament** $(\frac{R_T}{R_{room}})$ | **Temperature of the filament (K)** |
|---|---|
| 1 | 300 |
| 1.43 | 400 |
| 1.87 | 500 |
| 2.34 | 600 |

*Table 2.4 is focused on the related part of the table 2.3*




*The Graph 2.2 is a more focused graph of graph 2.1. The equation of the graph is*

$y = (224.1)x + 77.96$

Thus we can estimate the temperature by using the following equation,

$$T = (224.1)\frac{R_T}{R_{room}} + 77.96$$

Sample Calculation; the temperature of the filament when its relative resistance is equal to "1.249 ± 0.006"

$$T = (224.1) \times (1.249 \pm 0.006) + 77.96$$

$$T = 357.861 \pm 1.345\ Kelvin$$

| Relative Resistance of the Filament $(\frac{R_T}{R_{room}})$ | Temperature of the incandescent Tungsten Filament (K) |
|---|---|
| 1.044 ± 0.017 | 311.920 ± 3.810 |
| 1.119 ± 0.010 | 328.668 ± 2.241 |
| 1.199 ± 0.007 | 346.656 ± 1.569 |
| 1.249 ± 0.006 | 357.861 ± 1.345 |
| 1.329 ± 0.005 | 375.789 ± 1.120 |
| 1.452 ± 0.005 | 403.353 ± 1.120 |
| 1.492 ± 0.005 | 412.317 ± 1.120 |
| 1.622 ± 0.005 | 441.450 ± 1.120 |
| 1.692 ± 0.005 | 457.137 ± 1.120 |
| 1.762 ± 0.005 | 472.824 ± 1.120 |
| 1.840 ± 0.005 | 490.304 ± 1.120 |

*Table 2.5 is shows the Relative Resistance of the Filament and corresponding temperature values of the incandescent Tungsten Filament in Kelvin*

*iv.* **Total Power of Energy Radiated by the Tungsten Filament**

A potential difference is created in the pyrometer due to the falling light. That potential difference in volts is converted into radiant flux,"$j^*$" in *watts* per $m^2$ by multiplying the value by a pre-determined coefficient which was provided by the instrument.

Coefficient: $11.17 \times 10^{-3}\ mV/\frac{W}{m^2}$

| Voltage output of the Pyrometer (200mV) (±0.001) | Radiant Flux ( $j^*$) ($\frac{watts}{m^2}$) (±17.905) |
|---|---|
| 0.012 | 214.861 |
| 0.015 | 268.576 |
| 0.018 | 322.292 |
| 0.020 | 358.102 |
| 0.023 | 411.817 |
| 0.032 | 572.963 |
| 0.035 | 626.679 |
| 0.046 | 823.635 |
| 0.049 | 877.350 |
| 0.059 | 1056.401 |
| 0.065 | 1163.832 |

Table 2.6 shows the voltage output of the pyrometer and the total emitted power per area detected by the instrument.

To being with, the unit of the output potential difference has to be converted from "200 millivolts" unit into voltage SI unit, which is "*volt*".

$$V = x \times 200 \times 10^{-3}$$

Where $x$ is the output data which is obtained from the pyrometer.

Radiant flux, $j^*$, is calculated by dividing the voltage output by coefficient,

$$j^* = x \times 200 \times 10^{-3} volts \times \frac{watts}{11.17\ mV\ m^2} = \frac{x \times 200\ watts}{11.17 \times 10^{-3} m^2}$$

Light is emitted in all directions from the light bulb as it is seen in the figure.

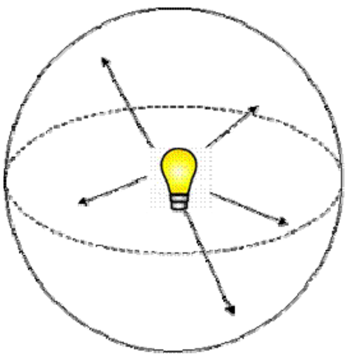


*Figure 2.1 shows the emission of light in all directions.*

Therefore the total power obtained from the light bulb could be found by multiplying the radiant flux by the area of sphere that illustrates the emission of light.

To find the area of the sphere the distance between the light source and the instrument is measured and the distance is found to be 20 centimeters.

This distance is thought to be the radius of the sphere, whose area is found as,

$$Area = 4\pi r^2 = 4\pi(0.200 \pm 0.001)^2 = 4\pi(0.0400 \pm 0.0004)$$

$$Area = 0.5026 \pm 0.0051\ m^2$$

If we multiply the radiant flux (total power per area) by the area of the sphere, the total emitted radiant power could be obtained,

$$P_{total} = \frac{x \times 200\ watts}{11.17 \times 10^{-3} m^2} \times 0.5026 \pm 0.0051 m^2$$

$$P_{total} = x \times 9000.0863 \pm 0.9008\ watts$$

| **Voltage output of the Pyrometer (200mV) (±0.001)** | **Total Emitted Power ($P$) ($watts$)** |
|---|---|
| 0.012 | 108.001 ± 10.080 |
| 0.015 | 135.001 ± 10.350 |
| 0.018 | 162.001 ± 10.620 |
| 0.020 | 180.002 ± 10.800 |
| 0.023 | 207.002 ± 11.070 |
| 0.032 | 288.003 ± 11.880 |
| 0.035 | 315.003 ± 12.150 |
| 0.046 | 414.004 ± 13.140 |
| 0.049 | 441.004 ± 13.410 |
| 0.059 | 531.005 ± 14.310 |
| 0.065 | 585.006 ± 14.850 |

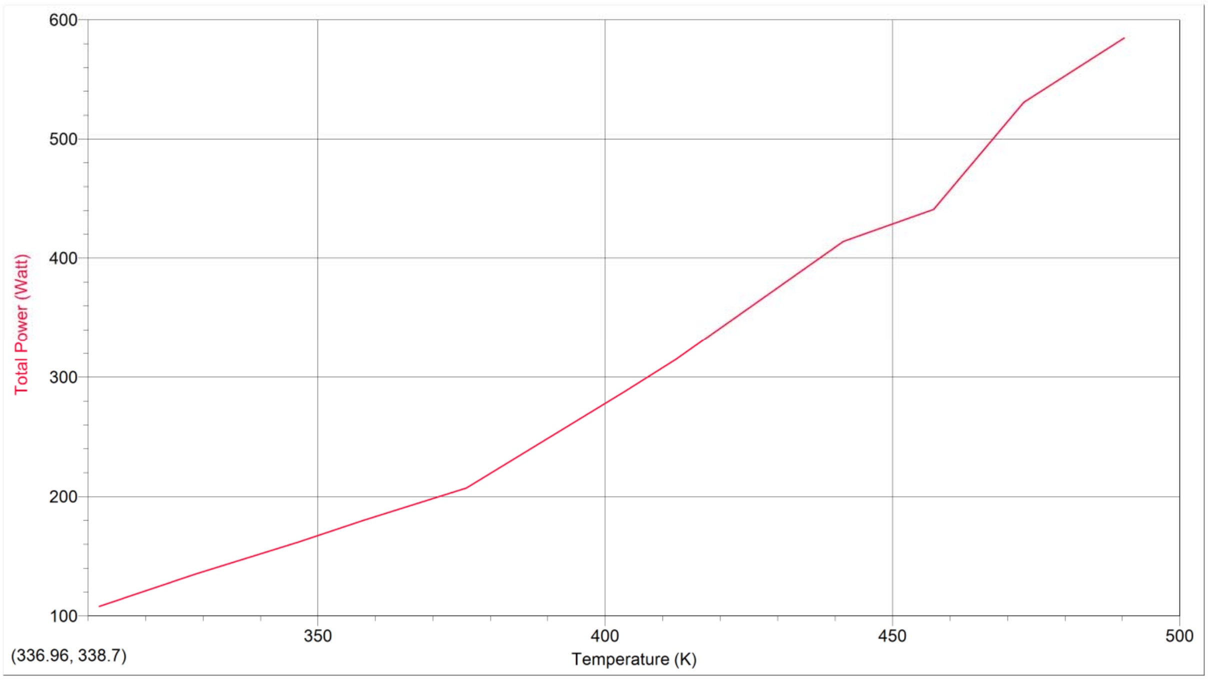
Table 2.7 shows the voltage output of the pyrometer and the total emitted power.

# Data Analysis

As a result of the data calculation, the necessary elements needed to reach the relationship between the temperature and the emitted power, are obtained. Those necessary elements are the total power emitted and a corresponding temperature value.

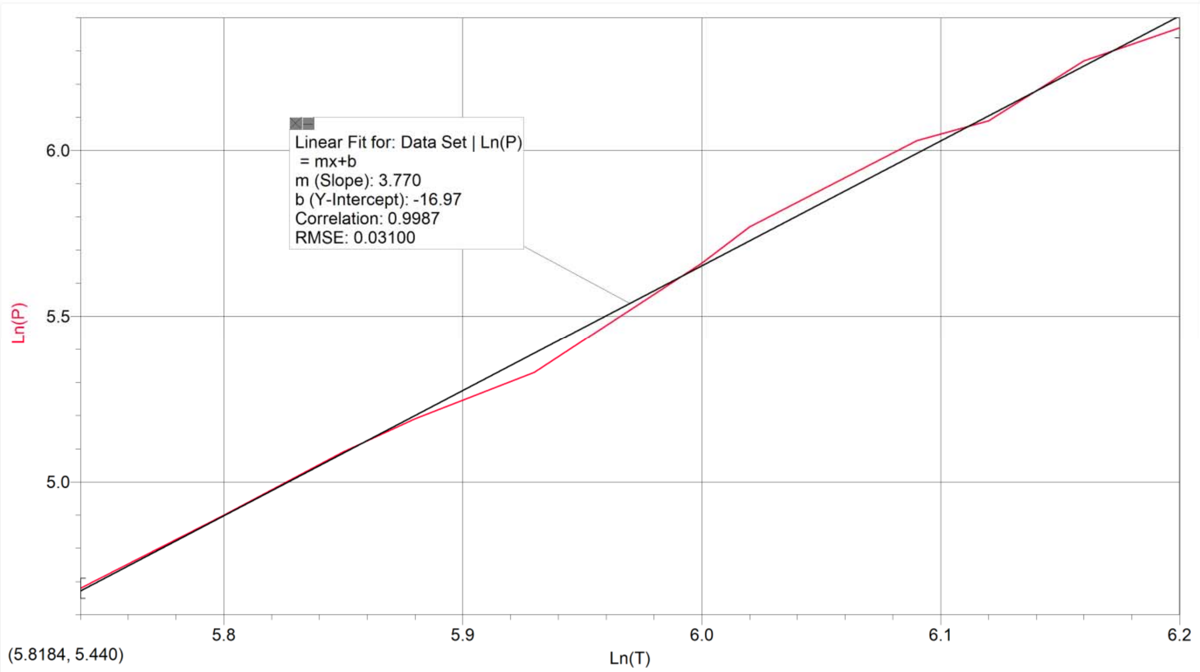
| **Temperature of the incandescent Tungsten Filament (K)** | **Total Emitted Power ($P$) ($watts$)** |
|---|---|
| 311.920 ± 3.810 | 108.001 ± 10.080 |
| 328.668 ± 2.241 | 135.001 ± 10.350 |
| 346.656 ± 1.569 | 162.001 ± 10.620 |
| 357.861 ± 1.345 | 180.002 ± 10.800 |
| 375.789 ± 1.120 | 207.002 ± 11.070 |
| 403.353 ± 1.120 | 288.003 ± 11.880 |
| 412.317 ± 1.120 | 315.003 ± 12.150 |
| 441.450 ± 1.120 | 414.004 ± 13.140 |
| 457.137 ± 1.120 | 441.004 ± 13.410 |
| 472.824 ± 1.120 | 531.005 ± 14.310 |
| 490.304 ± 1.120 | 585.006 ± 14.850 |

Table 3.1 shows the temperature of the tungsten and the total emitted power.




*The Graph 3.1 shows the* temperature of the tungsten versus the total emitted power

If we take *ln* of both columns (temperature column and power column), the graph would be as,




*The Graph 3.2 shows the ln* of temperature of the tungsten versus the *ln* of total emitted power.

$y = mx + n$

$\ln(P) = m \times \ln(T) + n$

Where m is the gradient of the graph and n is the y- intercept.

$\ln(P) = \ln T^m + \ln e^n$

$\ln(P) = \ln(T^m \times e^n)$

$P = e^n T^m$

Values of m and n could be obtained from the best line of the graph 3.2. Then,

$m = 3.770$ and $n = -16.97$

$$e^{-16.97} = 4.266017593 \times 10^{-8} \cong 4.27 \times 10^{-8}$$

Therefore,

$$\boldsymbol{P = 4.27 \times 10^{-8}\, T^{3.77}}$$

To compare the experimental value and the theoretical value, percent error for the value of the power of absolute temperature can be calculated using the following formula,

$$Percent\ Error = \frac{|theoretical\ value - experimental\ value|}{experimental\ value} \times 100$$

$$\%Error\ for\ T^m = \frac{|4 - 3.77|}{4} \times 100 = 5.75\ \%$$

Percent error for the value of σ constant, which is $e^{-16.97}$, can be calculated using the following formula,

$$\%Error\ for\ \sigma\ \text{constant} = \frac{|5.67 - 4.27| \times 10^{-8}}{5.67\ \times 10^{-8}} \times 100 = 24.69\ \%$$

Therefore the error is found 5.75% for the value of the power of absolute temperature.

# Conclusion and Evaluation

In this thesis, the temperature effect on the power of visible radiation is discussed. A set of experiments were carried out to observe and measure the relationship between the temperature and the emitted radiant power of incandescent tungsten.

This relationship is found to be as,

$$P = 4.27 \times 10^{-8} T^{3.77}$$

Where P is the power of visible radiation in watts and T is the absolute temperature in Kelvin.

Therefore the hypothesis, which states "The total emitted power of the tungsten would increase as its temperature increases." Is foreseen correctly. The purpose of the experiment is achieved; a correlation is calculated.

There are several possible sources of error in the experiment:

- The resistance measured consists of both the filament's and wires' resistance. Although the resistance of the wires are small enough to neglect, it might have caused a miscalculation therefore resulting an error.
- Although the box in which the pyrometer and the light bulb are present, is covered and isolated, there might be a leak of light and distort the values that pyrometer reads.
- The temperature values of the incandescent tungsten are estimated via the help of a graph and pre-determined values. Real temperature of the tungsten filament in a measure relative resistivity value might not be consistent with the estimated value or/and the pre-determined values might not be precise.

- As the filament heats up, its resistance varies. Although, to prevent this effect a circuit breaker was connected to the system and the values were measured quickly without wasting time to cause the filament to heat up, the filament might be heated up rapidly, therefore it might have caused a distortion in reading the values of resistance.

In order to conduct a more accurate experiment, several improvements could be made. To begin with, keeping the wire lengths short would be efficient enough to neglect the resistance that they contribute to the total resistance. Secondly, the medium of the experiment should be absolutely dark, and there should be no leak of visible radiation. Also, after each collection of data, the current flow could be cut and the resistor, tungsten filament could be allowed to cool down for an appropriate amount of time.

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- “Stefan Boltzmann Law”. Texas Christian University. 06 Feb. 2010 <http://personal.tcu.edu/~zerda/manual/lab22.htm>
- “Stefan-Boltzmann Law”. Wikipedia. 23 Feb. 2010 28 Feb. 2010 <http://en.wikipedia.org/wiki/Stefan%E2%80%93Boltzmann_law>

# Appendix

Experiment 1:

| Potential difference (V) (±0.001) | Electric Current (A) (±0.001) | Voltage output of the Pyrometer (200mV) (±0.001) | Resistance in Temperature of the Medium (Ω) (±0.001) |
|---|---|---|---|
| 1.000 | 0.060 | 0.012 | 14.300 |
| 2.000 | 0.120 | 0.015 | 14.300 |
| 3.000 | 0.175 | 0.018 | 14.300 |
| 4.000 | 0.221 | 0.020 | 14.300 |
| 5.000 | 0.259 | 0.022 | 14.300 |
| 6.000 | 0.286 | 0.030 | 14.300 |
| 7.000 | 0.325 | 0.035 | 14.300 |
| 8.000 | 0.342 | 0.046 | 14.300 |
| 9.000 | 0.370 | 0.049 | 14.300 |
| 10.000 | 0.395 | 0.059 | 14.300 |
| 11.000 | 0.415 | 0.064 | 14.300 |

Experiment 2:

| Potential difference (V) (±0.001) | Electric Current (A) (±0.001) | Voltage output of the Pyrometer (200mV) (±0.001) | Resistance in Temperature of the Medium (Ω) (±0.001) |
|---|---|---|---|
| 1.000 | 0.065 | 0.012 | 14.300 |
| 2.000 | 0.124 | 0.015 | 14.300 |
| 3.000 | 0.176 | 0.018 | 14.300 |
| 4.000 | 0.224 | 0.020 | 14.300 |
| 5.000 | 0.260 | 0.022 | 14.300 |
| 6.000 | 0.288 | 0.031 | 14.300 |
| 7.000 | 0.328 | 0.035 | 14.300 |
| 8.000 | 0.343 | 0.045 | 14.300 |
| 9.000 | 0.371 | 0.049 | 14.300 |
| 10.000 | 0.398 | 0.058 | 14.300 |
| 11.000 | 0.415 | 0.066 | 14.300 |

Experiment 3:

| **Potential difference (V) (±0.001)** | **Electric Current (A) (±0.001)** | **Voltage output of the Pyrometer (200mV) (±0.001)** | **Resistance in Temperature of the Medium (Ω) (±0.001)** |
|---|---|---|---|
| 1.000 | 0.077 | 0.013 | 14.300 |
| 2.000 | 0.134 | 0.015 | 14.300 |
| 3.000 | 0.178 | 0.018 | 14.300 |
| 4.000 | 0.229 | 0.020 | 14.300 |
| 5.000 | 0.268 | 0.023 | 14.300 |
| 6.000 | 0.294 | 0.032 | 14.300 |
| 7.000 | 0.330 | 0.036 | 14.300 |
| 8.000 | 0.348 | 0.046 | 14.300 |
| 9.000 | 0.375 | 0.050 | 14.300 |
| 10.000 | 0.401 | 0.060 | 14.300 |
| 11.000 | 0.421 | 0.065 | 14.300 |

Experiment 4:

| **Potential difference (V) (±0.001)** | **Electric Current (A) (±0.001)** | **Voltage output of the Pyrometer (200mV) (±0.001)** | **Resistance in Temperature of the Medium (Ω) (±0.001)** |
|---|---|---|---|
| 1.000 | 0.072 | 0.012 | 14.300 |
| 2.000 | 0.130 | 0.015 | 14.300 |
| 3.000 | 0.176 | 0.018 | 14.300 |
| 4.000 | 0.227 | 0.020 | 14.300 |
| 5.000 | 0.264 | 0.023 | 14.300 |
| 6.000 | 0.292 | 0.032 | 14.300 |
| 7.000 | 0.329 | 0.035 | 14.300 |
| 8.000 | 0.347 | 0.046 | 14.300 |
| 9.000 | 0.373 | 0.049 | 14.300 |
| 10.000 | 0.396 | 0.059 | 14.300 |
| 11.000 | 0.421 | 0.067 | 14.300 |

Experiment 5:

| Potential difference (V) (±0.001) | Electric Current (A) (±0.001) | Voltage output of the Pyrometer (200mV) (±0.001) | Resistance in Temperature of the Medium (Ω) (±0.001) |
|---|---|---|---|
| 1.000 | 0.063 | 0.012 | 14.300 |
| 2.000 | 0.122 | 0.015 | 14.300 |
| 3.000 | 0.168 | 0.018 | 14.300 |
| 4.000 | 0.220 | 0.020 | 14.300 |
| 5.000 | 0.263 | 0.023 | 14.300 |
| 6.000 | 0.287 | 0.032 | 14.300 |
| 7.000 | 0.327 | 0.035 | 14.300 |
| 8.000 | 0.346 | 0.046 | 14.300 |
| 9.000 | 0.372 | 0.049 | 14.300 |
| 10.000 | 0.395 | 0.059 | 14.300 |
| 11.000 | 0.417 | 0.065 | 14.300 |

Experiment 6:

| Potential difference (V) (±0.001) | Electric Current (A) (±0.001) | Voltage output of the Pyrometer (200mV) (±0.001) | Resistance in Temperature of the Medium (Ω) (±0.001) |
|---|---|---|---|
| 1.000 | 0.064 | 0.012 | 14.300 |
| 2.000 | 0.121 | 0.015 | 14.300 |
| 3.000 | 0.177 | 0.018 | 14.300 |
| 4.000 | 0.222 | 0.020 | 14.300 |
| 5.000 | 0.263 | 0.023 | 14.300 |
| 6.000 | 0.286 | 0.032 | 14.300 |
| 7.000 | 0.327 | 0.035 | 14.300 |
| 8.000 | 0.345 | 0.046 | 14.300 |
| 9.000 | 0.372 | 0.049 | 14.300 |
| 10.000 | 0.395 | 0.059 | 14.300 |
| 11.000 | 0.417 | 0.065 | 14.300 |