TED ANKARA COLLEGE FOUNDATION PRIVATE HIGH SCHOOL

International Baccalaureate

Physics - Standard Level

Extended Essay

<u>Topic:</u>

<u>Finding the Ideal Heating Element</u>

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1) Abstract:

This essay's main aim is to find an ideal resistance of the heating element and voltage for a simple water boiling kettle, if there exists, working under alternating current.

By adjusting the size of the nichrome wire, which was selected as the heating element after research, the resistance of the heating element will be adjusted to desired values by changing its length while its resistance is measured by an ohmmeter. Resistances are to be 6Ω, 8Ω, 10Ω, 12Ω and 15Ω since this is the range of which commercial kettles' heating elements have. After all desired wires are achieved, these will then be put into the prepared circuit and be put under alternating current under different voltages. The voltages to be used are 200V, 220V, 230V and 240V because these voltages are also the range of which commercial kettles work under. When the circuit was completed, 0.5L of tap water started to heat up from the initial 20^{o}C to the 100^{o}C boiling point of the water. Using this method is a simple and effective way to determine an ideal heating element for a kettle in terms of greatest power output, which is the main goal of this essay.

The experiment's resulting data showed that when the resistance of the heating element is equal to the total resistance of the circuit, which was taken as the internal resistance of the power source, the power output was maximum. This result proved to be correct through calculations based on the ohm's law and was further proven when the time required for each resistance value to heat water up to its boiling point, also was the shortest. Under the controlled variables of this essay, finding an ideal resistance value for the heating element is possible.

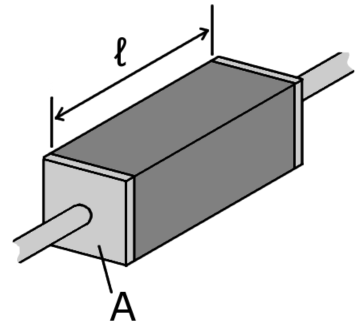
Word Count: 290

Contents

1) Abstract	*1*
2) Background Information	*3*
a. Resistivity	*3*
b. Power	*3*
c. Heat Transfer	*3*
d. Research on Electric Kettles	*4*
3) Introduction	*5*
a. Aim	*5*
b. Research Question	*5*
c. Hypothesis	*6*
d. Research	*7*
4) Experimentation	*8*
a. Variables	*8*
b. Materials	*9*
c. Method	*9 - 10*
5) Data Collection and Processing	*11-17*
a. Calculations and Graphs	*17-23*
6) Conclusion and Evaluation	*24*
a. Conclusion	*24*
b. Evaluation	*25-26*
7) Bibliography	*27*
8) Appendix	*28-*

2) Background Information

a) Resistivity:



Electrical resistivity (also called specific electrical resistance and volume resistivity) is an electrical measure which represents how much material opposes the flow of electric current. A low resistivity value would indicate that a material readily allows the movement of electrical charge to pass through it. The SI unit of electrical resistivity is ohm meters [Ω m].[1]

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

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

ρ: It is the static resistivity (measured in ohm-metres, Ω-m)

ℓ: It is the length of the piece of material measured (measured in meters, m)

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

b) Power:

In physics, power is the rate at which work is performed or energy is converted. In this experiment, we deal with Electric power, which is the rate at which electrical energy is transferred by an electric circuit. The SI unit of power is the watt.

$$P = I^2 R = \frac{V^2}{R},$$

Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference or voltage across the two points, and inversely proportional to the resistance between them. [2]

The mathematical equation that describes this relationship is: $I = \frac{V}{R}$

c) Heat Transfer:

Heat transfer, also known as heat flow, heat exchange, or simply heat, is the transfer of thermal energy from one region of matter or a physical system to another. When an object is at a different temperature from its surroundings, heat transfer occurs so that the body and the surroundings reach the same temperature at thermal equilibrium. In engineering, energy transfer by heat between objects is classified as occurring by heat conduction.[3]

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[1]: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/resis.html

[2]: http://www.physicsclassroom.com/class/energy/u5l1e.cfm

[3]: http://en.wikipedia.org/wiki/Heat_transfer

d) Research on Electric Kettles:

A kettle, which is commonly referred to as a tea kettle is a small and simple kitchen appliance used for boiling water, mainly for the reason to prepare boiling water for making tea or other beverages. A kettle in shape often resembles the shape of a teapot but with different functions.[4]

In this experiment, I will be doing my research on electric kettles. These kettle's are normally made of durable plastic material or steel and work under alternating current. Modern designed kettles all work under mains electricity which is the common usage of an alternating current.

A kettle in electrical design is a simple device made of a circuit with a few elements which are;

- On/Off Switch
- Indicator Light
- Thermostat
- Heating Element

The function of the switch is to control the electricity given to the kettle while the indicator light's purpose is to show the user if the device is working properly or not.

The thermostat is a fundamental element found inside of a modern kettle. Its purpose is to stop the flow of current inside of the kettle as soon as the water reaches 100^{o}C and starts to boil. The electric flow in the circuit must be stopped at that point so the kettle will automatically deactivate and prevent damaging the heating element as well as using excess electricity.

Last but not least, the heating element is the most important parts of the kettle and is a key element in this experiment. Every electric kettle is powered by a heating element made of different possible materials. The heating element is basically a metal resistor that resists the flow of electricity. Electricity that flows into this resistor is then turned into heat. It is this heat that heats up the water inside the kettle.

According to the research I have done, most heating elements found inside of electrical heating appliances use Nichrome as the material. Nichrome is an alloy of nickel (Ni) and chromium (Cr) which are blended at a percentage of 80% Nickel and 20% Chromium by mass. This percentage is the most common used one although it can be adjusted for different uses. Even though other materials such as Kanthal (alloy of iron + chromium + aluminum) or Cupronickel (alloy of copper + nickel) are also used as heating elements, the best choice is Nichrome 80/20 since its relatively high in terms of resistance and melting point. For heating purposes, the resistance wire must be stable in air when it gets hot, for which Nichrome has an advantage in this case since it forms an adherent layer of chromium oxide when its heated for the first time. Since the material beneath this formed layer wont oxidize, the wire will have a protective layer preventing it from breaking or burning out unlike other materials.

The reason I chose Nichrome as my heating element is that when compared to the others, it is much more abundant and cheap as well as many advantages I listed above.

[4]: http://en.wikipedia.org/wiki/Electric_kettle

3) Introduction:

Water boiling kettles are used in our everyday lives. They are popular tools for boiling water and are very easy to use. Kettles today, with the help of modern technology, can boil water within minutes, but how can we be sure that kettles used have the best possible resistance values for the heating elements used in it? What's meant by the best possible resistance value, in this experiments case is that the heating element should be heating a body of water in the shortest possible time meaning it should have the greatest power output.

Changing the resistance of the heating element as well as the voltage its put under, inside of a kettle would change the power used up by this resistor and thus changing the heat released into the water. As the resistance of the heating element is increased, so does the amount of heat produced by it. But it is assumed that there is a limit to this statement and the experiments main goal is to find this limit.

Having changed the resistor and the voltage would allow you to control the heat released into the water. In this experiment, it is important to understand that maximum power transfer does not result in maximum efficiency. My experiment will be on finding the ideal resistance which produces the maximum power. The boiling process of the kettle should be as fast as possible and this happens where there is maximum power output. Since changing the resistance of the heating element inside of a kettle would change the scale of power output, finding an ideal one was this experiments main goals.

a) Aim:

The mechanism of a kettle is quite simple; and the most important component of this mechanism is the heating element which could be made of different materials having different resistances. The change in resistance of the heating element would directly change the amount of power used by it in the kettle thus changing the amount of time required to heat a body of water to a certain temperature. The main aim of this essay is to find the ideal heating element material through experimentation by changing its resistance and putting it under voltages that range from what commercial kettles work under.

b) Research Question:

How does the power dissipated on the heating element of the kettle depend on the value of its resistance and the voltage it is put under? In other words, is there a value for the heating element of a kettle working under alternating current at which the power dissipated on it is maximum?

c) Hypothesis:

Water boiling using kettles in households are very common since its invention in the 20th century. On average, a simple three member family boils 4-5 liters of water per week. On a global scale, the usage of kettles are very common, so even a slightest amount of unnecessary power usage would build up to be a serious issue. This issue has to be looked into by officials since the world's energy resources are limited and preserving what little we have is necessary.

Excess usage of power, which is not time efficient, in electronics is a phenomenon happening in most commercial and industrial products. According to the research I have done on this topic as well as what I have learned in my physics course, I would say that if the heating element found inside the kettle, which works under alternating current, has a resistance that is equal to the resistance of the power source, it would result in the greatest power output which means that the heat transferred to the water would be the greatest, resulting in the most rapid water boiling possible.

--> It is hypothesized that if the resistance of the heating element inside of a kettle working under alternating current is adjusted to a value of which it is equal to the resistance of the power source, the power output will be maximum and the water boiling will be the fastest.

d) Research:

This is a simple circuit which is similar to the one which would be found inside of a kettle except the fact that this one works with direct current instead of alternating current.

To find the best possible resistance that gives out the maximum possible power, I followed the process:

$\mathcal{E} = I \cdot R$ This is the formula from Ohm's Law. The value of R in this case equals to both the internal resistance of the cell (r) and the resistance(R).

$P = I^2 R$ Is the formula used to find the power dissipated in the resistance R. the R value in the formula stands only for the resistance (R).

For calculations, I will give example values to the e.m.f. and r values; Let's take e.m.f. as V,

and resistance of the heating element as r.

According to these values, I = current would be found using Ohm's formula as:

$$V = I\ x\ (R + r) \longrightarrow I = \frac{V}{(R + r)}$$

If we were to insert this value of I into the Power formula, we would get the following:

$$P = I^2 x\ R = \frac{V^2\ x\ R}{(R + r)^2}$$

When the derivative of the above is take the result is as the following:

$$\frac{dP}{dR} = V^2\ x\ \left[\frac{1\ x\ (R + r)^2 -\ r\ x\ (R + r) x\ R}{(R + r)^4}\right] = 0$$

- As a result of the above equation, the value R is equal to r in Ω's.

From this we can conclude that under direct current, when the resistance (R) is equal to the internal resistance of the battery (r) the power (P) is maximum.

In this essay, I have made a circuit using alternating current to imitate a simple circuit that would be found in a kettle. As I have learned the above in my Physics class applies for direct current, in this experiment I will see if it could be applied to a circuit under alternating current.

4) Experimentation

a) Variables

Controlled Variables:

<table>
<tr><th>Controlled Variables</th><th>Method of control</th><th>Reason to control</th></tr>
<tr><td>Volume of Water</td><td>Volume of water was carefully measured before each trial and the same amount of water is used.</td><td rowspan="8">The reason to control all these variables was to create exactly same environments for the experiment to be conducted at. This would help greatly with the accuracy of the data later to be collected.</td></tr>
<tr><td>Volume of Water container</td><td>The same container was used for each trial</td></tr>
<tr><td>Water source and hardness</td><td>Water was used from the same source, having same hardness</td></tr>
<tr><td>Initial and Final Temperature</td><td>Temperature was measured before conducting the experiment and stopped as soon as reaching the final temperature.</td></tr>
<tr><td>Electricity Source</td><td>Same power source was used throughout the experiment</td></tr>
<tr><td>Room temperature</td><td>Room temperature was check before each trial using a room thermometer</td></tr>
<tr><td>Atmospheric pressure</td><td rowspan="2">The experiment was conducted at the exact same spot.</td></tr>
<tr><td>Altitude of place of experiment</td></tr>
</table>

Dependent Variables: Time (seconds)

Independent Variables: Resistance of the heating element (Ω) *b) Materials:*

In this experiment, we are to build a circuit in which we are able to change the main resistance of the circuit as well as the voltage given to the circuit.

A. Circuit Materials

- Standard urban electricity of 220V as an electric source (to be connected to the transformer)
- Voltmeter (± 0.1V) (Measures voltages between 0V -50V)
- Ammeter (± 0.1A) (Measures current between 0A -50A)
- Two plastic insulated conductive copper wires of different colors, at the length of 2 meters each.
- Alligator Clips

B. Other Materials

- Graduated Cylinder of 100mL (±0.1 mL)
- Tap Water
- Digital Thermometer (Calibrated on date: 10/10 2010 , ±0.2 °C) (Measures temperature between -50°C to 300°C)
- Glass Container of 500mL
- Chronometer (Calibrated on date: 10/10 2010, ±0.01 seconds)
- Ohm Meter (±0.1 Ω) (Measures resistance between 0Ω - 20Ω)

C. Transformer Materials

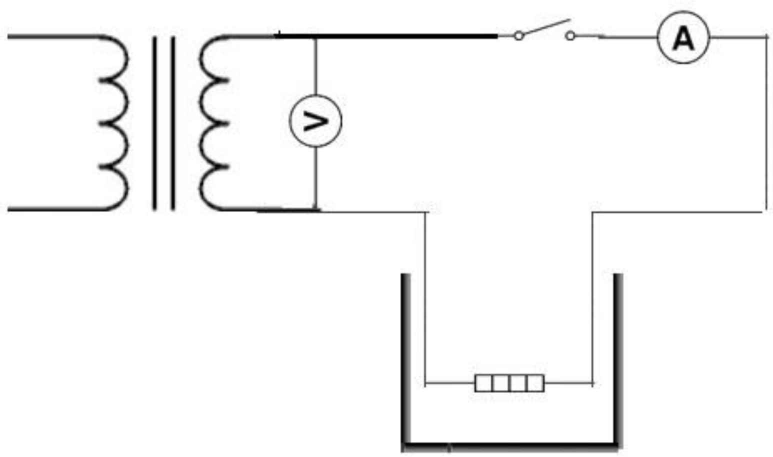
- Plug
- Connecting Electricity Cable

c) Method:

Part 1: Setting up the Transformer

- 1) Connect the electricity cable of the transformer into a nearby plug which supplies 220V of urban electricity.
- 2) Turn on the electricity for the transformer.

Diagram 1: Diagram of the electric circuit of the kettle and the transformer.

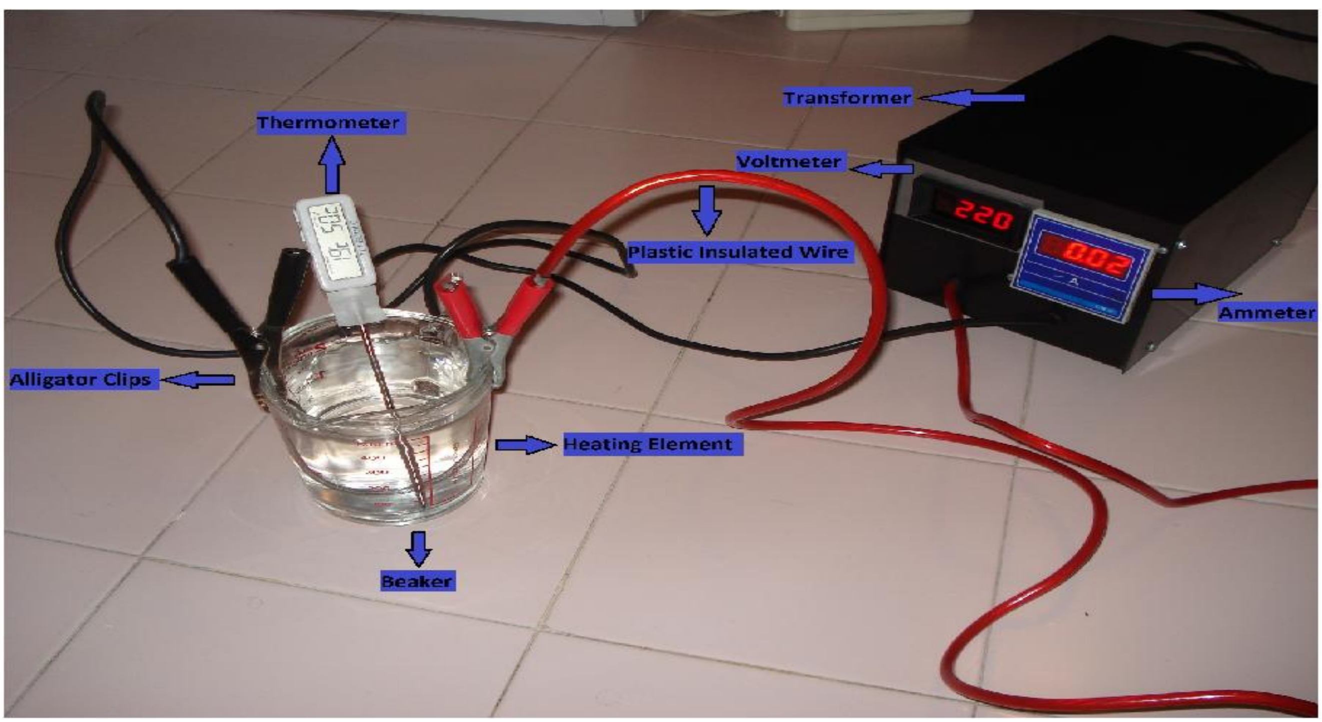


Part 2: Setting up the Circuit

- 1) Fill the glass container with 1 Liter of tap water using the graduated cylinder.
- 2) Connect the alligator clips to the conductive wires after having the wires connected to the transformer.
- 3) Place the trial resistance between the alligator clips and place it inside the water.
- 4) Mark a point on the glass container and using the digital thermometer, measure the initial temperature of the water specifically on the point marked. Make sure that the initial water temperature is 20 °C. (If it's not 20 °C, then add cold or hot water until reached the desirable temperature.)

Part 3: Observations and Data Collection

- 1) Turn on the first level of voltage on the transformer which is 200V, allowing the completion of the circuit.
- 2) Start the chronometer at the same time as you turn on the voltage.
- 3) Stop the current as soon as the time limit of 100°C is reached.
- 4) Repeat all the steps all over again for heating elements with resistance values of 8Ω, 10Ω, 12Ω and 15Ω and for voltage levels of 220V, 230V and 240V.



Picture 1: Picture showing the design of the experiment with all materials in use.

5) Data Collection and Processing

- The following table represents values for the controlled variables which have been kept the same for every trial.

Initial Temperature of Water (°C) (±0.2 °C)	Final Temperature of Water (°C) (±0.2 °C)	Volume of Water (dm^3)	Resistance of the heating element (Ω)	Room Temperature (°C) (±0.2 °C)	Atmospheric Pressure (kPa)
20.0	100.0	0.50	6.0	20.0	102.1

Table 1: Table representing constant variable values used in each trial.

- The following tables represent Current and Voltage readings during experimentation for every trial.

--> Current and Voltage readings for Nichrome 6Ω:

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	12.5	200.0	6.0
2	12.6	200.1	6.0
3	12.5	200.0	6.0
4	12.5	200.1	6.0
5	12.5	200.0	6.0

Table 2: Table showing current and voltage reading for Nichrome 6.0 Ω under 200 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	13.8	220.1	6.0
2	13.9	220.1	6.0
3	13.8	220.0	6.0
4	13.8	220.0	6.0
5	13.8	220.0	6.0

Table 3: Table showing current and voltage reading for Nichrome 6.0 Ω under 220 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	14.4	230.0	6.0
2	14.4	230.0	6.0
3	14.5	230.1	6.0
4	14.5	230.1	6.0
5	14.4	230.0	6.0

Table 4: Table showing current and voltage reading for Nichrome 6.0 Ω under 230 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	15.0	240.0	6.0
2	15.0	240.1	6.0
3	15.0	240.1	6.0
4	15.0	240.1	6.0
5	15.0	240.0	6.0

Table 5: Table showing current and voltage reading for Nichrome 6.0 Ω under 240 V

--> Current and Voltage readings for Nichrome 8Ω:

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	11.1	200.0	8.0
2	11.1	200.0	8.0
3	11.1	200.0	8.0
4	11.1	200.1	8.0
5	11.1	200.0	8.0

Table 6: Table showing current and voltage reading for Nichrome 8.0 Ω under 200 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	12.2	220.1	8.0
2	12.2	220.1	8.0
3	12.2	220.0	8.0
4	12.2	220.1	8.0
5	12.2	220.0	8.0

Table 7: Table showing current and voltage reading for Nichrome 8.0 Ω under 220 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	12.8	230.1	8.0
2	12.8	230.0	8.0
3	12.8	230.1	8.0
4	12.8	230.1	8.0
5	12.8	230.0	8.0

Table 8: Table showing current and voltage reading for Nichrome 8.0 Ω under 230 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	13.3	240.0	8.0
2	13.3	240.0	8.0
3	13.3	240.1	8.0
4	13.3	240.1	8.0
5	13.3	240.0	8.0

Table 9: Table showing current and voltage reading for Nichrome 8.0 Ω under 240 V

--> Current and Voltage readings for Nichrome 10Ω:

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	10.0	200.0	10.0
2	10.0	200.1	10.0
3	10.0	200.0	10.0
4	10.0	200.1	10.0
5	10.0	200.0	10.0

Table 10: Table showing current and voltage reading for Nichrome 10.0 Ω under 200 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	11.0	220.1	10.0
2	11.0	220.1	10.0
3	11.0	220.0	10.0
4	11.0	220.0	10.0
5	11.0	220.0	10.0

Table 11: Table showing current and voltage reading for Nichrome 10.0 Ω under 220 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	11.4	230.0	10.0
2	11.5	230.0	10.0
3	11.5	230.1	10.0
4	11.5	230.1	10.0
5	11.5	230.0	10.0

Table 12: Table showing current and voltage reading for Nichrome 10.0 Ω under 230 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	12.0	240.0	10.0
2	12.0	240.1	10.0
3	12.0	240.1	10.0
4	12.0	240.1	10.0
5	12.0	240.0	10.0

Table 13: Table showing current and voltage reading for Nichrome 10.0 Ω under 240 V

--> Current and Voltage readings for Nichrome 12Ω:

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	9.1	200.0	12.0
2	9.1	200.1	12.0
3	9.1	200.0	12.0
4	9.1	200.1	12.0
5	9.1	200.0	12.0

Table 14: Table showing current and voltage reading for Nichrome 12.0 Ω under 200 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	10.0	220.1	12.0
2	10.1	220.1	12.0
3	10.0	220.0	12.0
4	10.0	220.0	12.0
5	10.0	220.0	12.0

Table 15: Table showing current and voltage reading for Nichrome 12.0 Ω under 220 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	10.45	230.0	12.0
2	10.45	230.0	12.0
3	10.46	230.1	12.0
4	10.46	230.1	12.0
5	10.45	230.0	12.0

Table 16: Table showing current and voltage reading for Nichrome 12.0 Ω under 230 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	10.9	240.0	12.0
2	10.9	240.1	12.0
3	10.9	240.1	12.0
4	10.8	240.1	12.0
5	10.9	240.0	12.0

Table 17: Table showing current and voltage reading for Nichrome 12.0 Ω under 240 V

--> Current and Voltage readings for Nichrome 15Ω:

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	8.0	200.0	15.0
2	8.0	200.1	15.0
3	8.0	200.0	15.0
4	8.0	200.1	15.0
5	8.0	200.0	15.0

Table 18: Table showing current and voltage reading for Nichrome 15.0 Ω under 200 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	8.8	220.1	15.0
2	8.8	220.1	15.0
3	8.8	220.0	15.0
4	8.8	220.0	15.0
5	8.9	220.0	15.0

Table 19: Table showing current and voltage reading for Nichrome 15.0 Ω under 220 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	9.2	230.0	15.0
2	9.2	230.0	15.0
3	9.3	230.1	15.0
4	9.3	230.1	15.0
5	9.2	230.0	15.0

Table 20: Table showing current and voltage reading for Nichrome 15.0 Ω under 230 V

Trials	Current Reading (A) (± 0.1A)	Voltage Reading (V) (± 0.1V)	Resistance of the heating element (Ω)
1	9.6	240.0	15.0
2	9.7	240.1	15.0
3	9.7	240.1	15.0
4	9.7	240.1	15.0
5	9.6	240.0	15.0

Table 21: Table showing current and voltage reading for Nichrome 15.0 Ω under 240 V

- ✓ For all of the data values represented in tables 2-21, I changed the voltage value and measured the current which was dependent on it. I used this method with each resistance value and found gathered current reading from the ammeter.

- The following tables are data values reorganized as averages for the calculations following up:

Value of Resistance (Ω)	Average Voltage Reading (± 0.1V)	Average Current Reading (± 0.1A)
6.0	200.0	12.50
6.0	220.0	13.75
6.0	230.0	14.40
6.0	240.0	15.00

Table 22: Table showing average data values from tables 2-5.

Value of Resistance (Ω)	Average Voltage Reading (± 0.1V)	Average Current Reading (± 0.1A)
8.0	200.0	11.10
8.0	220.0	12.20
8.0	230.0	12.80
8.0	240.0	13.30

Table 23: Table showing average data values from tables 6-9.

Value of Resistance (Ω)	Average Voltage Reading (± 0.1V)	Average Current Reading (± 0.1A)
10.0	200.0	10.00
10.0	220.0	11.00
10.0	230.0	11.50
10.0	240.0	12.00

Table 24: Table showing average data values from tables 10-13.

Value of Resistance (Ω)	Average Voltage Reading (± 0.1V)	Average Current Reading (± 0.1A)
12.0	200.0	9.10
12.0	220.0	10.00
12.0	230.0	10.45
12.0	240.0	10.90

Table 25: Table showing average data values from tables 14-17.

Value of Resistance (Ω)	Average Voltage Reading (± 0.1V)	Average Current Reading (± 0.1A)
15.0	200.0	8.00
15.0	220.0	8.80
15.0	230.0	9.20
15.0	240.0	9.60

Table 26: Table showing average data values from tables 18-21.

- The following tables represent the voltage applied to the heating element and time for water specified at 20^{o}C to reach 100^{o}C:

Voltage Reading (Volts)	Time (Seconds) (±0.01s) measured while change in temperature From 20^{o}C to 100^{o}C						Resistance of the Heating Element (Ω)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	**Average**	
200.0	200.0	200.1	199.8	199.9	199.9	**200.0**	6.0
220.0	180.0	180.1	180.2	180.2	180.1	**180.1**	6.0
230.0	169.9	170.0	170.0	170.0	170.1	**170.0**	6.0
240.0	160.0	159.8	160.1	160.0	160.1	**160.0**	6.0

Table 27: Table showing the change in temperature for each trial with Nichrome 6.0Ω.

Voltage Reading (Volts)	Time (Seconds) (±0.01s) measured while change in temperature From 20^{o}C to 100^{o}C						Resistance of the Heating Element (Ω)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	**Average**	
200.0	180.1	180.1	180.2	180.2	180.2	**180.2**	8.0
220.0	160.1	159.9	160.1	160.1	160.1	**160.1**	8.0
230.0	149.9	150.0	150.0	150.0	150.1	**150.0**	8.0
240.0	140.0	139.9	139.9	139.8	139.9	**139.9**	8.0

Table 28: Table showing the change in temperature for each trial with Nichrome 8.0Ω.

Voltage Reading (Volts)	Time (Seconds) (±0.01s) measured while change in temperature From 20^{o}C to 100^{o}C						Resistance of the Heating Element (Ω)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	**Average**	
200.0	160.1	159.8	160.0	160.0	160.0	**160.0**	10.0
220.0	140.1	139.8	139.9	139.8	139.9	**139.9**	10.0
230.0	129.9	130.0	130.0	130.1	130.1	**130.0**	10.0
240.0	120.0	119.8	119.7	119.8	119.7	**119.8**	10.0

Table 29: Table showing the change in temperature for each trial with Nichrome 10.0Ω.

Voltage Reading (Volts)	Time (Seconds) (±0.01s) measured while change in temperature From 20^{o}C to 100^{o}C						Resistance of the Heating Element (Ω)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	**Average**	
200.0	169.9	170.2	170.2	170.3	170.1	**170.2**	12.0
220.0	149.9	150.2	150.1	150.0	150.1	**150.1**	12.0
230.0	140.1	139.9	139.8	139.8	139.9	**139.9**	12.0
240.0	129.7	130.0	130.1	130.1	130.1	**130.0**	12.0

Table 30: Table showing the change in temperature for each trial with Nichrome 12.0Ω.

Voltage Reading (Volts)	Time (Seconds) (±0.01s) measured while change in temperature From 20^{o}C to 100^{o}C						Resistance of the Heating Element (Ω)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	**Average**	
200.0	190.0	190.1	190.1	190.2	190.1	**190.1**	15.0
220.0	169.8	170.0	170.0	170.1	170.1	**170.0**	15.0
230.0	160.1	159.9	160.0	160.1	160.0	**160.0**	15.0
240.0	150.0	150.0	150.0	150.0	150.1	**150.0**	15.0

Table 31: Table showing the change in temperature for each trial with Nichrome 15.0Ω.

a) Calculations:

A. Calculating the internal resistance of the power source/transformer:

To calculate the internal resistance of the power source and other components except the heating element I will be using the ohm's law. I will use a random set of data above such as:

Ohm's Law: $V = I \cdot R$

For the trial with the 6.0Ω resistance;

Voltage Reading: **200.0V**

Current Reading: **12.5A**

- ✓ $200V = 12.5A\ x\ Total\ Resistance\ of\ the\ Circuit$
- ✓ $\frac{200}{12.5} = 16 = Total\ Resistance\ of\ the\ Circuit$
- ✓ $Internal\ Resistance\ of\ the\ Power\ Source = Total\ Resistance - 6.0\Omega$
- ✓ $\boldsymbol{Internal\ Resistance\ of\ the\ Power\ Source = 10.0\Omega}$

- The same calculations were made for every other trial and the same results were found.

B. Calculating the total power output of the circuit:

To calculate the total power output of the circuit I will be using the ohm's law on power.

I will use a random set of data as an example calculation:

Ohm's Law: $P = I^2R = IV = \frac{V^2}{R}$

For the trial with the 6.0Ω resistance;

Voltage Reading: **200.0V**

Current Reading: **12.5A**

- ✓ $Power = 200V\ x\ 12.5A$
- ✓ $Power = 2500\ Watts$

- ✓ Using the calculation method in the previous *Calculations Part B* the following table contains the resulting values of the total power output of the circuit for each trial:

Voltage Reading (Volts)	Total Power Output of the Circuit (Watts)				
	Resistance of the Heating Element (Ω)				
	6.0 Ω	**8.0 Ω**	**10.0 Ω**	**12.0 Ω**	**15.0 Ω**
200.0	2500.0	2220.0	2000.0	1820.0	1600.0
220.0	3025.0	2684.0	2420.0	2200.0	1936.0
230.0	3312.0	2944.0	2645.0	2404.0	2110.0
240.0	3600.0	3192.0	2880.0	2616.0	2304.0

Table 32: Table showing the total power output of the circuit for each trial.

C. Calculating the power dissipated on the Heating Element:

To calculate the power dissipated on the heating element, I will use the following formula with a random set of data as an example calculation:

$$Power\ Dissipated\ on\ the\ Heating\ Element = \frac{Total\ Power\ Output\ of\ the\ Circuit}{Total\ Resistance\ of\ the\ Circuit}\ x\ Resistance\ of\ the\ Heating\ Element$$

Let the power dissipated on the heating element = X

- ✓ $X = \frac{2500.0W}{16.0\Omega}\ x\ 6.0\Omega$
- ✓ $X = 937.5W$

- The same calculations were made for every other trial and the same results were found.

- Using the calculation method in the previous *Calculations Part C* the following table contains the resulting values of the power dissipated on the heating element for each trial:

Voltage Reading (Volts)	Power Dissipated on the Heating Element (Watts)				
	Resistance of the Heating Element (Ω)				
	6.0 Ω	**8.0 Ω**	**10.0 Ω**	**12.0 Ω**	**15.0 Ω**
200.0	937.5	986.7	1000.0	992.7	960.0
220.0	1134.4	1192.9	1210.0	1200.0	1161.6
230.0	1242.0	1308.5	1322.5	1311.3	1266.0
240.0	1350.0	1418.7	1440.0	1426.9	1392.4

Table 33: Table showing the power dissipated on the heating element for each trial.

D. Calculating the power dissipated on the Heating element using heat.

To calculate power through heat, I will use the following formulas and use a random set of data as an example calculation:

$$P = \frac{Q}{T}$$

$$Q = m \; x \; c \; x \; \Delta T$$

- ✓ P = Power (watts)
- ✓ Q = Heat added
- ✓ T = Time (seconds)
- ✓ m = Mass of water (Kg)
- ✓ c = Specific heat of water (J kg^{-1} K^{-1})
- ✓ ΔT= Change in Temperature (^{o}C)

For the trial with the 6.0Ω resistance;

Time (seconds) = 200.0

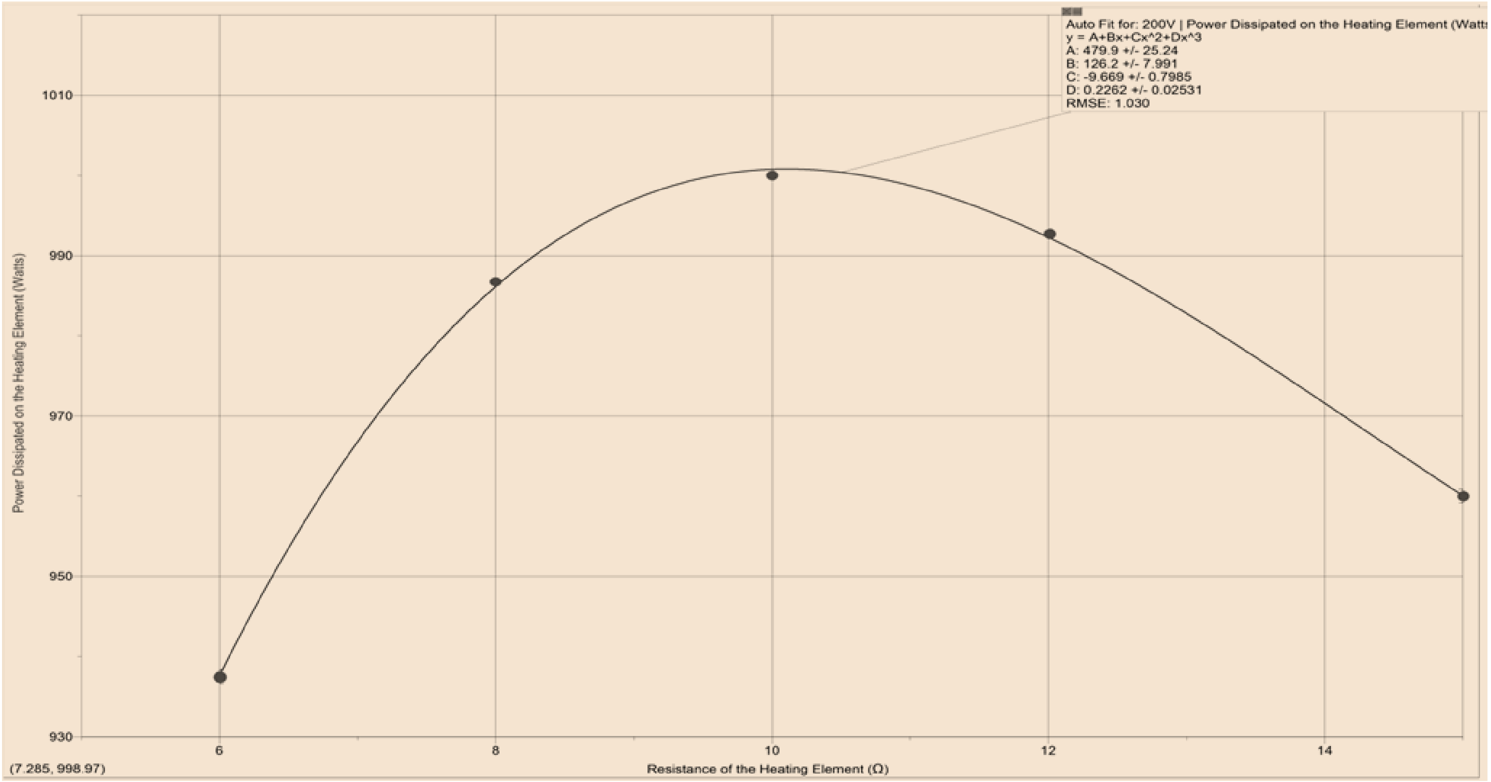
Mass (kg) = 0.5

C (J kg^{-1} K^{-1}) = 4200

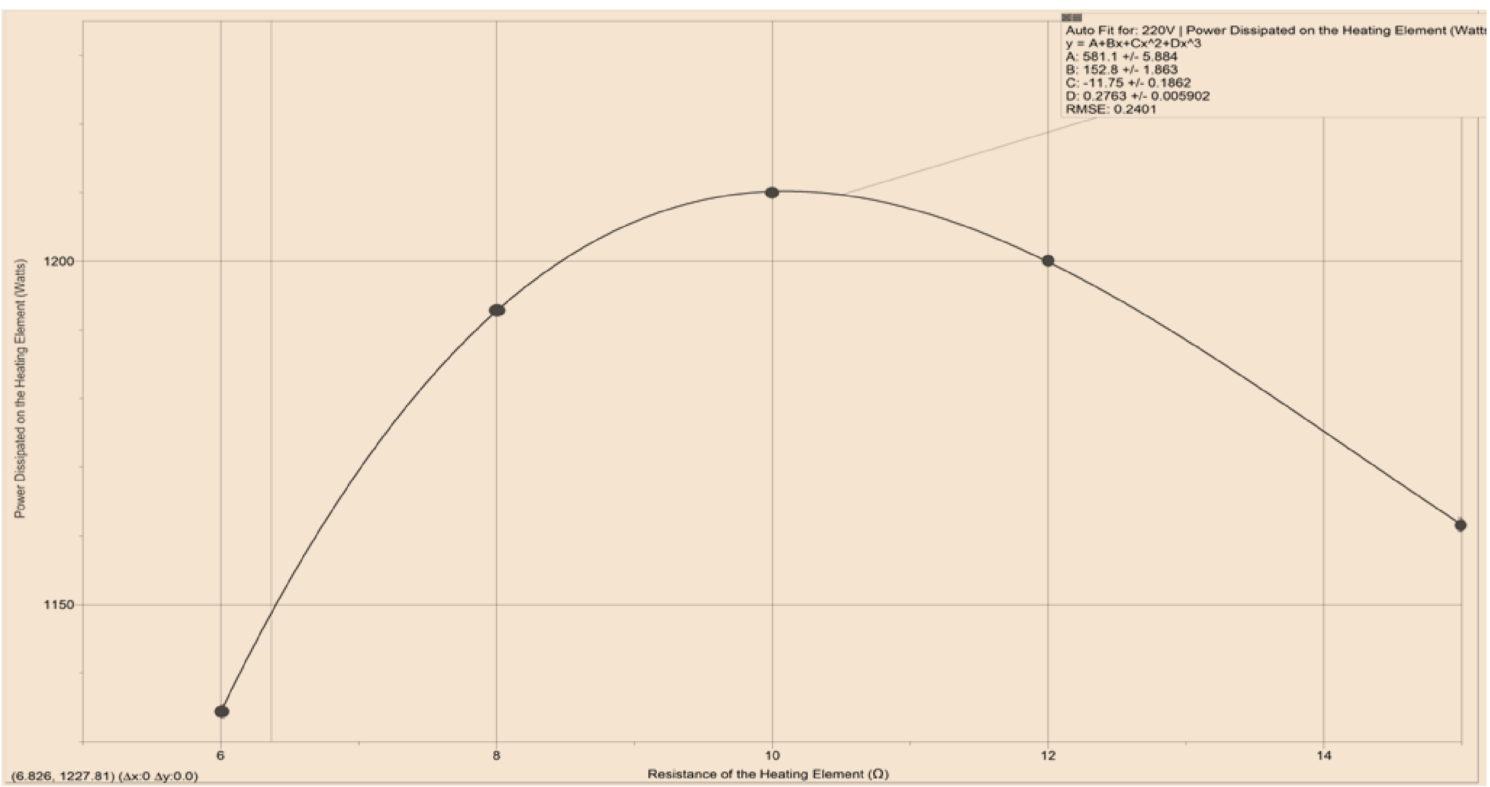
ΔT (^{o}C) = 80.0

- ✓ $P = \frac{m \; x \; c \; x \; \Delta T}{T}$
- ✓ $P = \frac{0.5 \; x \; 4200 \; x \; 80}{200}$
- ✓ $P = 840.0W$

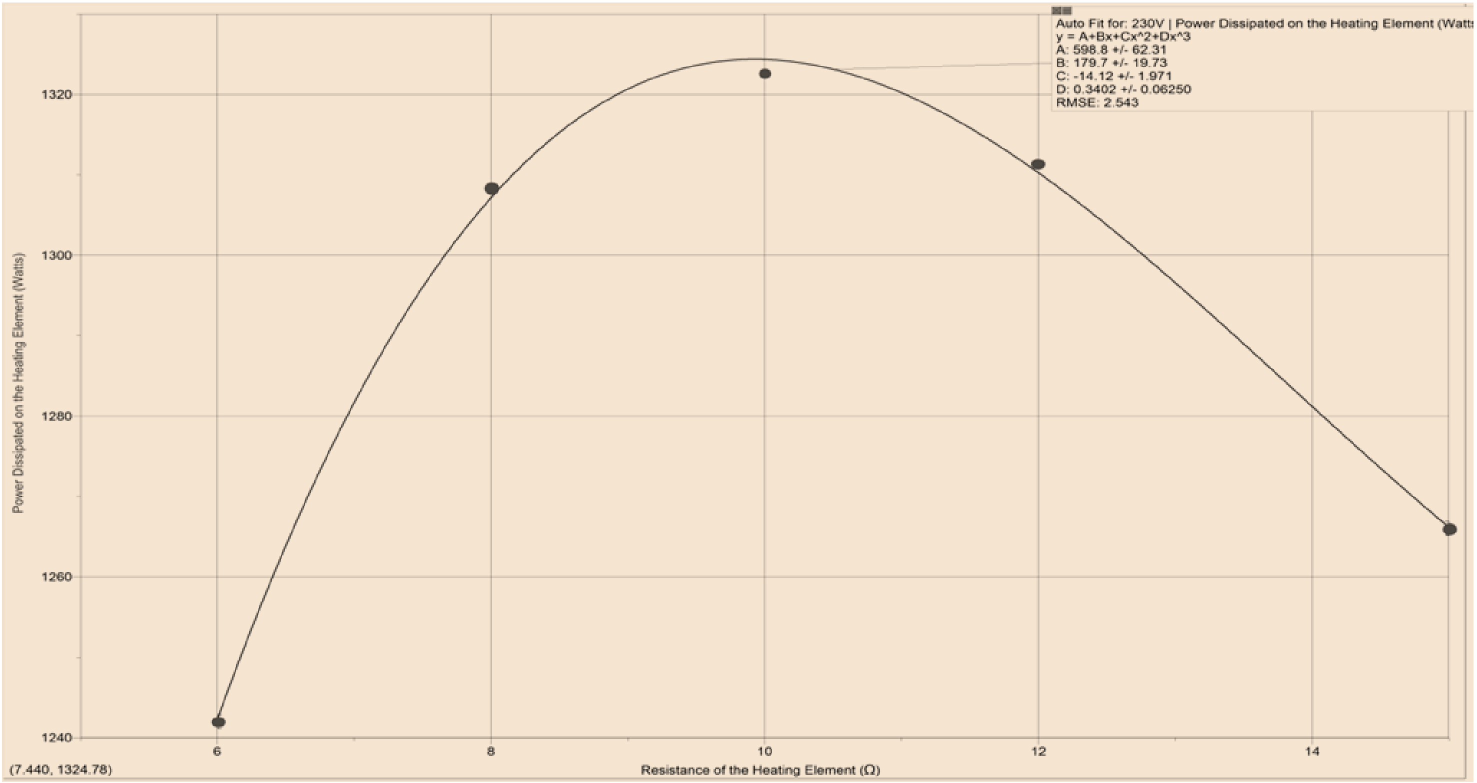
- The same calculations were made for every other trial and the same results according to those data were found.



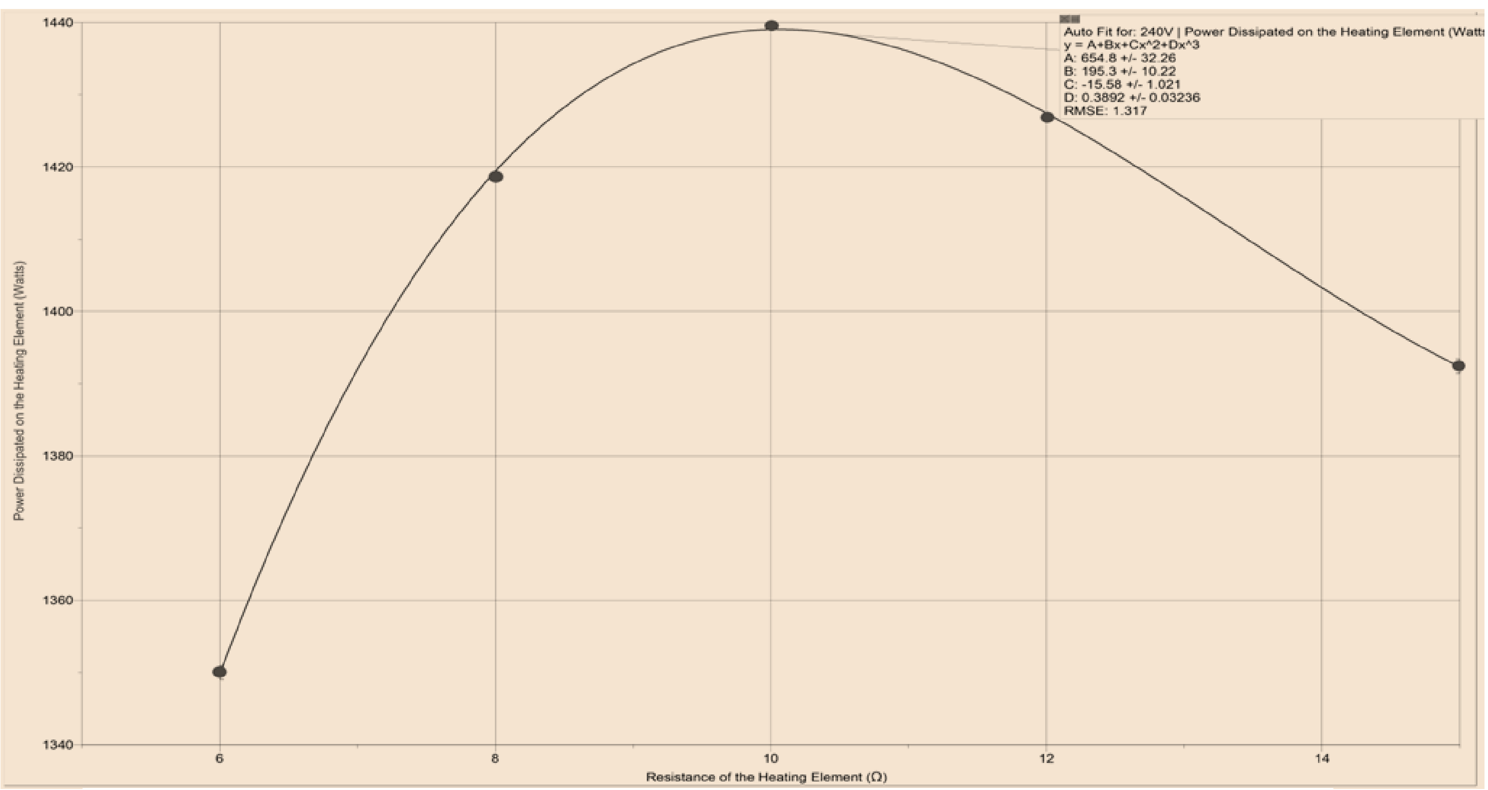
Graph 1: Graph showing power dissipated on the heating element against resistance of the heating element for 200 Volts.



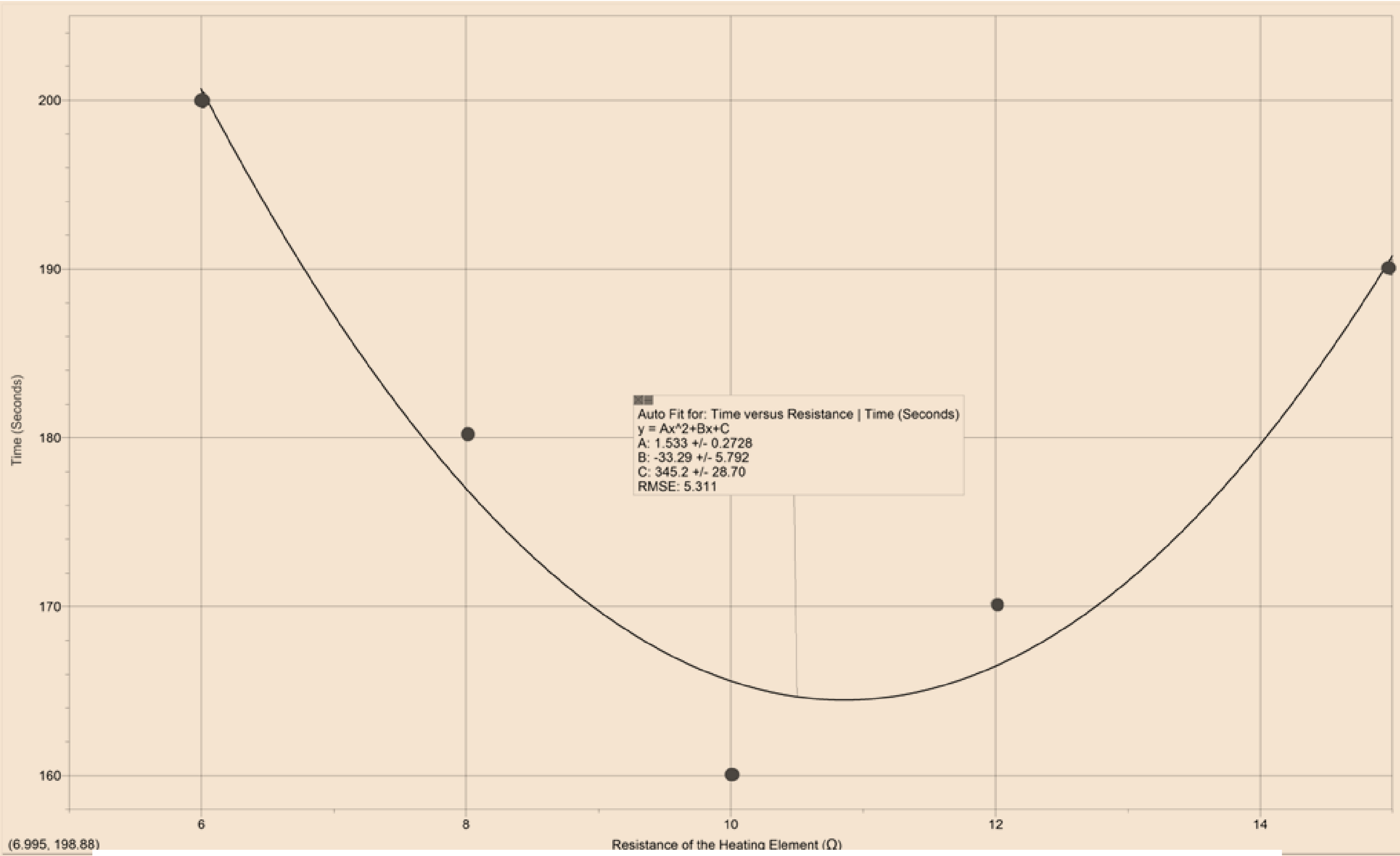
Graph 2: Graph showing power dissipated on the heating element against resistance of the heating element for 220 Volts.



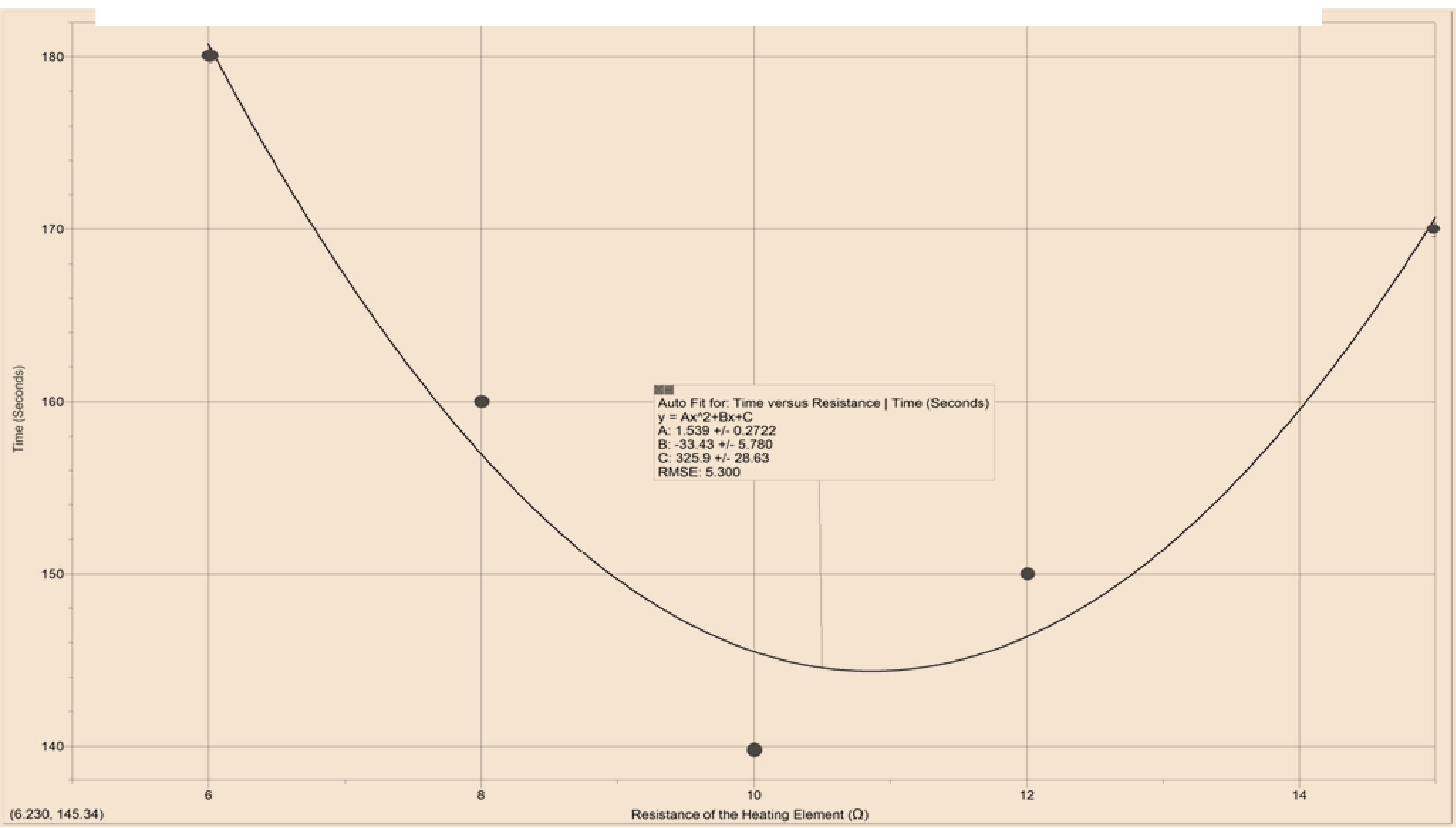
Graph 3: Graph showing power dissipated on the heating element against resistance of the heating element for 230 Volts.



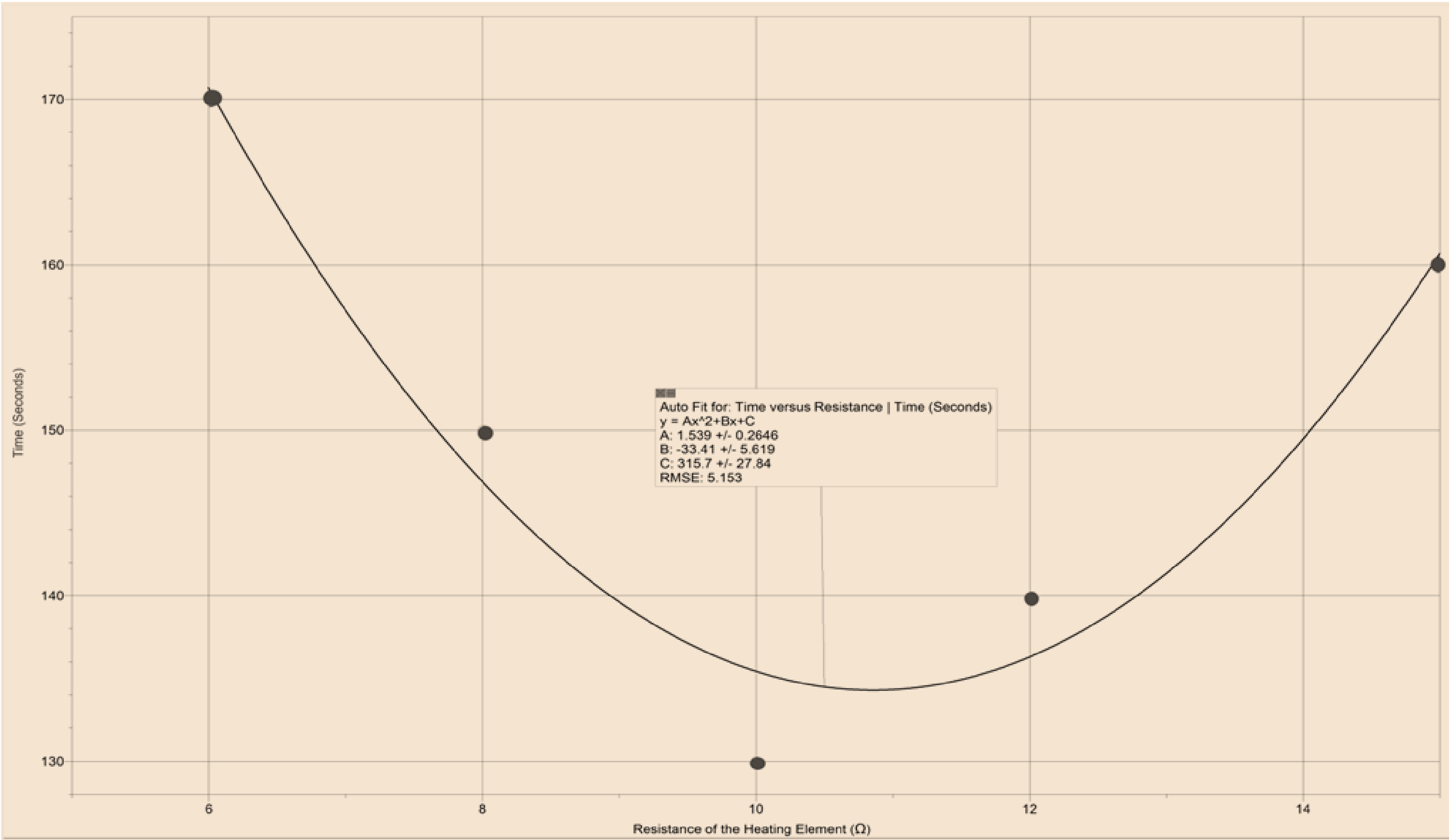
Graph 4: Graph showing power dissipated on the heating element against resistance of the heating element for 240 Volts.



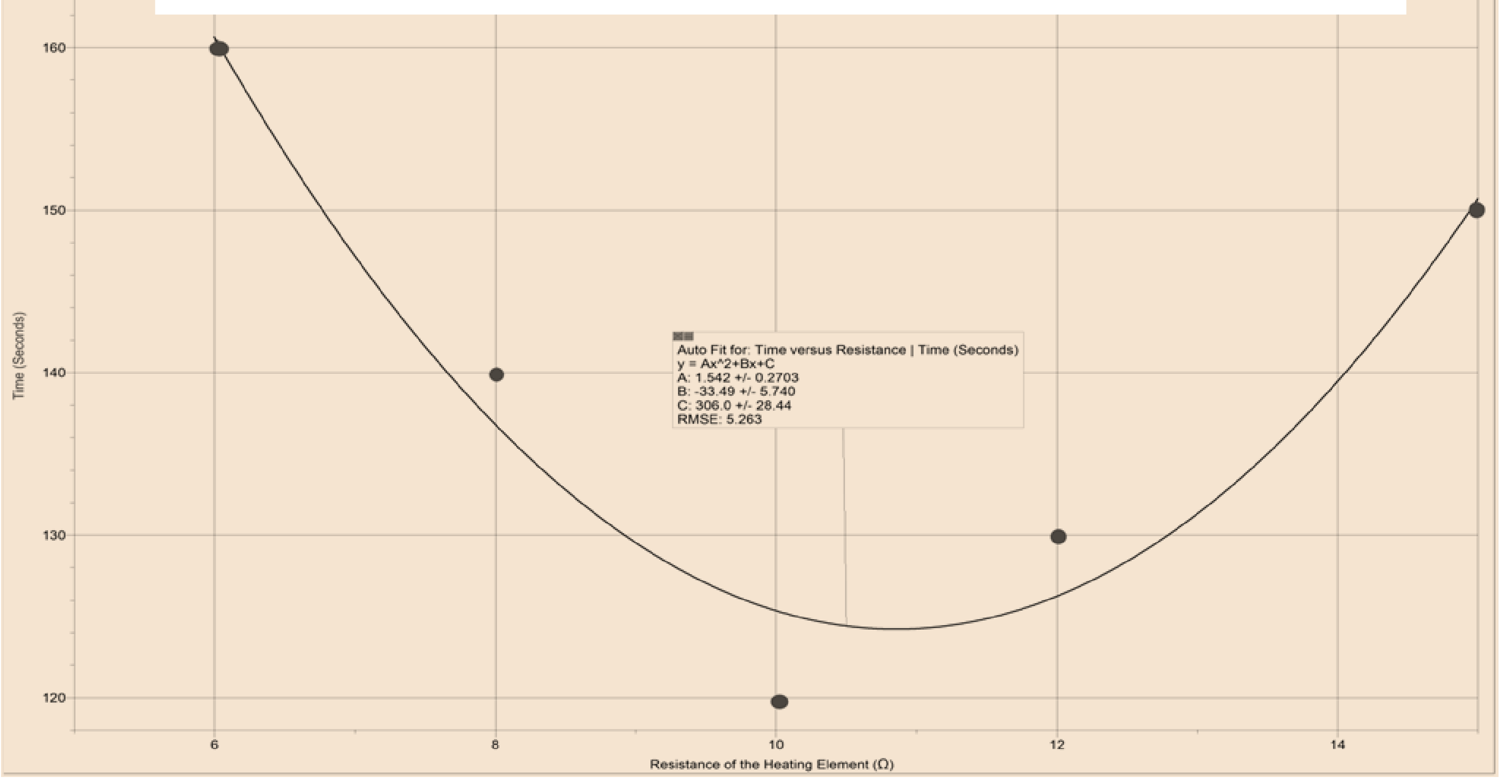
Graph 5: Graph showing Time (Seconds) (Required to heat up the water to 100^{o}C) against resistance of the heating element for 200 Volts.



Graph 6: Graph showing Time (Seconds) (Required to heat up the water to 100^{o}C) against resistance of the heating element for 220 Volts.



Graph 7: Graph showing Time (Seconds) (Required to heat up the water to 100°C) against resistance of the heating element for 230 Volts.



Graph 8: Graph showing Time (Seconds) (Required to heat up the water to 100°C) against resistance of the heating element for 240 Volts.

6) Conclusion and Evaluation:

a) Conclusion:

The first four of the graphs has taken a bell like shape where they all peak at the value of 10Ω. The peak point on the graphs represents the point at which the power output is maximum on the heating element. As I've mentioned before how when the internal resistance of the power supply is equal to that of the resistance in a direct current circuit, looking at the resulting data here, it can be said that this can also be applied to alternating current. Using this simple method can simplify the process of finding ideal resistances for house appliances, or kettles in this experiments case.

The statement of which the point where the internal resistance of the cell equals to the resistance of the heating element results in the greatest power output is further proven with the data found on tables 27-31 which represent the change in temperature over time. When we look at the data gathered there, it is seen that when the resistance chosen was 10Ω, being equal to the calculated internal resistance, the process of boiling the water was the fastest. This was also seen in the last for graphs as the graphs took an inverse bell like shape peaking at resistance values which equal to the internal resistance of the circuit.

As a result of this experiment, we can say that maximum power output on the heating element would result in the most rapid boiling of water. Looking back at the hypothesis, it is safe to say that it has been proven correct, and that when the resistance of the heating element is equal to the internal resistance of the power source, the power dissipated on the heating element is maximum in both direct and alternating current circuits, resulting in the fastest water boiling.

b) Evaluation:

The experimental design is simple to build and there is little variables in terms of which the experiment is carried on. As seen from the resulting data, there has not been any major errors and error sources.

Suggestions for further research would be that since the circuit is under alternating current, the experiment could be carried with different circuit components placed. The biggest error source in this essay was due to the components of the circuit. As it is seen from the resulting data, when calculating the power, using the Ohm's Law, it was greater than what was calculated by using heat. As seen in the previous calculations, for the trial set of data used, the power found using Ohm's law was 937.5 Watts and the power found using heat was 840.0 Watts. I believe the difference caused here was because of the shape of the heating element. The heating element in this experiment was shaped as a solenoid. This shape of heating element was used because it is the same in which commercial kettles use. Under alternating current, the Ohm's Law differs because of the power factor added in to the equation. Since a solenoid shaped wire would cause an inductive effect which changes the power factor. In this essay, calculations made through the Ohm's Law disregarded the power factor thus resulting in the difference between the two calculated values. Since this is the case, I believe it is a more healthy method to calculate power through heat.

This experiment was set out to find the ideal resistance for the heating element. As seen from the data gathered here, it isn't possible to identify a certain voltage that would be considered ideal. Finding the ideal voltage idea was dropped in this experiment because it has too many variables that could affect the term "ideal". According to the results of the experiment, the power output on the resistance would keep increasing for every voltage trial without end. Due to this, finding an ideal voltage under which the kettle should work is not possible. What was possible in this experiment was finding an ideal resistance value which was achieved. A suggested area of further investigation would be set to find an ideal voltage as well.

Last but not least, like I had mentioned at the beginning of this report, maximum power output does not mean maximum efficiency. These terms should not be confused since they are completely different terms. To give an example in this area, it was found in the conclusion of this experiment we found how the maximum power is dissipated on a heating element. According to research I have done in literature, maximum power output under direct current happens when efficiency is at 50%. For the efficiency to be 100% the internal resistance of the power source must be brought close to 0 which is impossible with current technology. An advanced investigation could be conducted in this area of science.

7) Bibliography:

[1]: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/resis.html (Visited on: 21 February 2011)

[2]: http://www.physicsclassroom.com/class/energy/u5l1e.cfm (Visited on: 21 February 2011)

[3]: http://en.wikipedia.org/wiki/Heat_transfer (Visited on: 21 February 2011)

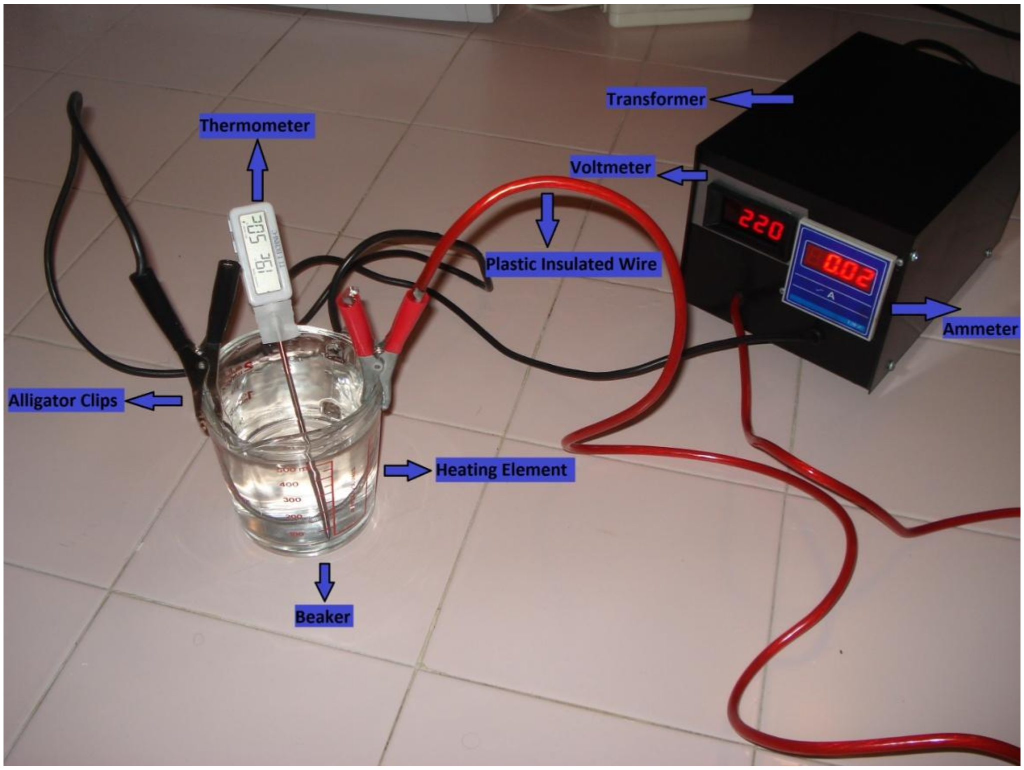
[4]: http://en.wikipedia.org/wiki/Electric_kettle (Visited on: 21 February 2011)

8) Appendix

Picture 2: Picture showing the water container and the measuring of the initial temperature.

Picture 3: Picture showing how the alligator clips are attached to the heating element.

Picture 4: Picture showing how the alligator clips and the heating element are placed inside the water container



Picture 5: Picture showing the whole circuit with all the components labelled.

Picture 6: Picture showing the transformer without any voltage level turned on and the plastic insulated conducting wires leading out from it.