EXPERIMENT 2TS1

The Stefan-Boltzmann law describes the power radiated from a black body in terms of its temperature. For a real object, this law is expressed as:

$$P = \varepsilon \sigma A T^4$$

Where:

- P is the total power radiated (in watts)
- ε is the emissivity of the object (dimensionless, between 0 and 1)
- σ is the Stefan-Boltzmann constant (approximately $\mathbf{5.6696 \times 10^{-8}}$ $\mathbf{W/m^2/K^4}$)
- A is the surface area of the object (in m^2)
- T is the absolute temperature of the object (in Kelvin)

In this experiment, we use an incandescent light bulb as our radiating object. The tungsten filament in the bulb acts as an approximate black body radiator, though its emissivity is less than 1. For such, the equation is modified to account for ambient temperature (T_0):

$$P = \varepsilon \sigma A \left(T^4 - T_0^{\,4}\right)$$

<u>Key theoretical points:</u>

1. Resistance-Temperature Relationship: The resistance of the tungsten filament changes with temperature according to the equation:

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

Where R_0 is the resistance at room temperature T_0, and α is the temperature coefficient of resistance for tungsten, which is $4.5\times10^{-3}/°C$ (Note; is per degree Celcius).

2. Power Input: The electrical power input to the bulb is given by:

$$P = IV$$

Where V is the voltage across the bulb and I is the current through it.

3. Equilibrium: At steady state, the electrical power input equals the power radiated plus small losses due to conduction and convection.

4. T^4 Dependence: By varying the current through the bulb and measuring the corresponding voltage, we can calculate the power and estimate the filament temperature. Plotting power against T^4 should yield a straight line, the slope of which is related to the Stefan-Boltzmann constant.

5. Filament Dimensions: The surface area of the filament is crucial for accurate calculations. For an E10 bulb, typical dimensions are used (length ≈ 1 cm, diameter ≈ 0.0254 mm).

Experimental Setup and Methodology:

1. Materials:

   a) E10 incandescent light bulb (as shown in the image)

   b) Variable DC power supply

   c) Digital multimeter for voltage measurements

   d) Constant Current (CC) Module

   e) Thermometer for room temperature measurement (You may use a digital thermometer instead)

2. Safety Precautions:

   a) Wear safety glasses

   b) Be cautious of hot surfaces as the bulb will heat up during the experiment.

Experiment Procedure:

1. Record the room temperature (T_0) and measure the resistance of the bulb at room temperature (R_0) using a multimeter.

2. Connect the E10 bulb to the constant current (CC) module.

3. Connect the CC module to the variable DC power supply.

4. Connect the voltmeter towards the CC module (details refer to instructor).

5. Connect the voltmeter in parallel with the bulb.

6. Starting with the lowest current (1 mA as per your data table), gradually increase the current through the bulb using the power supply.

   a) There will be several current region of interest: for low current range, i.e. 1 ~ 10 mA, the current incremental is 1 mA.

   b) For current ranging from 10 ~ 150 mA, the current incremental is 10 mA.

7. When a desired current is set, wait for at least 30 seconds for the bulb temperature to reach equilibrium, then perform measurements. You may take additional measurements after 30 seconds.

   a) The measurements referred to the voltage readings from both the bulb and CC module.

Data Analysis:

1. Calculate the power ($P = IV$) for each data point.

2. Calculate the resistance ($R = V / I$) for each data point.

3. Calculate the filament temperature (Note that the following equation will give values in terms of degree Celcius, and you need to perform conversion to Kelvin afterwards). You may refer to the following derivations for such: for each point using the equation:

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

$$1 + \alpha\left(T - T_0\right) = \frac{R}{R_0}$$

$$\alpha\left(T - T_0\right) = \frac{R}{R_0} - 1$$

$$T = \frac{1}{\alpha}\left(\frac{R}{R_0} - 1\right) + T_0$$

4. Calculate $T^4 - T_0^4$ for each temperature point.

5. Plot a graph of Power (P) vs. ($T^4 - T_0^4$).

6. Determine the slope of this graph.

<u>Calculating Stefan-Boltzmann Constant:</u>

1. Use the equation: slope = $\varepsilon\sigma A$

   Where:

   ε is the emissivity of tungsten (approximately 0.4)

   A is the surface area of the filament (π * d * L, where d = 0.0254 mm and L = 1 cm)

2. Solve for σ to get your experimental value of the Stefan-Boltzmann constant.

<u>Error Analysis:</u>

Discuss potential sources of error, such as:

1. Heat loss through conduction and convection

2. Uncertainties in filament dimensions and emissivity

3. Measurement uncertainties in voltage and current