Stefan's law of radiation

Motivation and Aim

A body at an absolute temperature T is found to radiate heat at a rate that is proportional to the fourth power of T. In this experiment a heated tungsten filament is taken to be a blackbody source of radiation. Since the filament is in vacuum, the only source of heat dissipation is by radiation. By measuring the electrical power consumed by the filament as a function of temperature, we determine whether the fourth power law holds.

Apparatus

1. A tungsten filament in an evacuated glass bulb
2. Constant voltage source
2. Millimameter
4. Voltmeter

Procedure

A tungsten filament is heated using a constant voltage source. Setting a voltage, the current in the filament is is allowed to stabilise and measured in a steady state. The voltage is increased in steps and from the measured steady current, the resistance of the filament is determined at each setting.

Finally, we carefully measure the current at which the filament just starts glowing, and determine R_G, the resistance at the temperature at which the filament just starts glowing.

Theory

Based on the equation for the spectral distribution of blackbody radiation, we can determine the total power radiated by the blackbody:

$$P_{\text{rad}} \propto T^4$$

This law is called Stefan's law. All bodies at finite temperature constantly radiate and simultaneously absorb heat from their surroundings. If the temperature of the body is T and the ambient temperature is T_a, the rate of heat exchange is given by the expression

$$\dot{Q} = \varepsilon\sigma(T^4 - T_a^4)$$

where σ is a universal constant called the Stefan's constant and ε is a factor less than 1, which accounts for non-ideal behaviour of the body. For a blackbody, $\varepsilon = 1$.

Analysis

The resistance R of heated tungsten filament changes as a function of temperature T, so the electrical power dissipated by the filament at a constant voltage also changes. The power dissipated is $P = VI$ where V and I are the voltage across and the current through the filament. The resistance of the filament is $R = V/I$. Since the resistance depends on the temperature of a substance, the temperature can be determined from the measured resistance at each stage.

The temperature dependence of resistance is given by the equation

$$R(T) = R_0(1 + \alpha T + \beta T^2)$$

For tungsten $\alpha = 5.21 \times 10^{-3}$ [K]$^{-1}$ and $\beta = 7.2 \times 10^{-7}$ [K]$^{-2}$.

1. Using the measured value of R_G and the known glowing temperature $T_G = 800$ K, we calculate R_0 using the above equation.

2. Plot the electrical power dissipated P $(= VI)$ at each setting vs. the temperature T calculated from the measured value of the resistance (V/I) at each setting.

3. Using the graph verify the fourth power law and determine the constant of proportionality in the equation for the radiated power for the tungsten filament.

Points to Ponder

1. How would you reduce the error in determining when the filament just starts glowing?
2. How much is the error in neglecting the T_a term in the heat exchange expression?