Measuring Planck's Constant using a Tungsten Wire

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We present a measurement of the Planck's Constant obtained through the measurement of radiation emitted by a tungsten wire in a vacuum. By putting a voltage across the resistive wire, it will get energized and will only be able to radiate that energy, as being a vacuum prevents conduction. By measuring this radiation using a PMT, we were able to measure a value of Planck's Constant to be $= (1.4 \pm 0.055) \times 10^{-34}$ Js, with a percent error of 79%.

INTRODUCTION

Planck's Constant is one of the most important constants in physics. It is how one relates the energy of a photon to its frequency. Due its relation to energy, it is also closely related to mass. It is therefore now used to define the kilogram. in 1900, Max Planck derived a formula for an electrical oscillator in a cavity that would radiate like a black body. He could related the energy radiated to the frequency, and called this constant h. This quantum was eventually found to be of importance to defining the photon by Albert Einstein using the photoelectric effect.

THEORY

In order to make such a measurement of such a small quantity, using ratios of independent variables is preferred to measuring absolute values. The following equation can be derived by assuming all electrical power P goes into radiation. We can related the temperature of a black body to the power radiated using Stefan's Law:

$$P = A\sigma T^4 \tag{1}$$

where σ is Stefan's constant:

$$\sigma = \frac{2\pi^5 k^4}{15h^[3]c^2} \tag{2}$$

And through derivation of the intensity seen at some distance r from the wire, one can derive the following formula for h:[1]

$$h \simeq \frac{15c^2}{2\pi^5 A\nu^4} \frac{P_1 P_2}{(P_1^{1/4} - P_2^{1/4})^4} \log^4 \frac{I_1}{I_2} \tag{3}$$

As we can see, with this equation we do not calculate h using absolute values - we are taking ratios of power and intensity. As such, we can expect to make a more precise measurement of h. ν is frequency, and is selected using a single-frequency filter that is put in front of a PMT which is used to measure the intensity.

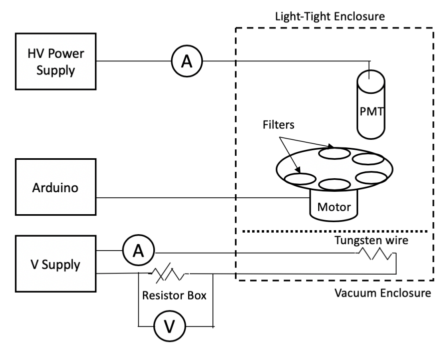

FIG. 1. An image of the setup used.

EXPERIMENTAL PROCEDURE

The setup consists of a steel vessel that is evacuated using a high-power vacuum pump. A tungsten wire is held in place within this vacuum. A plexiglass sheet separates the vacuumed out chamber from the PMT and a disk which holds 6 single-color filters that sit on a rotating plate. This plate can be spun with a stepper motor which is controlled by an Arduino to move a specific filter in front of the PMT. The filters used allowed light of wavelengths of 300nm to 700nm to reach the PMT. A heavy black rubber enclosure is then placed around the PMT to make the setup light-tight. The PMT is brought up to 1500V, and the wire inside the enclosure is fed some voltage V while in series with a resistor box. We calculate the power emitted by the wire by using an ammeter to measure the current draw of the resistor-wire circuit, and calculate the resistance of the wire by measuring the voltage drop across the resistor box. The ratio of voltages across each resistive component is directly proportional to the ratio of resistances of each component, so we can derive the resistance of the wire thusly. This is necessary because the resistance of the wire changes as it heats up, ranging from 100 Ω to 300 Ω. We obtain the intensity of the radiation emitted by measuring the DC current out of the PMT. The intensity of light received by the PMT is directly proportional to this current, and since we take a ratio, all constants drop out.

We are able to vary the measured wavelength of light by using different filters. We used 630-660nm, 540nm, 505nm, 450nm, 400nm, and 340nm light filters. We were also able to vary the voltage across the tungsten wire and the resistance of the resistor box. As such, we could eliminate multiple systematics by varying these parameters.

The general procedure was to use the Arduino to move a specific filter in front of the PMT, then take measurements of the PMT's current, the voltage across the tungsten wire, and the current drawn by the wire at varying voltages with a set resistance. We would then repeat this procedure with different filters or resistances.

DATA ANALYSIS

Our value for the Planck's Constant was found to be:

$$h = (1.4 \pm 0.055) \times 10^{-34} \quad (4)$$

Our result has a deviation of 79% from literature[2].

Our value has a low standard deviation of 3.9%, and so while our value is very precise, it is relatively inaccurate. Despite trying to eliminate systematics, it is possible that there is something in the system we are not accounting for that is causing a constant shift downwards of our value. One possible candidate is our assumption that the intensity of light seen by the PMT is directly proportional to its DC current. We recommend that the next group re-evaluate whether this is a valid assumption to make.

Another issue we ran into while taking data was that because the stepper motor sometimes skips steps, it is not possible to be always certain of the position of the filters within the enclosure. However, opening the enclosure means that we have to power down the PMT to avoid damaging it. Once the PMT is turned back on, it takes time for background to settled out and for the PMT to reach a steady state. We have addressed this issue and will discuss more in the next section.

IMPROVEMENTS

To improve this experiments for future Ad Lab scientists, we planned to attach a potentiometer to the rotating plate of filters. In doing so, the rotation of the plate sets the potentiometer to some resistance. By putting a voltage across this potentiometer and measuring the voltage across two pins of the potentiometer, we can then encode the position of the filter plate at any time. This removes the necessity to ever open the enclosure to check the positions of the filter plates.

A colleague named Constantinos Gerontis offered to help make a 3D printed mount for the potentiometer. It is currently sitting inside the enclosure and has been shown to work successfully. The next group will need to however rewrite the Arduino code in order to utilize this new feature.

CONCLUSION

We were able to make a precise measurement of Planck's Constant of $h = (1.4 \pm 0.055) \times 10^{-34}$ Js with a deviation from literature[2] of 79%. As stated before, this seems to suggest a systematic that consistently offsets the value of h that we measured. We hope that the improvements that we have made to the set up will aid future scientists in making more accurate measurements of Planck's Constant.

[1] R. E. Crandall and J. F. Delord. Minimal apparatus for determination of plancks constant. *American Journal of Physics*, 51(1):9091, 1983.

[2] Peter J. Mohr, David B. Newell, and Barry N. Taylor. Codata recommended values of the fundamental physical constants: 2014. *Journal of Physical and Chemical Reference Data*, 45(4):043102, 2016.

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