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Online and Offline Analysis of Planck Constant Measurement

Zhongqi LUAN, Lina WANG[1], Yanjun WANG, Haifeng GU and Yaxiang BAI
School of Marine Science and Environment, Dalian Ocean University, Dalian, China

Abstract. The online virtual experimental platform and the laboratory photoelectric effect method were used to measure Planck's constant. Excel software was used for linear fitting, and Planck's constant and errors were analyzed and calculated. It was found that the offline experimental value was better than the online virtual observed value. However, the error of the online virtual experiment value is also within the controllable range. In the particular current period of frequent epidemics or for schools lacking experimental instruments, it is also a perfect choice to use the virtual experiment platform to measure the relevant empirical data.

Keywords. Planck constant, photoelectric effect, cut-off voltage

1. Introduction

Planck's constant was first proposed by Max Planck more than a hundred years ago when he solved the problem of black body radiation by assuming that energy is quantized and can only be emitted or absorbed by integer multiples of a small unit [1]. The energy according to a particular quantum is described by the equation:

$$E = h\nu \tag{1}$$

Where υ is the frequency of radiation and h is Planck's constant. Then in 1905, Albert Einstein extended Planck's black-body model by likening light as consisting of discrete quanta of photons with energy hυ, where υ is expressed as the incident light's frequency [2]; however, this phenomenon is called the photoelectric effect. The photoelectric effect is explained according to Einstein's photoelectric equation, which is expressed as:

$$h\nu = \phi + E_{max} \tag{2}$$

Where ϕ is the work function of the metal, and E_{max} is the maximum kinetic energy of the ejected electrons. Since then, it has played an essential role in the proposal of Planck's constant in quantum physics and has become one of the constants commonly used in physics [3-4].

The most widely used method for determining Planck's constant is to use the photoelectric effect. This method is also a must-do experiment for science and engineering students in colleges and universities, especially for physics-related majors. The mode of processing students' experimental data offline in this experiment mainly adopts the method of manual drawing on graph paper, manually drawing a curve, creating a tangent at a point on the turn, finding the intersection of the two tangents, and performing linear fitting. All steps may lead to significant errors, and the amount of experimental data is large, so this processing method is very time-consuming [5,6].

[1] Corresponding author: l.n.w@163.com

Therefore, it is better to choose EXCEL or ORIGIN [7] to adopt the least squares method for the experimental data processing method. This paper uses EXCEL for direct linear fitting and data processing.

At the same time, due to the surge in demand for online virtual experiments due to the new crown epidemic in recent years, this experiment has also developed an online virtual experiment platform. The data processing of the online virtual experimental platform, the offline experiment practical measurement results, and the analysis of their errors and experiment practical and disadvantages can provide a better reference for selecting the Planck constant measurement method.

2. Experimental principle

Figure 1 in the following shows the photoelectric effect experiment diagram. In the figure, S is the photocell, the K pole is the cathode used to release electrons in the photocell, and A is the anode in the photocell. If there is no light irradiating the K pole plate, there will be no electrons escaping, and the A pole and the K pole are in an open circuit phenomenon, so there is no display in the galvanometer G, and no current flows. If we use a piece of monochromatic light with a short wavelength to irradiate the K plate, electrons will escape. Still, a photo current can be formed so that the galvanometer G will have an indication.

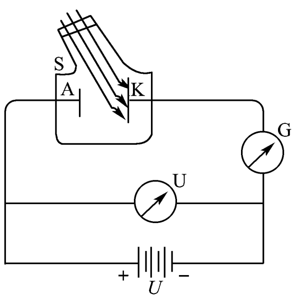

Fig.1. Schematic diagram of the photoelectric effect

When a photoelectron escapes from the K-pole metal plate, the photoelectron has initial kinetic energy and moves under the reverse force of the deceleration voltage; that is, the direction of movement of the photoelectron is opposite to the direction of the electric field force. The photoelectrons will move from the K pole plate to the A pole plate. However, if $U = U_0$ occurs, there will be no photoelectrons from the K pole plate to the A pole plate. The photocurrent decreases to zero, so the kinetic energy of the photoelectron is precisely equal to the work it does in the electric field to overcome the electric field force, that is the following equation:

$$\frac{1}{2}mv^2 = e|U_0| \qquad (3)$$

Thus, we can learn from Einstein's hypothesis about the nature of light that light is a particle in motion, and light particles are also called photons. The energy of each photon is E=hυ, and in this formula, h is Planck's constant, while υ is the frequency of the light wave. Therefore, the corresponding photons have different energies at different frequencies of light waves. After the photoelectron absorbs the photon energy hυ, part of the energy is used to overcome the energy consumed when the electron escapes from the metal surface, called the escape work W_0, and the other part of the energy is converted into the kinetic energy of the electron moving in the electric field when it escapes from the metal surface. Finally, we will get the following equation from the law of conservation of energy.

$$h\nu = \frac{1}{2}mv^2 + W_0 \qquad (4)$$

Eq. (4) is the famous Einstein equation for the photoelectric effect [8-10].

From the equation in equation (3) above and brought into equation (4) it can be seen:

$$h\nu = |U_0|e + W_0 \qquad (5)$$

The equation that can then be obtained is

$$|U_0| = \frac{h}{e}\upsilon - \frac{W_0}{e} \qquad (6)$$

This equation shows that the Planck constant h can be calculated from the slope of $U_{0\text{-}\upsilon}$, which can be expressed as

$$h = ek \qquad (7)$$

The curb voltage U_0 is measured by the zero-current method. In the zero-current process, the curb voltage U_0 is the absolute value of the voltage U_{AK} corresponding to the zero current measured under each spectral irradiation. This method has a necessary prerequisite, that is, the corresponding anode reverse current, dark current, and background current are very small; only then the difference between the curb voltage U0 and the theoretical value of the curb voltage measured by the zero-current method is minimal, and the difference ΔU of the curb voltage of each spectral line has little effect on the slope of the U0 - υ curve and thus has no significant impact on the measurement of Planck h [11].

3. Experimental principle

3.1. Off-line experimental data analysis

The laboratory line experimental apparatus, as shown in Figure 2, includes a light source (mercury lamp), photocell, filter set, and photoelectric effect tester composition.

Since the light source is a mercury lamp light source, which is a gas light source, it has the characteristics of a gas light source, such as the need to preheat for 15 minutes, does not have the instantaneous start characteristics, etc., and needs to be used as a critical instruction for students during the experiment.

Fig. 2. Underline Planck constant measuring instrument

Because the current generated in the experimental measurement process is tiny, and the size of the wind with the practical selection of the sensitivity of the phototube and the light source luminous intensity are closely related. Thus the off-line experimental measurement process in the experimental instrumentation adjustment, the current detector gear needs to be adjusted at about $10^{-10} A$/division. As the curb voltage is the voltage corresponding to the photocurrent is zero, if the current amplifier is not sensitive enough or the stability is not good, it will bring a significant error in the measurement [12]. Table 1 shows the data which measured in the laboratory. To reduce the experimental error, the aperture of the diaphragm was chosen to be 4 mm [13].

Table 1. $U_{0-\upsilon}$ data measured in the off-line laboratory

Wavelength λ/nm	265.0	415.0	436.0	546.0	578.0
Frequency $\upsilon/10^{14}$hz	8.216	7.410	6.882	5.491	5.196
Curb voltage U_0/V	1.734	1.443	1.214	0.663	0.524
Curb voltage U_0/V	1.732	1.441	1.212	0.656	0.515
Curb voltage U_0/V	1.726	1.429	1.216	0.655	0.513
Curb voltage U_0/V	1.731	1.421	1.203	0.651	0.522
Curb voltage U_0/V	1.735	1.423	1.202	0.644	0.511
Curb voltage U_0/V	1.731	1.415	1.191	0.641	0.513
Curb voltage average U_0/V	1.732	1.429	1.206	0.652	0.516

The data were processed as an Excel linear fit, and their slopes were obtained directly, i.e., the Planck constant h could be calculated.

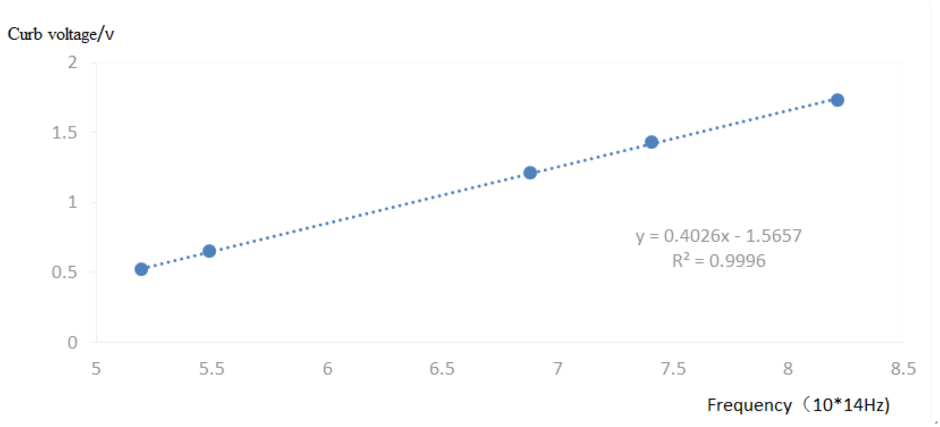

Fig. 3. Linear fit of offline laboratory measurement data

The slope K = 0.4026 of the linear fitting equation can be obtained from Figure 3, and h is calculated according to Equation (7).

$$h = k * e * 10^{-14} = 6.4416 * 10^{-34} J \cdot S \quad (8)$$

The theoretical value of Planck's constant is:

$$h_0 = 6.626 * 10^{-34} J \cdot S \quad (9)$$

so the error is calculated as

$$h_x = \frac{h-h_0}{h_0} * 100\% = 2.8\% \quad (10)$$

3.2. Online experimental data analysis

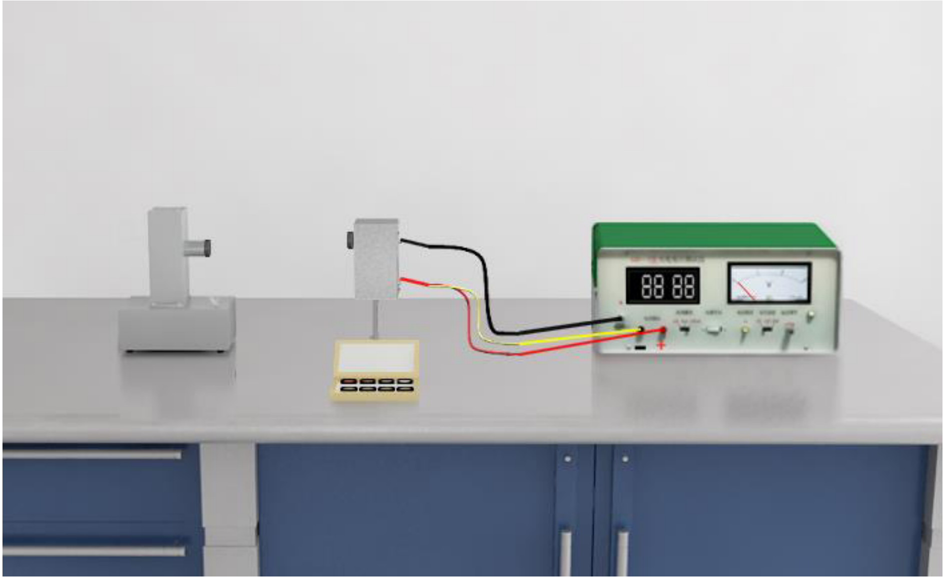

Fig. 4 Underline Planck constant measuring instrument

Online virtual experiment platform highly imitates offline experimental instruments, and in the practical operation, there will be error warning tips to avoid damage to the device due to incorrect operation. At the same time, the experimental instruments are easier and faster to adjust. They can be adapted to the best conditions in a concise period of time, thus saving much operating time. The data measured by the online virtual experiment platform are shown in Table 2.

Table 2. $U_{0\text{-}\upsilon}$ data measured in the online laboratory

Wavelength λ/nm	577	546	435.8	404.7
Frequency $\upsilon/10^{14}$hz	5.198	5.492	6.88	7.41
Curb voltage U_0/V	0.20	0.33	0.94	1.20
Curb voltage U_0/V	0.20	0.30	0.90	1.20
Curb voltage U_0/V	0.20	0.33	0.92	1.20
Curb voltage U_0/V	0.20	0.32	0.92	1.18
Curb voltage U_0/V	0.20	0.32	0.94	1.20
Curb voltage U_0/V	0.20	0.34	0.91	1.10
Curb voltage average U_0/V	0.20	0.323	0.922	1.18

The data processing method is also an Excel linear fit to obtain its slope and calculate its Planck constant h directly.

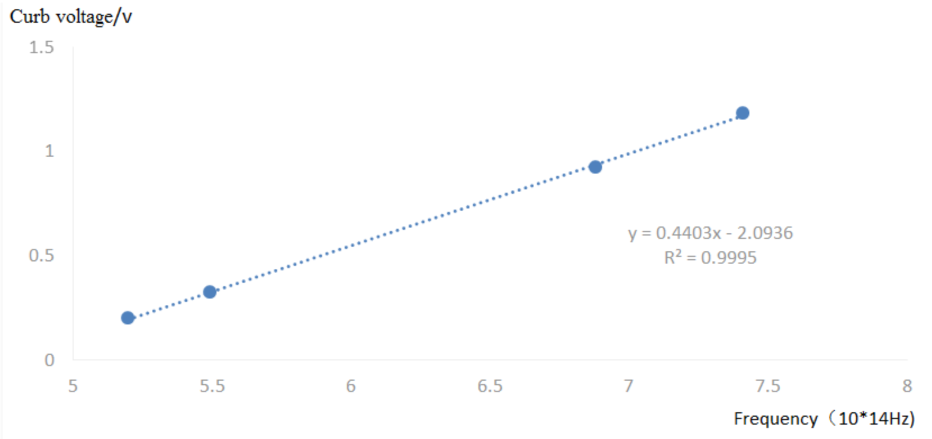

Figure 5 Linear fit of measurement data on the online virtual experiment platform

The slope K = 0.4403 of the linear fitting equation can be obtained from Figure 5, and the calculation of h according to Equation (7) yields.

$$h = k * e * 10^{-14} = 7.0448 * 10^{-34}\, J \cdot S \qquad (11)$$

and its error is calculated as

$$h_x = \frac{h-h_0}{h_0} * 100\% = 6.3\% \qquad (12)$$

A comprehensive analysis of the online and offline experiments results is shown in Table 3.

Table 3. Comprehensive analysis of online and offline experimental class data processing results

Measurement method	Offline laboratory data processing results	Online virtual experiment results
Planck constant/10^{-34}J·s	6.453	7.182
Relative error	2.8	6.3

4. Conclusion

In this paper, based on the analysis of the experimental principle, we measured the values of the curb voltage at different frequencies, measured the Planck constant using the offline laboratory photoelectric effect method and the online virtual experimental platform, and calculated and analyzed the experimental results, and finally obtained the value of Planck constant h. By analyzing the relative error, it was found that the data measured by the offline experimental apparatus were more detailed and reliable, and the calculation results were close to the theoretical value. In contrast, the experimental error obtained by the online experimental platform was more significant. Analysis of its causes may be.

(1) online experimental test platform voltage reading value sets fewer adequate numbers, only accurate to 0.01. In contrast, offline experimental instruments can be real to 0.001, and thus offline laboratory measurement results better than the virtual experimental platform. Still, this defect must only be set in the original program to improve its accuracy.

(2) online experimental operation is convenient and fast. However, the exercise of students' hands-on skills is not as good as offline operation but better than the faulty operation and damage to the instrument’s service life; especially for valuable experimental tools, online virtual experiments have more significant advantages.

(3) online experimental platform values are taken for the database; the original data in the database of the experimental data error setting range may be relatively large, and thus there will be experimental results must have deviations.

Although there are specific errors in the online experimental results that exist in the current epidemic of the painful period or for the lack of testing equipment in schools, online practical classes assume more of how to let students successfully learn and complete the relevant experimental courses students complete their studies. Therefore, in the current environment, the online virtual experiment platform assumes an important teaching task in undergraduate practical teaching and has become an indispensable part of undergraduate teaching.

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References

[1] Wu LJ, Li Q. Three methods for measuring Planck's constant by the photoelectric effect. University Physics Experiment, 2007, 20(4): 49 -52.
[2] Zhang JW, Yin SL. Measurement of Planck's constant by curvature method in photoelectric effect experiments. Physics Experiments, 2003, 23(11): 42- 44.
[3] Li X, Zhu L. Measurement of Planck's constant with the aid of Matlab. Physics Experiments, 2008, 28(12): 33- 35.
[4] Jin YY, Lu C, Li GQ. Application of Origin8.0 in the experiment of Planck's constant determination. Physics and Engineering, 2010, (6): 31- 34.
[5] Ma DL, Du RJ. Application of Origin to Fermi-Dirac experiments. Physics and Engineering, 2009, 19(4): 34- 36.
[6] Xie N, Zhang Y, Jiao YF, Liu JJ, Guo JW, Cao Y, Guo HMM. Analysis of experimental physics data with Origin software. Laboratory Science, 2007, (6) : 92- 93.
[7] Li YQ, Zhi LL, Chen HM. Application of Origin to experimental data processing of Planck constant measurements. Journal of Changji College, 2014, (3):31-34.
[8] Zhang JH, Hu WQ. Discussion of measurement methods in determining Planck's constant by the photoelectric effect. Journal of Jiaxing College, 2006, (6):23-26.
[9] Wang YZ, Zhao M. Data processing and error analysis of Planck constant measurement by the photoelectric effect. University Physics Experiment, 2011, (2):93-95.
[10] Ma SB, Ding YQ, Zhao XM, Dai W. Experimental study of Planck's constant by photoelectric effect Laboratory Research and Exploration, 1999, (1):61-65.
[11] Wang YZ, Zhao M. Data processing and error analysis of Planck constant measurement by the photoelectric effect. University Physics Experiment, 2011, (2):93-95.
[12] Bai YX et al. eds, Physics Experiments [M], Tsinghua University Press, 2016.
[13] Deng ZX, Duan ZR. Inverse curb voltage method to measure Planck's constant Value Engineering, 2013, (13):59-60.