A. Experimental preparation

(1) Plug the power cords of the Mercury lamp and the measurement unit, turn on power of the two units, pre-heat them for 20 minutes.

(2) Block the entrance of the photoelectric tube box (i.e. turn the filter wheel to position "B"), while letting the Mercury lamp illuminate onto the entrance port, and setting the distance between the Mercury lamp and the photoelectric tube to be about 30 cm.

(3) Before using the BNC cable to connect the measurement unit and the photoelectric unit (i.e. no photo current input), zero the measurement unit by setting the "Current Range" to 10^{-13} and adjusting "Current Zero" knob to achieve zero readout.

(4) Connect the anode and cathode of the photoelectric tube to the "Voltage Out" terminal of the measurement unit (on the back panel) using the provided wire (black/red-BNC) with correct polarities (Red-Red, Black-Black).

(5) Connect the Photocurrent Output of the photoelectric box to the current input port (labeled as "Current In") of the measurement unit with the BNC-BNC cable.

(6) For manual measurement (i.e. adjust voltage using "Voltage Adjust" knob while reading photoelectric current and voltage from the digital meters on the front panel), set the "PC/Meter" toggle switch on the back panel to "Meter".

(7) For auto measurement using the provided software (Planck DAQ) to control the output voltage while reading photoelectric current, and calculating Planck's constant with a PC, connect the "Signal Out" terminal on the back panel of the measurement unit to the PC via a USB port, and set the "PC/Meter" switch on the back panel to "PC"

B. Measurement of the dark current of the photoelectric tube (manual)

(1) Remain the entrance of the photoelectric box blocked. Set the "Current Range" switch to 10^{-13} and the "Voltage Range" button to II (-2 to +20 V).

(2) Slowly rotate the "Voltage Adjust" knob in clockwise direction to increase the voltage, and change "Voltage Range" to proper range. Record the current value under different voltage readings (Note: current value = Current × current meter reading × A). These current values are the dark currents of the photoelectric tube.

C. Measurement of *I~V* characteristics of the photoelectric tube (manual)

(1) Set "Current Range" switch to 10^{-13} and "Voltage Range" button to I (-2 to +2 V).

(2) Select the 365.0 nm filter, and set aperture size to 8 mm.

(3) Increase voltage slowly from -2 V using the "Voltage Adjust" knob while observing the change in photocurrent, record the voltage value in Table 1 when the current changes from zero to a non-zero value, and record denser data points around the region where the current changes sharply (the front portion of the *I~V* curve). Change "Voltage Range" to II (-2 to +20 V) for data taking of the rear portion of the *I~V* curve (change "Current Range" to 10^{-11} if necessary).

(4) At U_{AK}= 20 V, set "Current Range" to 10^{-11}, record photo currents of different aperture sizes of 4, 8, 10 and 12 mm into Table 2.

(5) Set aperture size to 8 mm, and select filters of 404.7 nm, 435.8 nm, 546.1 nm and 577.0 nm in sequence, repeat steps (3) and (4).

(6) Plot *V~I* characteristic curves under different illuminating wavelengths of the photoelectric tube using the data in Table 1, as shown in Figure 6.

Table 1 $I \sim U_{AK}$ data Φ (aperture) =_____mm L(distance)=_____cm

365.0 nm	U_{AK} (V)										
	I										
404.7 nm	U_{AK} (V)										
	I										
435.8 nm	U_{AK} (V)										
	I										
546.1 nm	U_{AK} (V)										
	I										
577.0 nm	U_{AK} (V)										
	I										

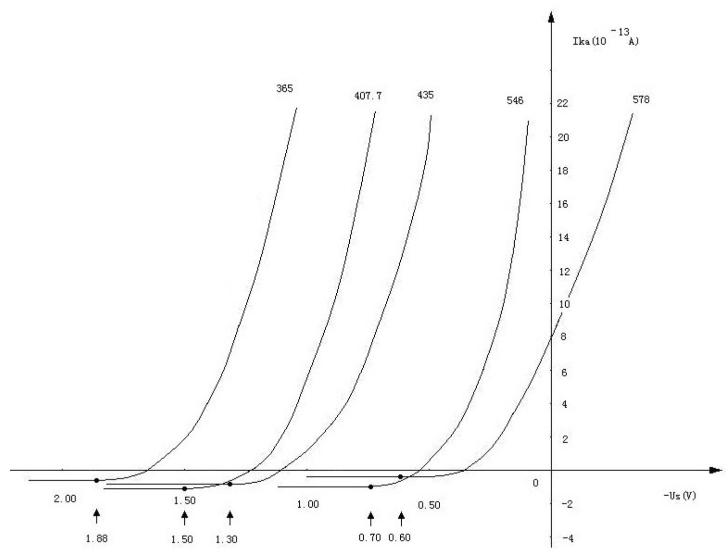

Figure 6 *V~I* characteristic curves of different light frequencies

(7) Verify that the photocurrent is proportional to the light energy illuminating on the photoelectric tube using the data in Table 2.

Table 2 Relationship between photo current and light energy U_{AK}=______V

Aperture Size	2 mm	4 mm	8 mm
$I_{365.0\ nm}$			
$I_{404.7\ nm}$			
$I_{435.8\ nm}$			

$I_{546.1\ \mathrm{nm}}$			
$I_{577.0\ \mathrm{nm}}$			

D. Determination of Planck's constant (manual)

To evaluate the Planck's constant in this experiment, the following factors must be considered:

a) Dark current and background current: the phototube will generate current even without light illumination, called the dark current that consists of two types of current: thermal current and leakage current. The background current is caused by the environmental stray light. These currents vary with the applied voltage. It is necessary to remove or minimize these currents in the experiment.

b) Reverse current: cathode material could be sputtered to the anode during the fabrication process of the phototube. When light or stray light illuminates on the anode, the anode will also emit photoelectrons. In addition, the photoelectrons emitted by the cathode may be reflected back by the anode. These photoelectrons will form reverse current.

Therefore, the measured photocurrent should be the sum of the cathode current, dark current, background current, and reverse current. The measured *I~V* curve of the photoelectric tube will be altered as the solid line as seen in Figure 7. These currents are the error factors for the determination of the cutoff voltage.

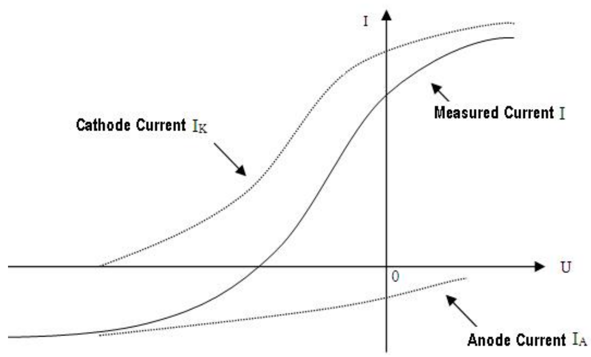

Figure 7 Error analysis of current

For the photoelectric tube used in this apparatus, the cathode current increases quickly around cutoff voltage, and the anode current is very small. The intersection point of the *I~V* curve with the *U* axis can be approximated as the cutoff voltage.

Three methods can be used to determine Planck's constant as follows:

(1) Turning point method

From each *I~V* curve in Figure 6, find the cutoff voltage *U*s, where the current starts to increase rapidly from its flat portion. Data is recorded in Table 3 as shown below.

Table 3 Light frequency~U_s data Distance L= cm

Wavelength (nm)	365	405	436	546	577	h (×10^{-34}J·s)	σ (%)
Frequency (×10^{14}Hz)	8.214	7.408	6.879	5.490	5.196		
U_s (V)							

Plot U_s versus light frequency graph using the data recorded in Table 3 as shown in Figure 8. If the photoelectric effect complies with Einstein's equations, the U_s ~ Frequency curve should be a straight line. Conduct curve-fitting using Excel and find the slope of the line: $k = \Delta U_s/\Delta v$, and substitute it in equation (5) to calculate the Planck's constant. Compare the result with the recognized Planck's constant value.

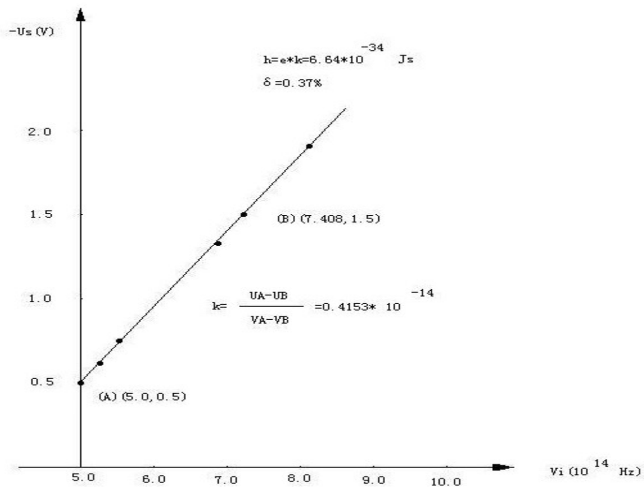

Figure 8 Plot of cutoff voltage vs light frequency

(2) Zero current method

Zero current method directly takes voltage U_{AK} as cutoff voltage U_s when the photoelectric tube is applied with voltage U_{AK} and the output photo current is zero under the illumination of a specific light frequency. Since the anode current, dark current and stray current are quite small for this apparatus, the measured cutoff voltage with zero current method has little error compared to the true value.

Set "Voltage Range" to I (i.e. -2 – 2 V) and "Current Range" to 10^{-13}. Disconnect the photo current cable from the measurement unit, zero the unit, and reconnect the cable. Set the light aperture to 8 mm or 4 mm.

Select 365 nm filter, adjust voltage from high to low when current is zero, and record this voltage as U_s in Table 4. Select filters of 404.7 nm, 435.8 nm, 546.1 nm, and 577.0 nm, repeat the measurement.

Table 4 U_s~ν relationship Aperture =______mm

Wavelength (nm)	365.0	404.7	435.8	546.1	577.0
Frequency (10^{14}Hz)	8.214	7.408	6.879	5.490	5.196
U_s (V)					

Process the data of Table 4 using one of the following two methods:

a) Plot U_s versus light frequency graph using the data recorded in Table 4. Find the slope of the best fitted straight line: $k = \Delta U_s/\Delta v$, and substitute it in equation (5) to calculate the Planck's constant.

b) Use successive difference method to acquire the slope of the straight line: 4 slope values can be derived from the 5 sets of data (U_s, ν) in Table 4 by using formula:

$$k = \Delta U_s / \Delta \nu = [(U_s)_m - (U_s)_n]/(\nu_m - \nu_n)$$

Use the average slope in equation (5) to calculate the Planck's constant.

(3) Compensation method

Set "Voltage Range" to I (i.e. -2 – 2 V) and "Current Range" to 10^{-13}. Disconnect the photo current cable from the measurement unit, zero the unit, and reconnect the cable. Set the light aperture to 8 mm or 4 mm.

Select 365 nm filter, measure cutoff voltage U_s using the procedure: First, adjust voltage U_{AK} to achieve zero current; then keep U_{AK} unchanged while blocking the light and reading current output I_l as the total dark current and stray current of the photoelectric tube; finally unblock the illumination light and adjust voltage U_{AK} until current I_l is achieved again. Now voltage U_{AK} is considered as the cutoff voltage U_s in Table 5. This method compensates the dark current and stray current for the measurement result.

Select filters of 404.7 nm, 435.8 nm, 546.1 nm, and 577.0 nm, repeat the measurement.

Table 5 U_s~ν relationship Aperture =______mm

Wavelength (nm)	365.0	404.7	435.8	546.1	577.0
Frequency (10^{14}Hz)	8.214	7.408	6.879	5.490	5.196
U_s (V)					

E. Measurement of *I~V* characteristics of the photoelectric tube (software)

Data acquisition software named "Planck DAQ" is provided with this apparatus for PC use via a USB port. Connect the "Signal Out" termianl of the measurment unit to a PC via a USB port and set toggle switch "PC/Meter" to "PC". By running the program, the above experiments in Sections B, C and D can be performed automatically. An instruction for installing and using this program is given in Appendix.

A simple sequence of running the software is as follows.

1) Select DAQ device from the pull-down list;
2) Set current range to "10^{-13}" on the front panel of the main controller, and set the filter wheel to "B" position to block Mercury light to the photocell; set "V-Range" of the software to "-2.5 V – 1.0 V".
3) Set the filter of the software to "Dark" from the pull-down list; select the same physical filter from the filter wheel of the photoelectric unit and wait until the digital current meter on the main controller stabilizes before hitting "Measure" to measure and record dark current with voltage.
4) Wait until the "Dark" indicator stops blinking (color becomes white) and "Idle" indicator resumes blinking. Set filter wheel to "365 nm" and aperture 8 mm (can select

a different aperture size), and correspondingly set the filter of the software to “365 nm” from the pull-down list. Wait until current reading stabilizes on the digital meter of the main controller before hitting “Measure” on the software.

5) Wait until the “365 nm” indicator stops blinking (color becomes white) and “Idle” indicator resumes blinking, place the filter wheel to the next wavelength and repeat the measurement process for the specific wavelength.
6) After the V~I measurements complete for all the wavelengths, set the “Manual/Auto” switch on the program panel to “Auto” by left clicking on the knob using mouse, then hit “Calculate” to review the curve-fitting and Planck constant calculation results.
7) Alternatively, when the “Calculate” button is ON (i.e. green), change “Manual/Auto” switch of the program to “Manual” and then use mouse and cursor to determine the cutoff voltage (the knee point or zero current point) manually on the V~I curve of a specific wavelength until all the cutoff voltage values are obtained, the calculation results based on these manually determined cutoff voltage values are presented.
8) To measure the V~I characteristics of the photoelectric tube, set “V-Range” to “-2.5V ~ 20 V” and run measurements same as the above. Various V-I curves can be acquired. For these measurements, if the V-I curve is saturated at large voltage, please adjust the current range selector on the front panel of the main controller to a lower multiplier.

A screen shot of the user interface panel of the software is shown in Figure 9. Please refer to Sec. 6 for more description of the software.

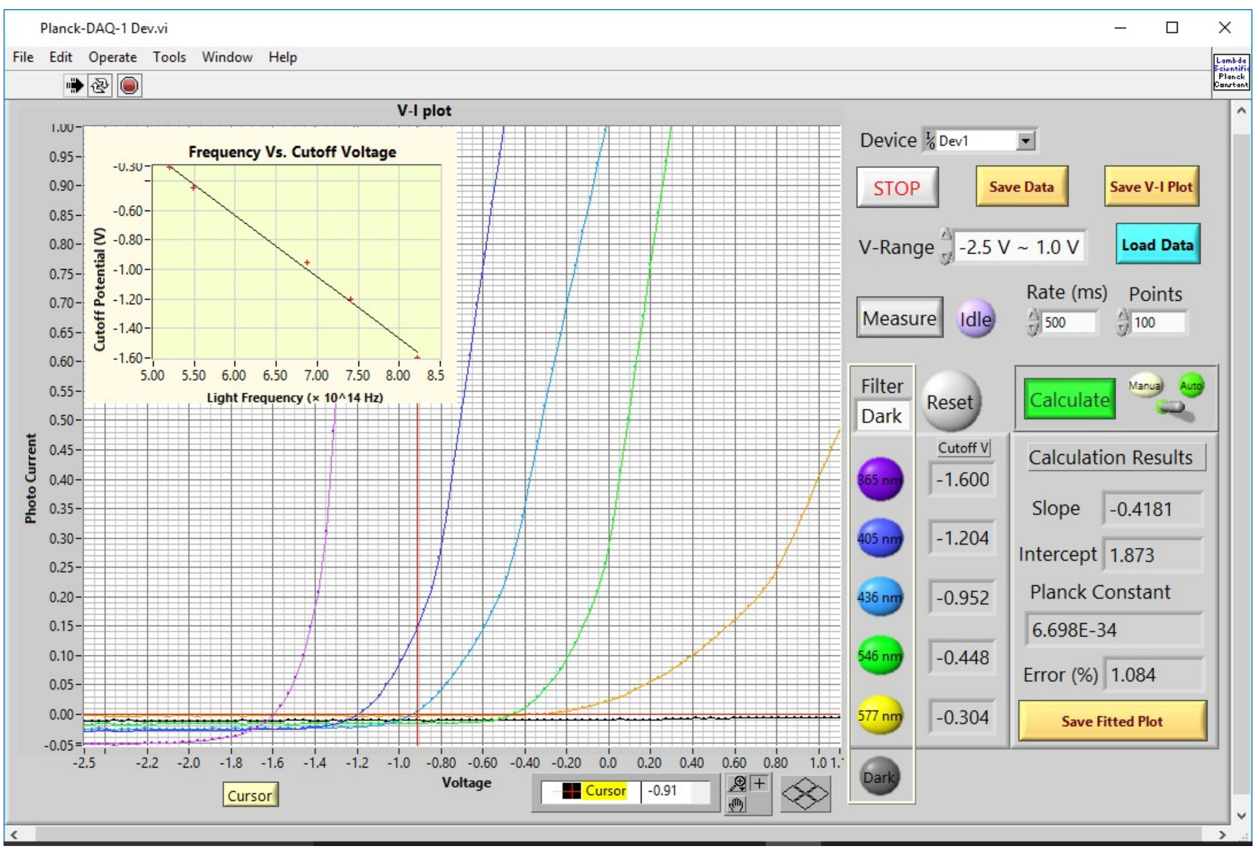

Figure 9 Screen shot of user interface panel of software