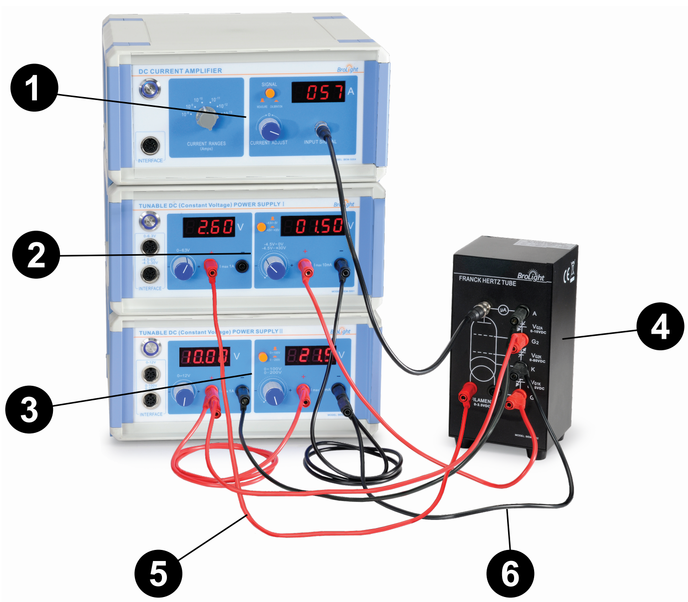
Franck-Hertz Experiment (SE-9639)

Introduction

In 1914, in the course of their investigations, James Franck and Gustav Hertz discovered an "energy loss in distinct steps for electrons passing through mercury vapor", and a corresponding emission at the ultraviolet line (λ = 254 nm) of mercury. As it is not possible to observe the light emission directly, demonstrating this phenomenon requires an extensive and cumbersome experiment apparatus. Performance of this experiment has become one of the classic demonstrations of the quantization of atomic energy levels. Franck and Hertz were awarded the Nobel Prize for this work in 1925.

In this experiment, we will repeat Franck and Hertz's energy-loss observations, using argon, and interpret the data in the context of modern atomic physics. We will not attempt the spectroscopic measurements, as the emissions are weak and in the extreme ultraviolet portion of the spectrum.

Equipment list



❶ DC Current Amplifier (SE-6621)

❷ Tunable DC (Constant Voltage) Power Supply I (SE-6615)

❸ Tunable DC (Constant Voltage) Power Supply II (SE-9644)

❹ Franck-Hertz Enclosure (SE-9660)

❺ 5× Connecting cable, 850 mm, red (EM-9740)

❻ 5× Connecting cable, 850 mm, black (EM-9745)

Not pictured:

❼ Franck-Hertz Argon Tube (SE-9645A)

❽ 3× Power cord (not pictured)

❾ BNC cable (not pictured)

❿ 2× 8-pin DIN Extension Cable (UI-5218; not pictured)

Recommended Items:

- 850 Universal Interface (UI-5000) *or* 550 Universal Interface (UI-5001)
- PASCO Capstone data collection software

Principle of the experiment

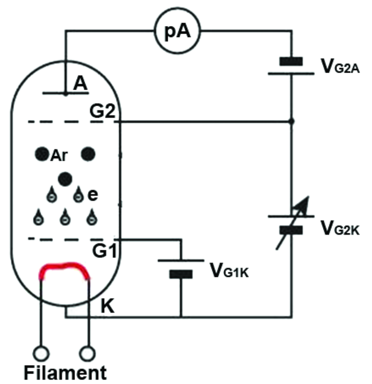


Figure 1. Layout of a Franck-Hertz tube

The Franck-Hertz tube is an evacuated glass cylinder containing argon, with four electrodes (collectively called a "tetrode"). The four electrodes consist of: an indirectly heated oxide-coated cathode as an electron source (cathode *K*); two grids, G_1 and G_2; and a plate, *A*, which serves as an electron collector (anode *A*). Grid 1 (G_1) is positive with respect to the cathode (K), with a voltage of about 1.2 V between them. A variable potential difference is applied between the cathode and Grid 2 (G_2) so that electrons emitted from the cathode can be accelerated to a range of electron energies. The distance between the cathode and the anode is large compared to the mean free path length in the argon, in order to ensure a high collision probability. On the other hand, the separation between G_2 and the collector anode (A) is small.

A small constant negative potential U_{G2A} (the "retarding potential") is applied between G_2 and collector plate A (in other words, A is less positive than G_2). The resulting electric field between G_2 and anode A opposes the motion of electrons to the collector electrode, preventing electrons with kinetic energy less than $e \bullet U_{G2A}$ at Grid 2 from reaching anode A. As will be shown later, this retarding voltage helps to differentiate the electrons that experience inelastic collisions from electrons that do not.

A sensitive current amplifier is connected to the collector electrode so that the current due to electrons reaching the collector plate may be measured. As the accelerating voltage is increased, the following is expected to happen: Up to a certain voltage (which we will call V_1), the plate current I_A will increase as more electrons reach the plate. When the voltage V_1 is reached, it is noted that the plate current I_A suddenly drops. This is due to the fact that, at this voltage, the electrons have gained just enough energy to collide inelastically with the argon atoms before reaching the grid G_2. Having lost energy to the argon atoms, these electrons do not have sufficient energy to overcome the retarding voltage between G_2 and A, causing the decrease in the plate current I_A.

However, as the voltage is further increased, the electrons continue to gain energy until they have enough to reach the anode even after an inelastic collision with an argon atom. As such, I_A will increase again as more and more electrons arrive at the plate. This continues until another specific voltage V_2 is reached, at which point I_A sharply decreases again. This second drop indicates that the electrons have now obtained enough energy to experience two inelastic collisions before reaching G_2, but not enough to overcome the retarding voltage afterwards. As the voltage continues to increase, I_A trends upward again until experiencing another drop at a third value, V_3, corresponding to the electrons now having three inelastic collisions before reaching G_2, and so on. The crucial takeway from this is that, regardless of the circumstances, $V_3 - V_2$ is equal to $V_2 - V_1$, a pattern which repeats for all subsequent voltage values at which current drops. This shows that the argon atom has definite excitation levels and absorbs energy only in quantized amounts.

When an electron experiences an inelastic collision with an argon atom, the kinetic energy lost to the atom causes one of the outer orbital electrons to be pushed up to the next higher energy level. Within a very short time, this excited electron will fall back into the ground state level, emitting the excess energy in the form of photons, while the original bombarding electron is again accelerated toward the grid anode. Therefore, the excitation energy can be measured in two ways: by the current monitoring method outlined previously, or by spectral analysis of the radiation emitted by the excited atoms.

Figure 2 displays a typical measurement of the anode current I_A as a function of the increasing voltage. As soon as $V_{G2K} > V_{G2A}$ (the origin on the graph), the current begins to increase as V_{G2K} rises. Note that the current sharply decreases for some voltage U_1 and then begins to increase again up to U_2, at which point the pattern recurs. The interpretation of these observations is successful with the following assumptions:

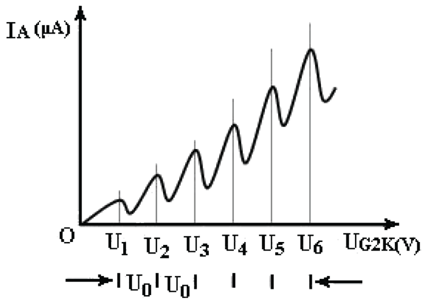


Figure 2. Anode current curve

- Having reached an energy of about $e \cdot U_0$ (where U_0 denotes the resonance voltage), electrons can transmit their kinetic energy to a discrete excitement state of the argon atoms.
- As a result of the inelastic collision, the electrons pass the braking voltage.
- If the electrons' energy is twice the required value, or $2e \cdot U_0$, they can collide twice inelastically, and so on for higher voltages.
- In fact, a strong line can be found for emission and absorption corresponding to an energy of $e \cdot U_0$, the excitation energy of argon, in the optical spectrum (specifically at 108.1 nm).

Safety information

WARNING: To avoid possible electric shock or injury, follow these guidelines at all times.

- Do NOT clean the equipment with a wet cloth.
- Before use, verify that the apparatus is not damaged. *Do not use the apparatus if it is damaged.*
    - Always inspect the case for signs of damage before using the equipment. Pay particular attention to the insulation surrounding the connectors.
- **Do NOT** disconnect the power cord safety ground feature.
- When plugging in the equipment, always plug it into a grounded (earthed) outlet.
- Do not use the equipment in any manner that is not specified by the manufacturer.
- Do not install substitute parts or perform any unauthorized modification to the product. When servicing the equipment, *only* use specified replacement parts.
- Line and Current Protection Fuses: To ensure protection against fire, replace the line fuse and current-protection fuse *only* with fuses of the specified type and rating.
- Main Power and Test Input Disconnect: Unplug equipment from wall outlet, remove power cords, and remove all probes from all terminals *before* servicing. Only qualified, service-trained personnel should remove the cover from the power supplies or DC Current Amplifier.
- Immediately stop using the equipment if it operates abnormally, as protection may be impaired. When in doubt, have the equipment serviced.
- Do not operate the equipment under wet conditions, or under conditions where explosive gas, vapor, or dust are present.
- Use caution when working with voltages above 60 V DC, 30 V AC rms, or 42 V peak. Such voltages pose a shock hazard.
- To avoid electric shock, do not touch any bare conductor with hands or skin.
- Adhere to all local and national safety codes. Individual protective equipment must be used to prevent shock and arc blast injury where hazardous live conductors are exposed.
- *Keep in mind:* If a dangerous voltage is applied to an input terminal, then the same voltage may occur at **all** other terminals.

Electrical symbols

∿ Alternating Current
⎓ Direct Current
⚠ Caution, risk of danger; refer to the operating manual before use
⚠ Caution, possibility of electric shock
⏚ Earth (ground) Terminal
Protective Conductor Terminal
Chassis Ground
CE Conforms to European Union directives
WEEE, waste electric and electronic equipment
Fuse
On (Power)
Off (Power)

PASCO

"In" position of a bi-stable push control
"Out" position of a bi-stable push control

Setup and maintenance

WARNING: To reduce the risk of electric shock or damage to the instrument, turn off the power switch AND disconnect the power cord before installing or replacing the argon tube or fuse.

Installing or replacing the argon tube

Follow these instructions for installing or replacing the Franck-Hertz Ar-Tube (SE-9645A).

1. Unscrew the thumbscrews on the back of the case.
2. Remove the front panel of the enclosure to access the inner compartment.
3. If replacing the argon tube, gently pull upward on the old argon tube to remove it from its socket. (NOTE: If you are using an older enclosure where the tube is held in place by a wire bail, remove the bail before removing the tube. The bail can be disposed of after being removed.)
4. Gently insert the new tube into the socket. Make sure to line up the holes in the socket with the prongs on the bottom of the tube.
5. Replace the front panel of the enclosure and secure it in place by tightening the thumbscrews.

IMPORTANT: Handle with care! The tube is a thin-walled, evacuated glass bulb. Do not expose the tube to mechanical stress or strain.

Fuse replacement

Follow these steps to replace the fuse on the power supplies or current amplifier.

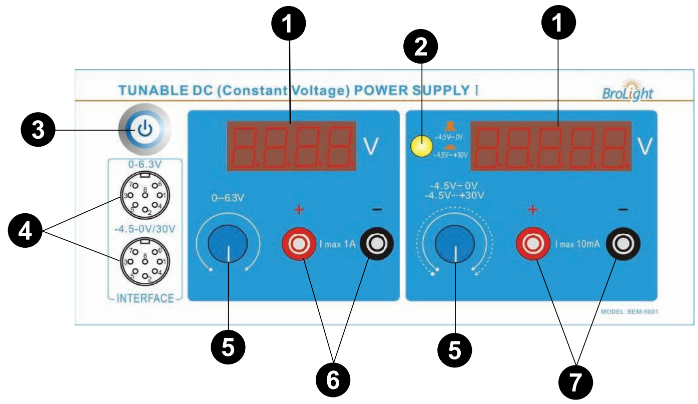
Fuse slot

1. Open the fuse cover and remove the fuse. (The fuse is inside a tray, as shown above. Use a small screwdriver or other tool to pry the tray open.)
2. Replace the fuse(s). Use the same type of fuse (250 V T2A). One spare fuse is included.
3. Reconnect the power cord and turn on the instrument.

If the equipment still does not work after replacing the fuse, contact Brolight Corporation for customer service.

Equipment components

Tunable DC (Constant Voltage) Power Supply I



1 Voltmeter
Displays voltage across the argon tube.

2 Voltage range switch
Sets the voltage range for the right output as -4.5 to 0 V ( ) or -4.5 to +30 V ( ).

3 Power switch
Press to turn the instrument on or off.

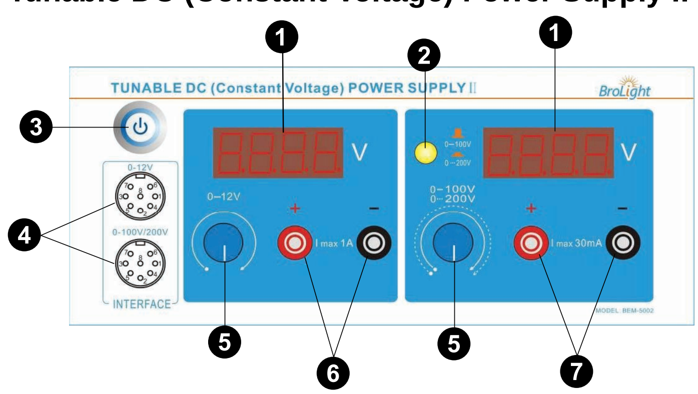
4 Data interface
Use to connect the power supply to the analog channels of the 850 or 550 Universal Interface.

5 Voltage Adjust
Use to set the voltage across the argon tube.

6 Output: 0 – 6.3 V
Outputs a voltage between 0 V and 6.3 V.

7 Output: -4.5 – 0 V *or* -4.5 – +30 V
Outputs a signal within the range specified by the position of the voltage range switch.

Tunable DC (Constant Voltage) Power Supply II



1 Voltmeter
Displays voltage across the argon tube.

2 Voltage range switch
Sets the voltage range for the right output (the accelerating voltage) as 0 to 100 V ( ) or 0 to 200 V ( ).

3 Power switch
Press to turn the instrument on or off.

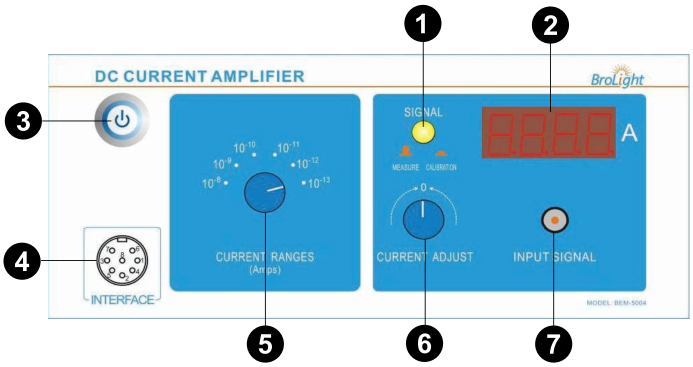
❹ **Data interface**
Use to connect the power supply to the analog channels of the 850 or 550 Universal Interface.

❺ **Voltage Adjust**
Use to set the voltage across the argon tube.

❻ **Output: 0 – 12 V**
Outputs a voltage between 0 V and 12 V.

❼ **Output: 0 – 100 V *or* 0 – 200 V**
Outputs a signal within the range specified by the position of the voltage range switch.

DC Current Amplifier



❶ **Signal switch**
Sets the signal to MEASURE (⎍) or CALIBRATION (⏥).

❷ **Ammeter**
Displays the current through the argon tube.

❸ **Power switch**
Press to turn the instrument on or off.

❹ **Data interface**
Use to connect the current amplifier to the analog channels of the 850 or 550 Universal Interface.

❺ **Current range switch**
Sets the current range for the instrument's current amplifier (10^{-8} to 10^{-13} A).

❻ **Current adjust**
Sets the current through the instrument to zero.

❼ **Input signal**
Connect the input current signal here.

Connect cables and cords

Follow the steps at right to connect the argon tube to the power supplies and Current Amplifier for the experiments. The steps are labeled in Figure 3.

IMPORTANT: Before connecting any cords or cables, make sure that:

- *All* power switches on the power supplies and Current Amplifier are in the OFF position, and *all* voltage controls are turned fully counterclockwise.
- The voltage level switch above the power cord socket on each device is set to the correct setting (110–120 V or 220–240 V) based on your AC voltage level.

DANGER: High voltage is applied to the argon tube! Avoid contact with *any* part of the body, and use only safety equipment leads (shrouded patch cords) for connections.

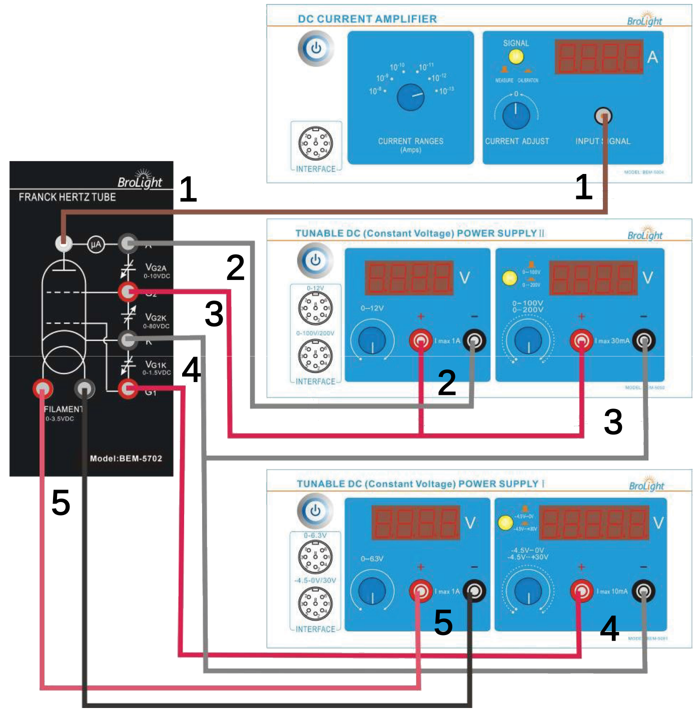


Figure 3. Wiring diagram for the components

1. On the DC Current Amplifier, connect the BNC-to-BNC cable between the port labeled "**INPUT SIGNAL**" on the amplifier and the port labeled "**μA**" on the Argon Tube Enclosure.
2. On the Power Supply II, connect the positive terminal of the **0 – 12 V DC** output to the grid-like electrode labeled "**G2**" (red socket) on the Argon Tube Enclosure. Connect the negative terminal of the 0 – 12 V DC output to the terminal labeled "**A**" (black socket) on the enclosure.
3. On the Power Supply II, connect the positive terminal of the **0 – 100 V DC** output to the port labeled "**G2**" on the Argon Tube Enclosure. Connect the negative terminal of the output to the terminal labeled "**K**" (black socket) on the enclosure.
4. On the Power Supply I, connect the positive terminal of the **-4.5 – +30 V DC** output to the grid-like electrode labeled "**G1**" on the Argon Tube Enclosure. Connect the negative terminal of the output to the terminal labeled "**K**" on the enclosure.
5. On Power Supply I, connect the positive terminal of the **0 – 6.3 V DC** output to the red socket of the port labeled "**FILAMENT**" on the Argon Tube Enclosure. Connect the negative terminal of the output to the black socket of the "FILAMENT" port.
6. (*Not pictured*) For both power supplies and the Current Amplifier, connect a power cord between the port on the back labeled "**AC POWER CORD**" and an appropriate electrical outlet.

Experiment Procedure 1

Adjust Operating Voltages

NOTE: Before switching on the power, be sure that all voltage controls are turned fully counterclockwise.

1. Connect all the cables and cords as shown in **Connect cables and cords**.
2. Turn on the power on the Power Supply I, Power Supply II, and DC Current Amplifier.
3. On the Current Amplifier, turn the CURRENT RANGES switch to **10^{-10} A**. To set the Current Amplifier to zero, press the SIGNAL button in to **CALIBRATION** (⊓) and adjust the CURRENT CALIBRATION knob until the current reads zero. When you are done, press the SIGNAL button to **MEASURE** (⊓).
4. On Power Supply I, set the Voltage Range switch to **-4.5 – +30 V** (⊓). On Power Supply II, set the Voltage Range switch to **0 – 100 V** (⊓).
5. On Power Supply I, rotate the **0 – 6.3 V** Voltage Adjust knob until the voltmeter reads approximately 4 V. This sets the filament voltage to about $\mathbf{V_H}$ = 4 V.
6. On Power Supply I, rotate the **-4.5 – +30 V** Voltage Adjust knob until the voltmeter reads 1.2 V. This sets the voltage between the first grid and the cathode to $\mathbf{V_{G1K}}$ = 1.2 V.
7. On the Power Supply II, rotate the **0 – 12 V** Voltage Adjust knob until the voltmeter reads 8.5 V. This sets the retarding voltage (the voltage between the second grid and anode) to $\mathbf{V_{G2A}}$ = 8.5 V.
8. On the Power Supply II, rotate the **0 – 100 V** Voltage Adjust knob until the voltmeter reads 0 V. This sets the accelerating voltage to $\mathbf{V_{G2K}}$ = 0 V.
9. Allow the argon tube and the apparatus to warm up for 15 minutes.

When you have finished all of the above steps, check to make sure that $\mathbf{V_H}$ = 4 V, $\mathbf{V_{G1K}}$ = 1.2 V, and $\mathbf{V_{G2A}}$ = 8.5 V. If so, the equipment is ready for you to perform the experiment. (Note that these are the suggested settings for the experiment, but other values can be tried.)

Manual measurements

IMPORTANT: During the experiment, pay attention to the output current ammeter when the voltage is over 60 V. If the ammeter's reading suddenly increases, decrease the voltage *immediately* to avoid damage to the tube.

NOTE:

- If you want to change the value of $\mathbf{V_{G1K}}$, $\mathbf{V_{G2A}}$, and $\mathbf{V_H}$ during the experiment, rotate the **0 – 100 V** Voltage Adjust knob fully counterclockwise before making the changes.
- The filament voltage is tunable from 0 to 6.3 V. If the anode output current is too high and causes the amplifier to overflow, the filament voltage should be decreased.
- As soon as you have finished the experiment, return the $\mathbf{V_{G2A}}$ voltage to 0 V to prolong the life of the argon tube.

1. Increase the accelerating voltage $\mathbf{V_{G2K}}$ by a small amount (for example, 1 V). Record the new values of V_{G2K} (read on the voltmeter) and current $\mathbf{I_A}$ (read on the ammeter) in a table like the one in Table 1.1. Stop when the accelerating voltage V_{G2K} = 100 V. (If the current $\mathbf{I_A}$ exceeds the range of the ammeter, reduce the fillament voltage (for example, by 0.1 V) and start over.)
2. Try to identify the "peak positions" by watching for those values of $\mathbf{V_{G2K}}$ for which the current reaches a local maximum and begins to drop as V_{G2K} increases further. Take a few data points (V_{G2K}, I_A) around the peak positions and record them in Table 1.2.
3. Try to identify the "valley positions" by watching for those values of $\mathbf{V_{G2K}}$ for which the current reaches a local minimum and begins to rise as V_{G2K} increases further. Take a few data points (V_{G2K}, I_A) around the peak positions and record them in Table 1.2.

NOTE: Make sure you take enough voltage values to allow you to determine the positions of the peaks and valleys.

Table 1.1: Accelerating Voltage and Tube Current

V_{G2K} (V)									
I_A ($\times 10^{-10}$ A)									

Table 1.2: Peak and Valley Voltage

		First	Second	Third	Fourth	Fifth	Sixth
Peak positions	**V_{G2K} (V)**						
	I_A ($\times10^{-10}$ A)						
Valley positions	**V_{G2K} (V)**						
	I_A ($\times10^{-10}$ A)						

Analysis

1. Plot the graphs of **Current** (y-axis) versus **Voltage** (x-axis).
2. Find the peak (or valley) positions which match the accelerating voltages. Label them as $\mathbf{V_1}$, $\mathbf{V_2}$, $\mathbf{V_3}$, $\mathbf{V_4}$, $\mathbf{V_5}$, and $\mathbf{V_6}$.
3. Obtain the value of an argon atom's first excitation potential $\mathbf{V_0}$ using the following equation:

$$V_0 = \frac{(V_2 - V_1) + (V_3 - V_2) + (V_4 - V_3) + (V_5 - V_4) + (V_6 - V_5)}{5} = \frac{(V_6 - V_1)}{5}$$

4. Calculate the value of Planck's Constant, **h**, using the following equation:

$$h = e\lambda\left(\frac{V_0}{c}\right)$$

   where **e** = 1.60×10^{-19} C, λ = 108.1 nm, and **c** = 3×10^{8} m/s. The answer will be in units of J•s.

5. Calculate the percent difference between the experimental value and the accepted value ($h_0 = 6.626\times10^{-34}$ J•s) using this equation:

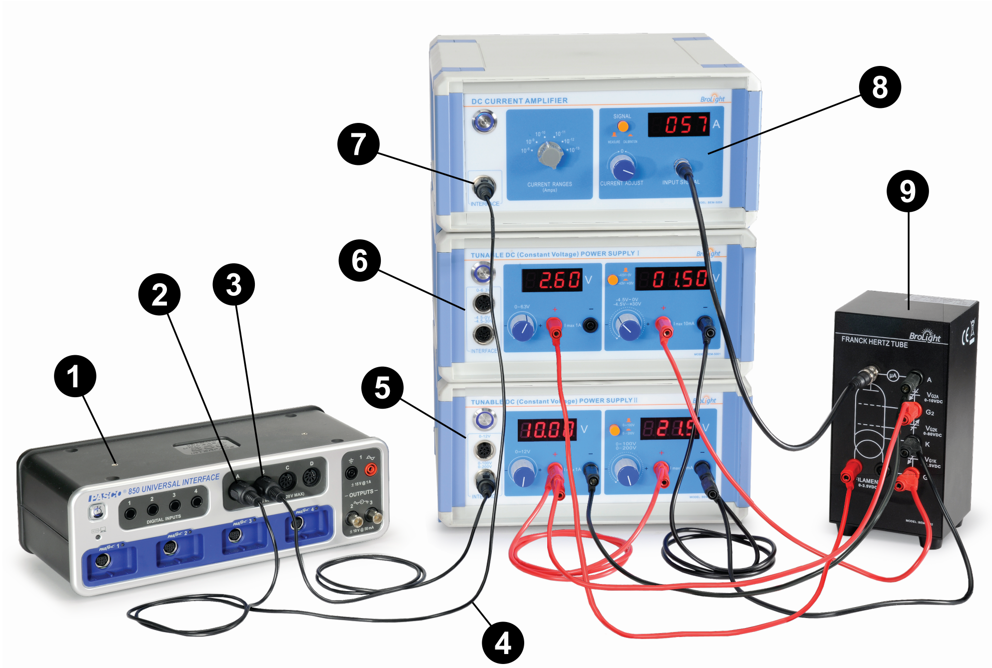
$$\Delta h = |(h - h_0)/h_0| \times 100\% =$$

Questions

1. To determine the excitation energy, should you use the positions of the peaks, the valleys, or both? Explain.
2. Why are the peaks and valleys spread out rather than sharp?
3. How precisely can you determine the peak/valley position? Explain and justify your estimates.
4. How would molecular contaminants in the tube affect your results?

Experiment Procedure 2

Using a PASCO interface and data acquisition software



1. 850 Universal Interface (can be substituted with 550 Universal Interface)
2. Analog Input A
3. Analog Input B
4. 8-pin DIN extension cable
5. Power Supply II
6. Power Supply I
7. Interface port
8. Current Amplifier
9. Argon Tube Enclosure

Items required:

- 850 Universal Interface (UI-5000) *or* 550 Universal Interface (UI-5001)
- PASCO Capstone software

Hardware setup

> **NOTE:** Before connecting any cords or cables, make sure that the Interface, power supplies, and Current Amplifier are all turned OFF and that all voltage controls are turned fully counterclockwise.

1. Connect all the cables and cords between the Argon Tube Enclosure and the power supplies and current amplifier, as described in **Connect cables and cords**.
2. Connect one 8-pin DIN Extension Cable from the INTERFACE port on the DC Current Amplifier to ANALOG INPUT A on the Universal Interface.
3. Connect a second 8-pin DIN Extension Cable from the **0 – 100 V / 0 – 200 V** INTERFACE port on Power Supply II to the ANALOG INPUT B on the Universal Interface.
4. Turn ON the power for the Universal Interface, Power Supply I and II, and Current Amplifier.
5. On the Current Amplifier, turn the CURRENT RANGES switch to **10^{-10} A**. To set the current amplifier to zero, press the SIGNAL button in to **CALIBRATION** ( ) and adjust the CURRENT CALIBRATION knob until the current reads zero. When you are done, press the SIGNAL button to **MEASURE** ( ).

6. On Power Supply I, set the Voltage Range switch to **-4.5 – +30 V** ( ). On Power Supply II, set the Voltage Range switch to **0 – 100 V** ( ).
7. On Power Supply I, rotate the **0 – 6.3 V** Voltage Adjust knob until the voltmeter reads approximately 4 V. This sets the filament voltage to $\mathbf{V_H}$ = 4 V.
8. On Power Supply I, rotate the **-4.5 – +30 V** Voltage Adjust knob until the voltmeter reads 1.2 V. This sets the voltage between the first grid and the cathode to $\mathbf{V_{G1K}}$ = 1.2 V.
9. On Power Supply II, rotate the **0 – 12 V** Voltage Adjust knob until the voltmeter reads 8.5 V; this sets the retarding voltage (voltage between the second grid and anode) to $\mathbf{V_{G2A}}$ = 8.5 V.
10. On Power Supply II, rotate the **0 – 100 V** Voltage Adjust knob until the voltmeter reads 0 V. This sets the accelerating voltage to $\mathbf{V_{G2K}}$ = 0 V.
11. Allow the argon tube and the apparatus to warm up for 15 minutes.

When you have finished all of the above steps, check to make sure that $\mathbf{V_H}$ = 4 V, $\mathbf{V_{G1K}}$ = 1.2 V, and $\mathbf{V_{G2A}}$ = 8.5 V. If so, the equipment is ready for you to perform the experiment. (Note that these are suggested settings for the experiment, but other values could be tried.)

Software setup

1. Connect the Universal Interface to your computer if you have not already done so.
2. Start the PASCO Capstone software. The software should automatically recognize the Universal Interface and the devices connected to it.
3. Double-click the **Graph** icon in the Displays palette to create a Graph display. Click the **<Select Measurement>** boxes to plot Current on the y-axis and Voltage on the x-axis.
4. Click **Current** on the y-axis, highlight **Quick Calc**, and select **-I** from the list to invert the current display. This will cause the current, which is negative from the perspective of the Universal Interface, to be displayed as positive on the graph.
5. Double-click the **Digits** icon in the Displays palette to create a Digits display and click **<Select Measurement>** to assign it to measure Voltage. This will clearly show you the accelerating voltage so you can monitor it throughout the experiment.
6. Double-click the **Table** icon in the Displays palette to create a table. Use the **Insert Column** to add two extra columns to the table.

TIP: If desired, move the displays around and change their size to improve visibility and clarity.

7. In the first column, click **<Select Measurement>**, highlight **Create New** from the menu, and select **Run-Tracked User-Entered Data**. Enter **Peak Voltage** for the name and **V** for the units.
8. In the second column, click **<Select Measurement>**, highlight **Create New**, and select **Calculation**. Enter **Diff between Peaks** for the name and **V** for the units. Enter the following calculation, calculating the voltage difference between adjacent current peaks, into the bar at the top of the table:

Diff between Peaks = diff(1,[Peak Voltage (V)])

9. In the third column, create a new Run-Tracked User-Entered Data called **Trough Voltage** with units of **V**.
10. In the fourth column, create a calculation called **Diff between Troughs** with units of **V**. Enter the following calculation, calculating the voltage difference between adjacent current troughs, into the bar at the top of the table:

Diff between Troughs = diff(1,[Trough Voltage (V)])

11. In the table, click the arrow next to **Statistics** ( ). Select **Mean** and **Standard Deviation** from the list and click the icon to make the statistics visible at the bottom of the table.

Recording Data

1. Make sure that the accelerating voltage V_{G2K} is zero.
2. After the filament has warmed up for about 15 minutes, click **Record**.
3. Over the course of the next two minutes, slowly increase the accelerating voltage. Do not exceed 100 V.

> **CAUTION:** While increasing the voltage, if you see the current suddenly increase, *immediately* return the voltage to zero and decrease the filament voltage slightly. Wait for a few minutes for the filament to cool and repeat the recording.

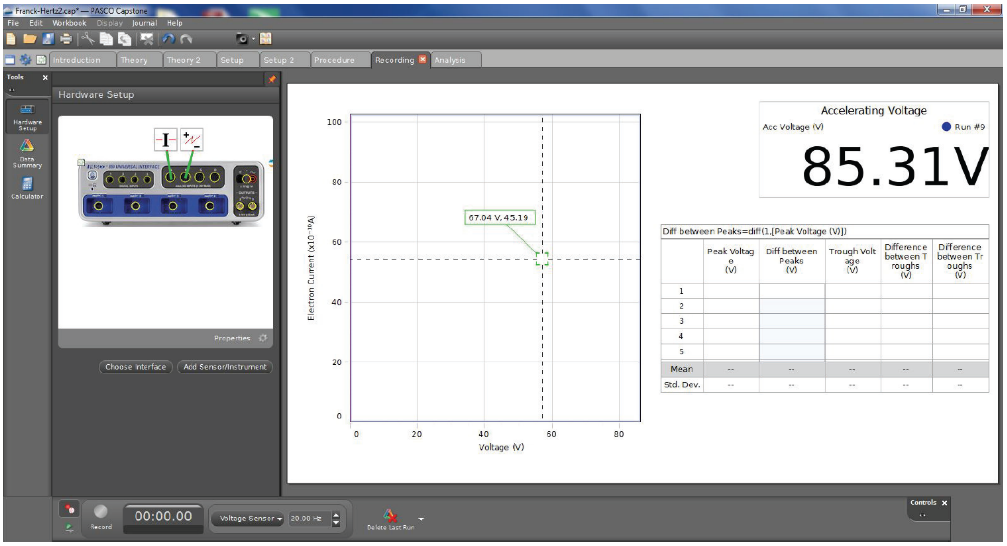


Figure 3. A sample layout for the Capstone workbook page.

Analysis

1. Using the coordinates tool on the graph, find the voltage of each of the peaks and troughs and record them in the table in the **Peak Voltage** and **Trough Voltage** columns respectively.
2. The voltage differences between adjacent peaks and the voltage differences between adjacent troughs will be calculated automatically in the second and fourth columns of the table respectively. Record the **Mean** and **Standard Deviations** for the differences in both columns. The standard deviations give the uncertainties in the difference measurements.
3. Use the mean voltage difference (V_0) from the previous step to calculate the value of Planck's Constant, **h**:

$$\mathrm{h} = e\lambda\left(\frac{\mathrm{V_0}}{\mathrm{c}}\right)$$

   where **e** = 1.602×10^{-19} C, λ = 108.1 nm, and **c** = 3×10^{8} m/s. The answer will be in units of **J•s**.

4. Calculate the percent difference between the experimental value and the accepted value (**h_0** = 6.626×10^{-34} J•s), using the following equation:

$$\Delta\mathrm{h} = |(\mathrm{h} - \mathrm{h_0})/\mathrm{h_0}| \times 100\% =$$

5. Estimate the uncertainty in your experimental value of Planck's Constant using the uncertainty in the voltage difference.

Questions

1. To determine the excitation energy, should you use the positions of the peaks, the valleys, or both? Explain.
2. Why are the peaks and valleys spread out rather than sharp?
3. How precisely can you determine the peak/valley position? Explain and justify your estimates.
4. How would molecular contaminants in the tube affect your results?

Teacher's Notes

Sample Data 1: Manual measurements

Filament voltage (V) = 3.55 V

V_{G1K} = 1.5 V

V_{G2A} = 11.0 V

Table 1: Accelerating Voltage and Tube Current

V_{G2K} (V)	1	2	3	4	5	6	7	8	9	10
I_A (×10^{-10} A)	0	0	0	0	0	0	0	0	0	0

V_{G2K} (V)	11	12	13	14	15	16	17	18	19	20
I_A (×10^{-10} A)	0	0	1	5	14	32	59	81	112	128

V_{G2K} (V)	21	22	23	24	25	26	27	28	29	30
I_A (×10^{-10} A)	143	153	153	145	130	118	131	183	270	343

V_{G2K} (V)	31	32	33	34	35	36	37	38	39	40
I_A (×10^{-10} A)	413	448	441	391	332	243	173	145	220	417

V_{G2K} (V)	41	42	43	44	45	46	47	48	49	50
I_A (×10^{-10} A)	609	772	825	806	702	547	352	199	113	197

V_{G2K} (V)	51	52	53	54	55	56	57	58	59	60
I_A (×10^{-10} A)	446	771	1032	1174	1216	1101	883	660	343	167

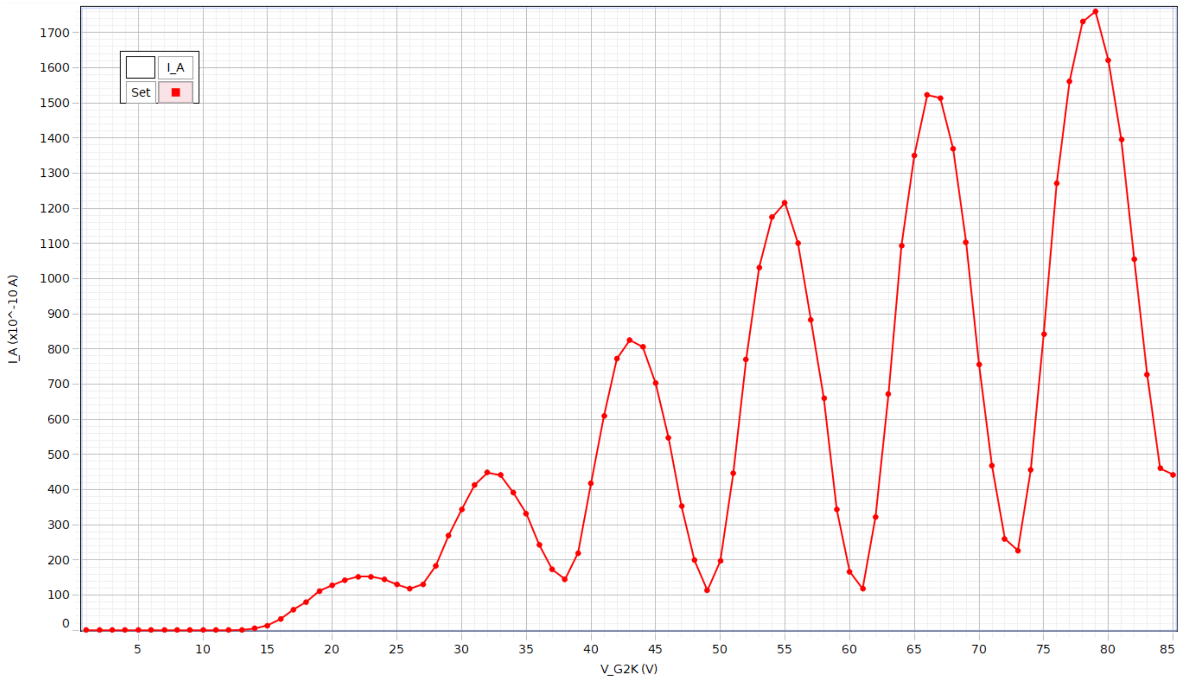
V_{G2K} (V)	61	62	63	64	65	66	67	68	69	70
I_A (×10^{-10} A)	118	323	671	1093	1351	1522	1514	1369	1104	756

V_{G2K} (V)	71	72	73	74	75	76	77	78	79	80
I_A (×10^{-10} A)	468	260	227	456	842	1270	1561	1730	1760	1621

V_{G2K} (V)	81	82	83	84	85
I_A (×10^{-10} A)	1395	1055	727	460	443

Table 2: Peak and Valley Voltages

		First	Second	Third	Fourth	Fifth	Sixth
Peak positions	**V_{G2K} (V)**	22.5	32	43	55	66	79
	I_A (×10^{-10} A)	153	448	825	1216	1522	1760
Valley positions	**V_{G2K} (V)**	13	26	38	49	61	73
	I_A (×10^{-10} A)	1	118	145	113	118	227



Analysis:

Using the equation, we obtain the value of an argon atom's first excitation potential $\mathbf{V_0}$:

V_0 (peak) = $(V_6 - V_1)/5$ = (79 - 22.5)/5 = 11.3 V

V_0 (valley) = $(V_6 - V_1)/5$ = (73 - 13)/5 = 12.0 V

Therefore, V_0 = (11.3 V + 12.0 V)/2 = **11.65 V**.

We use V_0 to calculate the value of Planck's Constant:

$\mathbf{h = e\,\lambda\,(V_0/c)} = (1.602\times10^{-19}\text{C})(108.1\text{ nm})(11.65\text{ V} / 3\times10^{8}\text{ m/s}) = \mathbf{6.725\times10^{-34}\text{ J•s}}$

The percent difference between our experimental value and the accepted value ($h_0 = 6.626\times10^{-34}$ J•s) is given by:

$\Delta h = |(h - h_0) / h_0| \times 100\% = \mathbf{1.5\%}$

Sample Data 2: Using a PASCO interface

Filament voltage (V) = 3.55 V

V_{G1K} = 1.5 V

V_{G2A} = 11.0 V

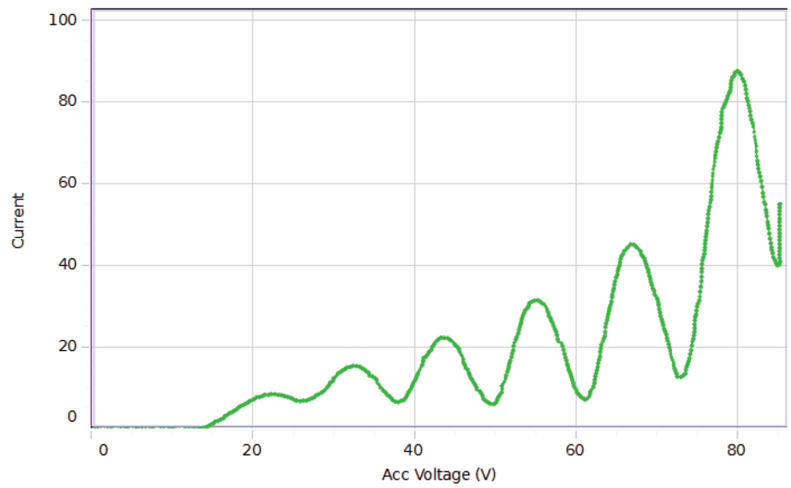


Figure 4. Capstone Graph display containing a sample data set.

Difference between Troughs=diff(1,[Trough Voltage (V)])				
	▲ Run #1	■ Run #1	● Run #1	◆ Run #1
	Peak Voltage (V)	Diff between Peaks (V)	Trough Voltage (V)	Difference between Troughs (V)
1	22.11	10.62	26.51	11.44
2	32.73	11.08	37.95	12.09
3	43.81	11.34	50.04	11.13
4	55.15	11.88	61.17	11.94
5	67.03		73.11	
Mean	44.17	11.23	49.76	11.65
Std. Dev.	17.75	0.53	18.41	0.44

Figure 5. Table data from the data set in Figure 4.

Analysis:

By taking the average of the mean differences for the peak and trough voltages, we obtain the value of an argon atom's first excitation potential $\mathbf{V_0}$:

$V_0 = (11.23 + 11.64)/2 =$ **11.44 V**

We use V_0 to calculate the value of Planck's Constant:

$\mathbf{h} = \mathbf{e}\,\lambda\,(\mathbf{V_0/c}) = (1.602\times10^{-19}\text{C})(108.1\text{ nm})(11.44\text{ V} / 3\times10^{8}\text{ m/s}) = \mathbf{6.604\times10^{-34}\ J\cdot s}$

The percent difference between our experimental value and the accepted value ($h_0 = 6.626\times10^{-34}$ J•s) is given by:

$\Delta h = |(h - h_0) / h_0| \times 100\% =$ **0.3%**.

The average of the standard deviations is (0.53 + 0.44)/2 = **0.49 V**. Plugging this into the equation for **h**, we find that our measurement of h has a margin of error of approximately **0.28×10^{-34} J•s**. Therefore, our experimental measurement of h is **$(6.6\pm0.3)\times10^{-34}$ J•s**. This means that our measurement is accurate to 0% to as many significant figures as we have, but its precision is only about **±4.5%**.

Questions

1. To determine the excitation energy, should you use the positions of the peaks, the valleys, or both? Explain.

Use both. Taking the average of the V_0 value derived from the accelerating voltages matching peak positions and the value derived from the voltages matching valley positions yields the closest value to the excitation energy, $e\cdot U_0$.

2. Why are the peaks and valleys spread out rather than sharp?

The shape of the peaks and valleys in the curve is affected by the fact that there is a potential drop of 1.2 V at the cathode, which is the source of the electrons. The cathode potential causes each peak and valley to occur over a range of 1.2 V, rather than at a sharp point.

3. How precisely can you determine the peak/valley position? Explain and justify your estimates.

Student answers will vary. Note that the current fluctuations in the vicinity of the peaks/valleys, the widths of the peaks/valleys, the steepness of the drop-off or rise, and the background height and shape may all play a role in this.

4. How would molecular contaminants in the tube affect your results?

The molecular contaminants in the tube have different first excitation potentials (V_0) than argon, so the measurement of an argon atom's first excitation potential would be increased or decreased by these contaminants.

Software help

The SPARKvue and PASCO Capstone Help provide additional information on how to use this product with the software. You can access the help within the software or online.

SPARKvue

Software: Main Menu > Help

Online: help.pasco.com/sparkvue

PASCO Capstone

Software: Help > PASCO Capstone Help

Online: help.pasco.com/capstone

Specifications and accessories

Visit the product page at pasco.com/product/SE-9639 to view the specifications and explore accessories. You can also download experiment files and support documents from the product page.

Experiment files

Download one of several student-ready activities from the PASCO Experiment Library. Experiments include editable student handouts and teacher notes. Visit pasco.com/freelabs/SE-9639.

Specifications

Item	Specifications
Tunable DC (Constant Voltage) Power Supply I (SE-6615)	0~6.3 V DC, I ≤ 1A (ripple < 1%), 3.5 Digit Display; -4.5~0 V DC / -4.5~30 V DC (ripple < 1%) (Two ranges), I ≤ 10 mA, 3.5 Digit Display
Tunable DC (Constant Voltage) Power Supply II (SE-9644)	0~12 V DC, I ≤ 1A (ripple < 1%), 3.5 Digit Display; 0~100 V DC / 0~200 V DC (ripple < 1%) (Two ranges), 1 ≤ 30 mA, 3.5 Digit Display
DC Current Amplifier (SE-6621)	Current range: 10^{-8}~10^{-13} A, in six ranges, 3.5 Digit Display; Zero drift ≤ 1% of full range reading in 30 minutes at the range of 10^{-13} A (after a 20 minute warm-up)
Argon Tube (SE-9645A)	Filling gas: argon Filament voltage: ≤6.3 V DC Accelerating voltage: ≤100 V DC Wave crest (or trough) number: 7

Technical support

Need more help? Our knowledgeable and friendly Technical Support staff is ready to answer your questions or walk you through any issues.

Chat	pasco.com
Phone	1-800-772-8700 x1004 (USA) +1 916 462 8384 (outside USA)
Email	support@pasco.com

Regulatory information

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CE statement

This device has been tested and found to comply with the essential requirements and other relevant provisions of the applicable EU Directives.