PRACTICAL MANUAL
PHYSICS Lab-VI
PH-312

FOR
FINAL YEAR APPLIED PHYSICS

Fall Semester 202_

NAME OF STUDENT: _____

CLASS ROLL NO.: _____ SECTION: _____

DISCIPLINE: _____

BATCH: _____

DEPARTMENT OF PHYSICS

NED UNIVERSITY OF ENGINEERING & TECHNOLOGY,
KARACHI, PAKISTAN.

<u>CERTIFICATE</u>

Certified that Mr. / Ms. _____

of Class **Final Year BS Physics** Bearing Seat No. _____

Department_____ has completed the practical course

Physics Lab-VI (**PH-312)** of **BS Physics** as prescribed by the NED University of Engineering &

Technology, Karachi for the Academic Session_____.

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Lab. Teacher

PHYSICS lab-VI (PH-312) PRACTICAL

NAME OF STUDENT: _____

CLASS ROLL NO.:_____

S.NO.	Description	Remarks	Signature & Date
1.	Experimental verification of the existence of discrete energy states of Ar atoms using Franck-Hertz tube.		
2.	To determine the excitation energy of Ar atoms and Plank's Constant(h) from Franck-Hertz experiment.		
3.	To draw the plateau and determine the optimal operating voltage of a Geiger-Müller counter.		
4.	To investigate and compare Poisson and Gaussian distribution related to measurement of radioactive decay with Geiger counter.		
5.	To generate calibration curve of Helium source using spectrometer and diffraction grating.		
6.	To estimate the spectrums of the given sources using helium calibration curve.		
7.	To develop a computer program to compute the root of given equation using a bracketing numerical method.		
8.	To develop a computer program for the solution of ordinary differential equation (ODE) by second order numerical method (R-K method).		

EXPERIMENT # 01

OBJECT:

Experimental verification of the existence of discrete energy states of Ar atoms using Franck-Hertz tube.

Equipment:

Included Equipment	Model	Quantity
1. Tunable DC (Constant Voltage) Power Supply I	SE-6615	1
2. Tunable DC (Constant Voltage) Power Supply II	SE-9644	1
3. DC Current Amplifier	SE-6621	1
4. Argon Tube Enclosure with Argon Tube	SE-9650	1
5. Connecting cable, 850 mm, red	EM-9740	Set of 5
6. Connecting cable, 850 mm, black	EM-9745	Set of 5
7. Power Cord	-	3
8. BNC Cable	-	1
9. 8-pin DIN Extension Cable	UI-5218	2

Theory:

In 1914, James Franck and Gustav Hertz discovered in the course of their investigations 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 extensive and cumbersome experiment apparatus. They performed this experiment that has become one of the classic demonstrations of the quantization of atomic energy levels. They 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 try to interpret the data in the context of modern atomic physics. We will not attempt the spectroscopic measurements, since the emissions are weak and in the extreme ultraviolet portion of the spectrum.

Principle of the Experiment

The Franck-Hertz tube is an evacuated glass cylinder with four electrodes (a "tetrode") which contains argon. The four electrodes are: an indirectly heated oxide-coated cathode as an electron source, 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) (about 1.5 V). 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 with 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 electrode (A) is small. A
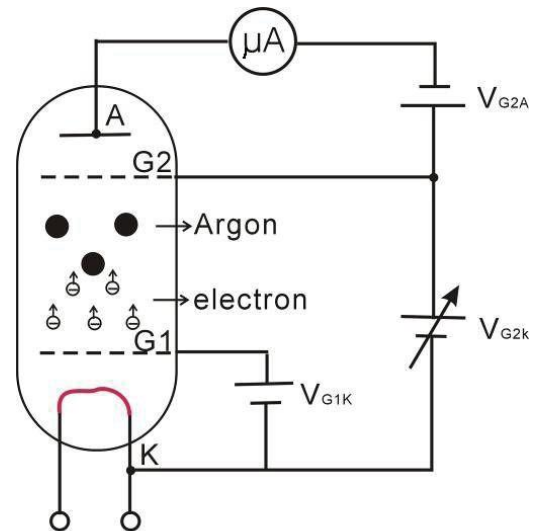
small constant negative potential U_{G2A} ("retarding potential") is applied between G_2 and the collector plate A (i.e. A is less positive than G_2). The resulting electric field between G_2 and collector electrode A opposes the motion of electrons to the collector electrode, so that electrons which have kinetic energy less than $e \cdot U_{G2A}$ at Grid 2 cannot reach the collector plate A.

As will be shown later, this retarding voltage helps to differentiate the electrons having inelastic collisions from those that don't.

A sensitive current amplifier is connected to the collector electrode so that the current due to the 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, say V_1, the plate current I_A will increase as more electrons reach the plate. When the voltage V is reached, it is noted that the plate current, I_A, takes a sudden drop. This is due to the fact that the electrons just in front of the grid G_2 have gained enough energy to collide inelastically with the argon atoms. Having lost energy to the argon atom, they do not have sufficient energy to over-come the retarding voltage between G_2 and collector electrode A. This causes a decrease in the plate current I_A. Now as the voltage is again increased, the electrons obtain the energy necessary for inelastic collisions before they reach the anode. After the collision, by the time they reach the

1Figure 1.1 Franck-Hertz tube

grid, they have obtained enough energy to overcome the retarding voltage and will reach the collector plate. Thus I_A will increase. Again when a certain voltage V_2 is reached we note that I_A drops. This means that the electrons have obtained enough energy to have two inelastic collisions before reaching the grid G_2, but have not had enough remaining energy to overcome the retarding voltage. Increasing the voltage again, I_A starts upward until a third value, V_3, of the voltage is reached when I_A drops. This corresponds to the electrons having three inelastic collisions before reaching the anode, and so on. The interesting fact is that $V_3 - V_2$ equals $V_2 - V_1$, etc., which shows that the argon atom has definite excitation levels and will absorb energy only in quantized amounts.


When an electron has 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. This excited electron will within a very short time fall back into the ground state level, emitting energy in the form of photons. The original bombarding electron is again accelerated toward the grid anode. Therefore, the excitation energy can be measured in two ways: by the method outlined above, or by spectral analysis of the radiation emitted by the excited atom.

Figure 2 displays a typical measurement of the anode current, I_A, as a function of the accelerating voltage. As soon as $V_{G2K} > V_{G2A}$ the current increases with rising V_{G2K}. Notice that the current sharply decreases for a voltage U_1 and then increases up to U_2, and then this pattern recurs. The interpretation of these observations is successful with the following assumptions:

- Having reached energy of about $e \cdot U_0$, electrons can transmit their kinetic energy to a discrete excitement state of the argon atoms.
- As a result of the inelastic collision, they pass the braking volt- age.
- If their energy is twice the required value, or $2\, e \cdot U_0$, they can collide two times inelastically and similarly for higher voltages.

- As a matter of 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 (108.1 nm).
In figure 2, the resonance voltage is denoted by U_0.
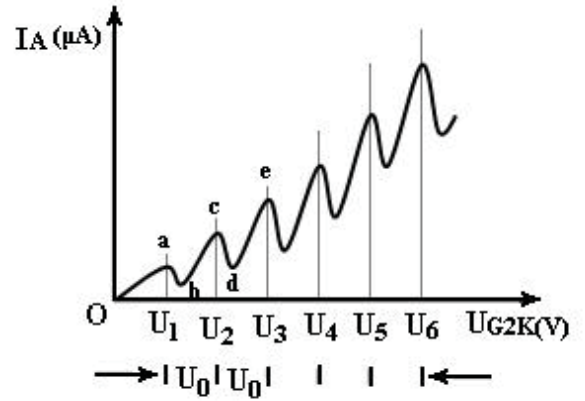
$$e \cdot U_0 = hf = hc/\lambda$$

or

$$h = e\lambda \left(\frac{U_0}{c}\right)$$

where e is the charge on an electron, h is Planck's Constant, and c is the speed of light.

Procedure:

1. Connections

1. On the DC Current Amplifier, connect the special BNC-to-BNC cable between the port on the amplifier marked "INPUT SIGNAL" and the port on the Argon Tube Enclosure marked "µA".

2. On Power Supply II, (SE-9644) connect the positive terminal of the 12 V DC output to the grid-like electrode labeled "G2" (red sockets) on the Argon Tube Enclosure (SE-9650) and connect the negative terminal of the 12 V DC output to the terminal labeled "A" (black sockets) on the enclosure.

3. On Power Supply II, connect the positive terminal of the 100 V DC output on the power supply to the grid-like electrode labeled "G2" (red sockets) on the Argon Tube Enclosure and connect the negative terminal of the power supply to the terminal labeled "K" (black sockets) on the enclosure.

4. On Power Supply I (SE-6615), connect the positive terminal of the -4.5 – +30 V DC output on the power supply to the grid-like electrode labeled "G1" on the Argon Tube Enclosure and connect the

negative terminal of the power supply to the terminal labeled "K" (black sockets) on the enclosure,

5. On Power Supply I, connect the positive terminal of the 0 – 6.3 V DC output on the power supply to the red socket of the port labeled "FILAMENT" on the Argon Tube enclosure and connect the negative terminal of the power supply to the black socket of the "FILAMENT" port.

• Note: Before connecting the power cords, please check that the setting for the input voltage range (110 – 120 V or 220 – 240 V) matches the local AC voltage. For the two 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.

DANGER:

High Voltage is applied to the Argon Tube. Avoid contact with any part of the body.

• Only use safety equipment leads (shrouded patch cords) for connections.

• Make sure that the power supplies and current amplifier are OFF before making the connections.

• Make sure that the power supplies and current amplifier are OFF before installing or replacing the argon tube in the Argon Tube Enclosure
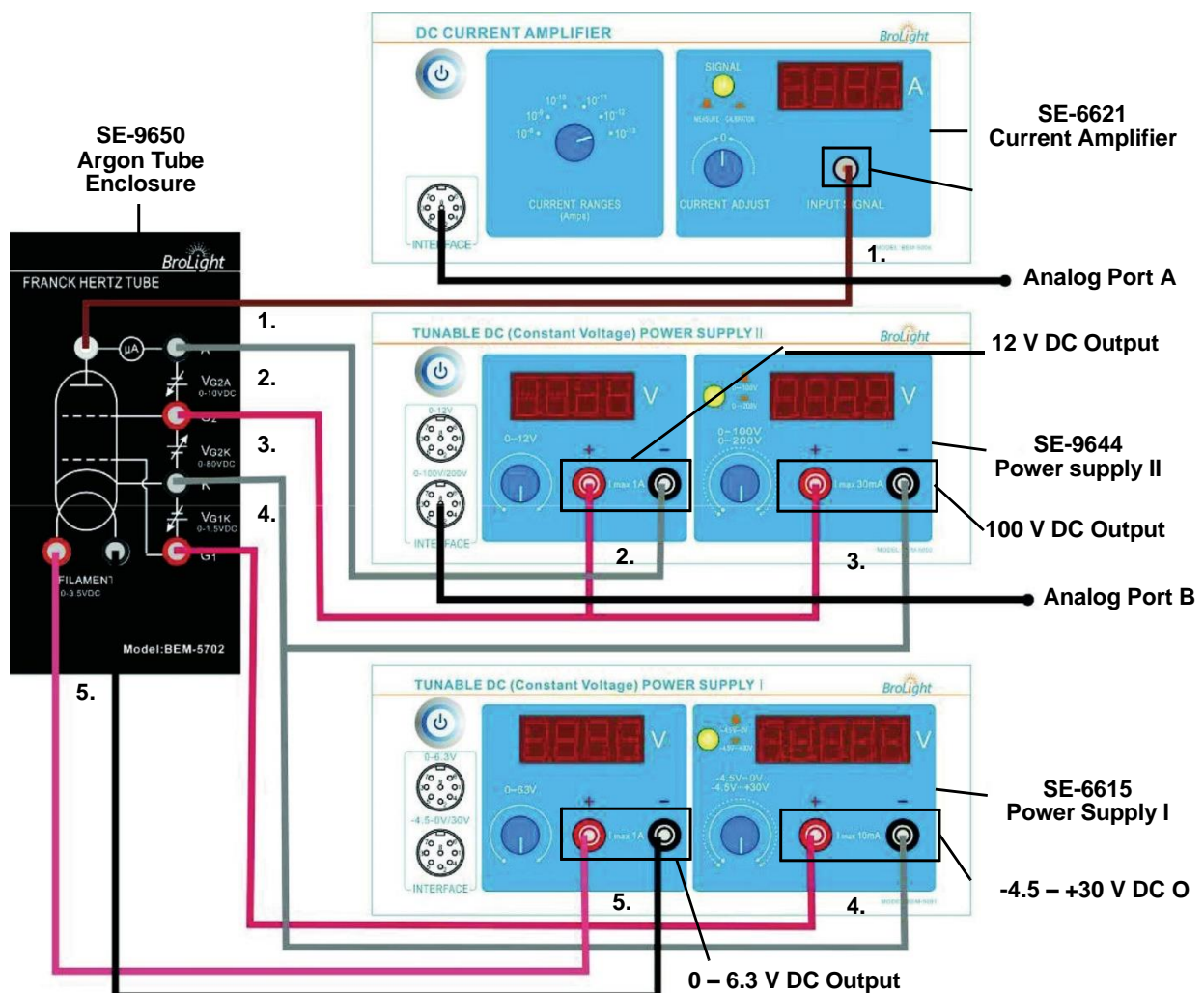
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2. Tunable DC (Constant Voltage) Power Supply I
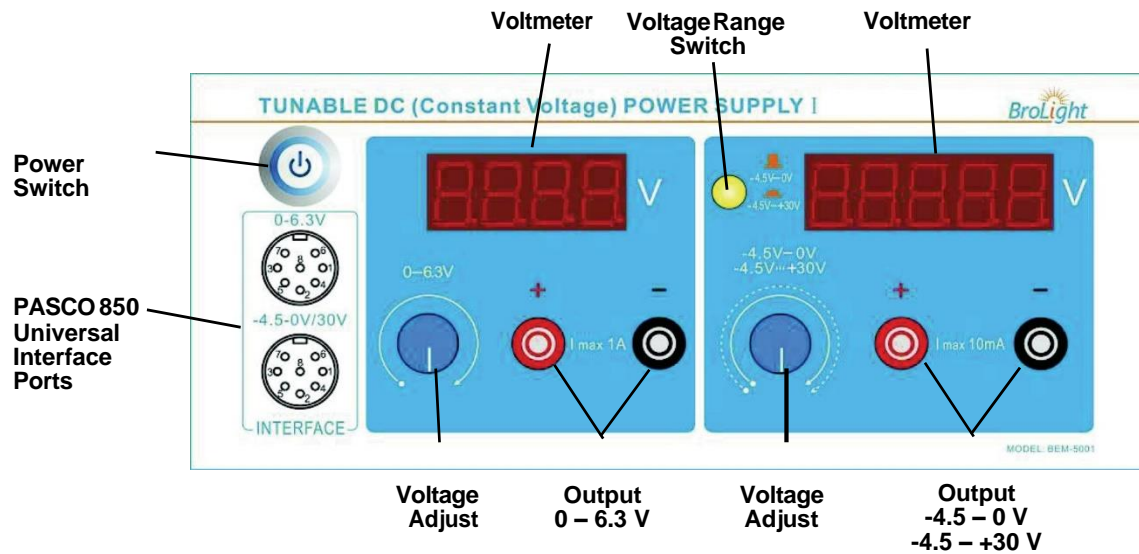
- Voltmeter: Displays voltage across the argon tube.
- Voltage Range Switch: Sets the voltage range as -4.5 – 0 V ($\sqcap$) or -4.5 – +3 0 V ($\sqcap$)
- Power Switch: Turns the power to the instrument ON or OFF.
- Voltage Adjust: Sets the voltage across the argon tube.
- Output: Output power.
- Data Interface: Connect to the analog channels of the PASCO 850 Universal Interface.

3. Tunable DC (Constant Voltage) Power Supply II
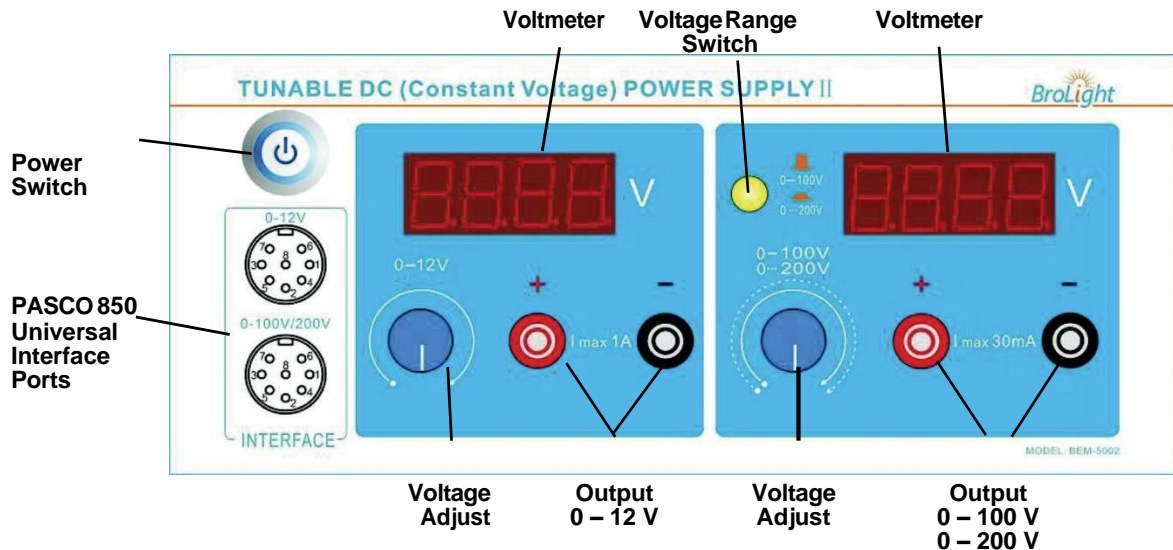
- Voltmeter: Displays voltage across the argon tube.
- Voltage Range Switch: Sets the voltage range as 0 to 100 V (⌓) or 0 to 200 V (⌁) for the accelerating voltage.
- Power Switch: Turns the power to the instrument ON or OFF.
- Voltage Adjust: Sets the voltage for both voltage ranges.
- Output: Output power.
- Data Interface: Connect to the analog channels of the PASCO 850 Universal Interface.

4. DC Current Amplifier
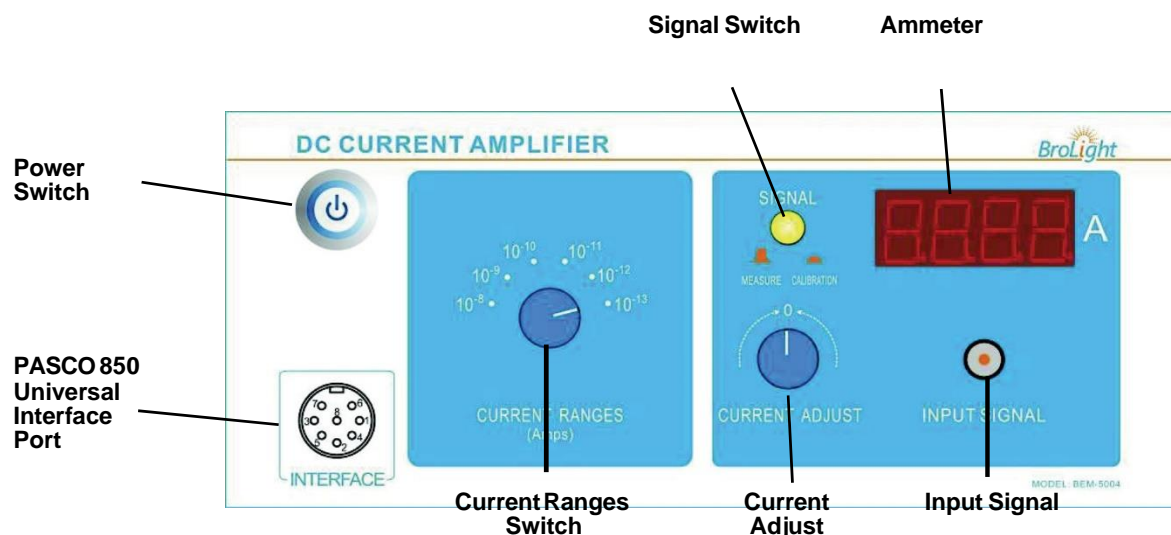
- Power Switch: Turns the power to the instrument ON or OFF.
- Data Interface: Connect to the analog channels of the PASCO 850 Universal Interface.
- Current Range Switch: Sets the current range for the instrument's current amplifier (10^{-8} to 10^{-13} A).
- Signal Switch: Sets the signal to MEASURE (⌓) or CALIBRATION (⌁).
- Current Adjust: Sets the current through the instrument to zero.
- Ammeter: Displays the current through the argon tube.
- Input Signal: Input current signal.

5. 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 the section "Connect Cables and Cords"

2. On the Tunable DC (Constant Voltage) Power Supply I, Tunable DC (Constant Volt- age) Power

Supply II, and the DC Current Amplifier, push in the Power Switch to the ON position.

3. On the DC 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. Adjust the CURRENT CALIBRATION knob until the current reads zero. Press the SIGNAL button to MEASURE.

⚠️

NOTE: It is very important to allow the argon tube and apparatus to warm up for 15 minutes prior to making any measurements.

4. On the DC (Constant Voltage) 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 adjust knob until the voltmeter reads 3.5 V. This sets $V_H = 3.5$ V (Filament Volt- age). Note: The Argon Tube Enclosure may have a different suggested filament voltage. If so, use it instead of 3.5 V.

6. On Power Supply I, rotate the -4.5 – +30 V adjust knob until the voltmeter reads 1.5 V. This sets $V_{G1K} = 1.5$ V (the volt- age between the first grid and the cathode)

7. Rotate the 0 – 12 V adjust knob until the voltmeter reads 10.0 V to set $V_{G2A} = 10.0$ V (Retarding voltage).

8. Rotate the 0 – 100 V adjust knob until the voltmeter reads 0 V. This sets $V_{G2K} = 0$ V (Accelerating voltage).

9. Remember, allow the argon tube and the apparatus to warm up for 15 minutes.

10. When you have finished the above steps, check that $V_H = 3.5$ V (Filament voltage), $V_{G1K} = 1.5$ V (the voltage between the first grid and cathode), and $V_{G2A} = 10.0$ V (voltage between the second grid and anode – "retarding voltage"). If so, the equipment is ready to do the experiment. Note: These are suggested settings for the experiment, but other values could be tried. You can do the experiment by parameters that are marked on the Argon Tube Enclosure.

Experiment Procedure 1 (Manual Measurements)

Note:

- During the experiment, pay attention to the output current ammeter when the voltage is over 60 V. If the ammeter's reading increases suddenly, decrease the voltage at once to avoid the damage to the tube.

- If you want to change the value of **V_{G1K}**, **V_{G2A}** and **V_H** during the experiment, rotate the "0 ~ 100 V" adjust knob fully counter-clockwise before making the changes.

- The filament voltage is tunable from 0 to 6.3V. 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 **V_{G2A}** voltage to 0 V to prolong the life of the argon tube.

1. Increase the accelerating voltage V_{G2K} by a small amount (for example, 1 V). Record the new

accelerating voltage V_{G2K} (value read on voltmeter) and current IA (read on "Ammeter") in Table 1:1. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 1:1. Stop when the accelerating voltage $V_{G2K} = 85V$. (If the current IA exceeds the range, reduce the filament voltage (for example, 0.1V) and start over again.)

2. Try to identify the "peak positions", i.e. watch for those values of the accelerating voltage V_{G2K} for which the current reaches a local maximum and begins to drop on further increase of the accelerating voltage. Take a few data points (V_{G2K}, I_A) around these peak positions and record them in Table 1:2. Try to identify the "valley positions", i.e. watch for those values of the accelerating voltage V_{G2K} for which the current reaches a local minimum and begins to rise on further increase of the accelerating voltage. Take a few data points (V_{G2K}, I_A) around these valley positions and record them in Table 1:2.

3. Take sufficiently many voltage values so as to allow you to determine the positions of the peaks and valleys.

Experiment Procedure 2

Using a PASCO Interface and Data Acquisition Software

Items Needed

Item*	Quantity
850 Universal Interface (UI-5000)	1
PASCO Capstone Software (UI-5400)	1

*See the PASCO web site at www.pasco.com for more information

Hardware Setup: Connect Cables and Cords

> **Note:** Before connecting any cords or cables, be sure that all power switches on the Interface, Power Supplies, and Current Amplifier are in the OFF position and 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.

2. Connect one 8-pin DIN Extension Cable (UI-5218) from the INTERFACE port on the DC Current Amplifier to ANA- LOG INPUT A on the Universal Interface (UI-5100).

3. Connect a second 8-pin DIN Extension Cable from the 0 - 100V / 0 - 200V INTERFACE port on Power Supply II to ANALOG INPUT B on the Universal Interface.

4. Turn ON the power for the Universal Interface, the power supplies, and the current amplifier.

Current Amplifier

Interface Port

Argon Tube Enclosure

Power Supply I

Analog Input A **Analog Input B**

850 Universal Interface

Power Supply II

8-pin DIN Extension Cable
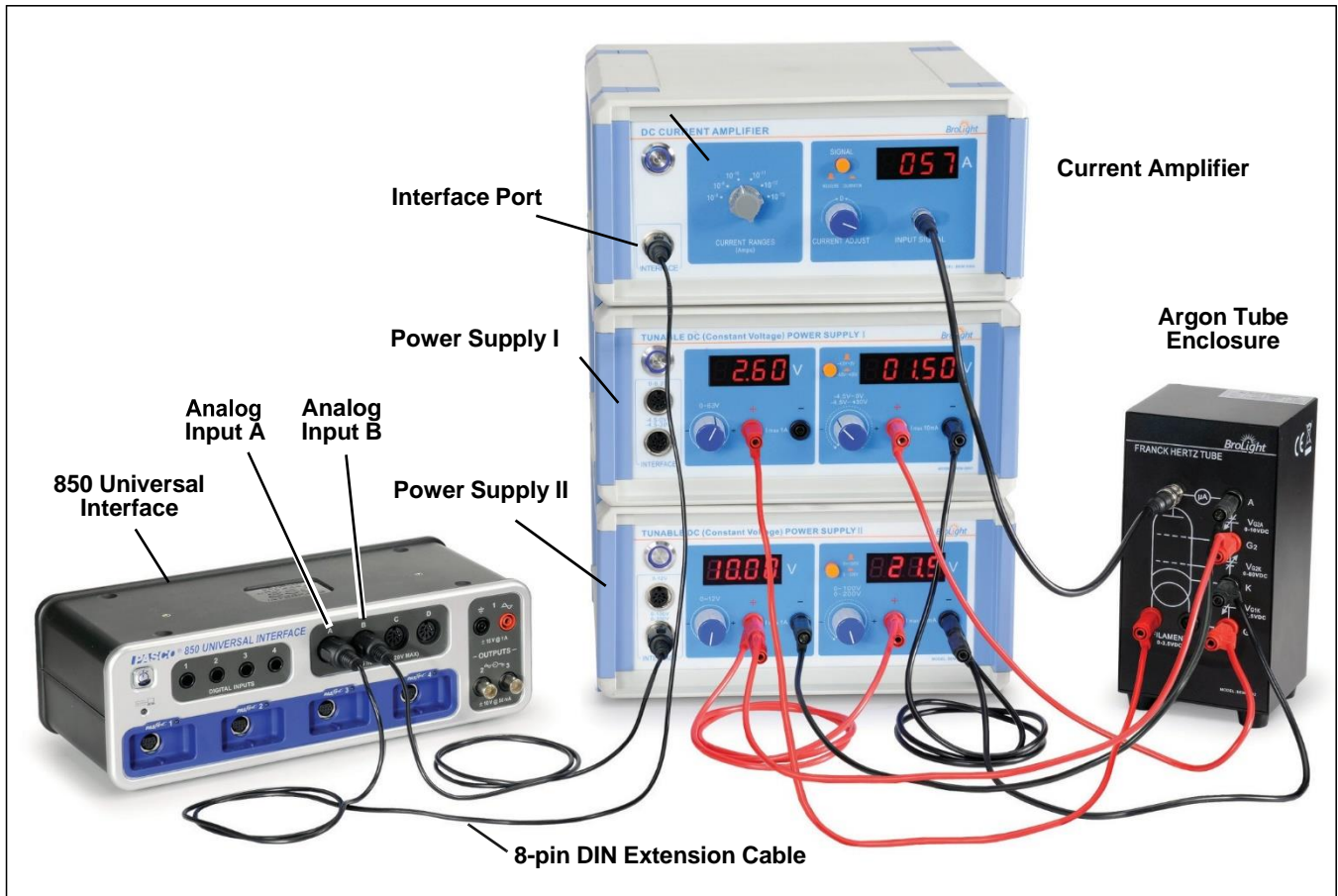
5. On the DC Current Amplifier, turn the CURRENT RANGES switch to 10-10 A. To set the current amplifier to zero, press the SIGNAL button into CALIBRATION. Adjust the CURRENT CALIBRATION knob until the current reads zero. Press the SIGNAL button to MEASURE.

6. On the DC (Constant Voltage) 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 adjust knob until the voltmeter reads 3.5 V. This sets VH = 3.5 V (Filament Voltage). Note: The Argon Tube Enclosure may have a different suggested filament volt- age. If so, use it instead of 3.5 V.

8. On Power Supply I, rotate the -4.5 – +30 V adjust knob until the voltmeter reads 1.5 V. This sets VG1K = 1.5 V (the volt- age between the first grid and the cathode)

9. Rotate the 0 – 12 V adjust knob until the voltmeter reads 10.0 V to set V_{G2A} = 10.0 V (Retarding voltage).

10. Rotate the 0 – 100 V adjust knob until the voltmeter reads 0 V. This sets V_{G2K} = 0 V (Accelerating voltage).

11. Remember, allow the argon tube and the apparatus to warm up for 15 minutes.

12. When you have finished the above steps, check that V_H = 3.5 V (Filament voltage), V_{G1K} = 1.5 V (the voltage between the first grid and cathode), and VG2A = 10.0 V (voltage between the second grid and

anode – "retarding voltage"). If so, the equipment is ready for the experiment. Note: These are suggested settings for the experiment, but other values could be tried. You can do the experiment by parameters that are marked on the Argon Tube Enclosure.

Software Setup

1. Start the PASCO Capstone software.

2. The current is a very small number, so to make the current to appear as a number between zero and 100 on the graph, cre- ate a calculation:

- Electron Current = [Current, Ch A (A)] x 10^10 with units of (x 10^-10 A)

3. Create a graph of "Electron Current" vs. Voltage.

4. Create a digits display of the Voltage. This will clearly show you the accelerating voltage so you can monitor it to make sure that you do not exceed 85 V.

5. Create a table and create Run-tracked User-Entered Data called Peak Voltage with units of (V).

6. In the second column of the table, create a calculation:

- Diff between Peaks = diff(1,[Peak Voltage (V)]) with units of (V)

  (This calculation calculates the voltage difference between adjacent current peaks.)

7. Add a column and create Run-tracked User-Entered Data called Trough Voltage with units of (V).

8. In the fourth column of the table, create a calculation:

- Diff between Peaks = diff(1,[Trough Voltage (V)]) with units of (V)

(This calculation calculates the voltage difference between adjacent current troughs.)

9. In the table, turn on the mean and standard deviation.

Recording Data

1. Make sure the accelerating voltage VG2K is zero.

2. After the filament has warmed up for about 15 minutes, click Record and slowly increase the accelerating voltage (take about two minutes). Do not exceed 85 V.

CAUTION: While you are 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 it to cool, and repeat the recording.

Observations and Calculations:

Manual Measurements Data
Filament voltage (V) 3.55V

$V_{G1K} = 1.5$ 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 (x 10^{-10} A)										
V_{G2K} (V)	11	12	13	14	15	16	17	18	19	20
I_A (x 10^{-10} A)										
V_{G2K} (V)	21	22	23	24	25	26	274	28	29	30
I_A (x 10^{-10} A)										
V_{G2K} (V)	31	32	33	34	35	36	37	38	39	40
I_A (x 10^{-10} A)										
V_{G2K} (V)	41	42	43	44	45	46	47	48	49	50
I_A (x 10^{-10} A)										
V_{G2K} (V)	51	52	53	54	55	56	57	58	59	60
I_A (x 10^{-10} A)										
V_{G2K} (V)	61	62	63	64	65	66	67	68	69	70
I_A (x 10^{-10} A)										
V_{G2K} (V)	71	72	73	74	75	76	77	78	79	80
I_A (x 10^{-10} A)										
V_{G2K} (V)	81	82	83	84	85					
I_A (x 10^{-10} A)										

Results and Discussion:

Precautions:

EXPERIMENT # 02

OBJECT:

To determine the excitation energy of Ar atoms and Plank's Constant(h) from Franck-Hertz experiment.

Equipment:

Included Equipment	Model	Quantity
1. Tunable DC (Constant Voltage) Power Supply I	SE-6615	1
2. Tunable DC (Constant Voltage) Power Supply II	SE-9644	1
3. DC Current Amplifier	SE-6621	1
4. Argon Tube Enclosure with Argon Tube	SE-9650	1
5. Connecting cable, 850 mm, red	EM-9740	Set of 5
6. Connecting cable, 850 mm, black	EM-9745	Set of 5
7. Power Cord	-	3
8. BNC Cable	-	1
9. 8-pin DIN Extension Cable	UI-5218	2

Theory:

Same As experiment no. 01

Procedure:

Same as experiment no. 01

Observations and Calculations:

Table 1.1: Accelerating Voltage and Tube Current

V_{G2K} (V)									
I_A (x 10^{-10} A)									

Table 1.2: Peak and Valley Voltages

		V_1	V_2	V_3	V_4	V_5	V_6
Peak positions	V_{G2K} (V)						
	I_A (x 10^{-10} A)						
Valley positions	V_{G2K} (V)						
	I_A (x 10^{-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 labeled "V1, V2, V3, V4, V5, and V6".

3. Obtain the value of argon atom's first excitation potential (V_0).

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

4. Calculate the value of Planck's Constant, h:

$$h = e\lambda(\frac{U_0}{c})$$

where e = 1.602 x 10^{-19} C, λ= 108.1 nm, and c = 3 x 108 m/s.

5. Calculate the percent difference between the experimental value and the accepted value (h_0 = 6.626 x 10-34 J•s)

$$\% \, Erroe = \left|\frac{h - h_o}{h_o}\right| x100$$

Results and Discussion:

Precautions:

EXPERIMENT # 3

Object

To draw the plateau and determine the optimal operating voltage of a Geiger-Müller counter.

Equipment

- Set-up for ST-360 Counter with GM Tube and stand (Counter box, power supply – transformer, GM Tube, shelf stand, serial cable, and a source holder for the stand) as shown in Figure 1.
- Radioactive Source (e.g., Cs-137, Sr-90, or Co-60) – One of the orange, blue, or green sources shown above in Figure 1.

Figure 1: ST360 setup with sources and absorber kit.

Theory

All Geiger-Müller (GM) counters do not operate in the exact same way because of differences in their construction. Consequently, each GM counter has a different high voltage that must be applied to obtain optimal performance from the instrument.

If a radioactive sample is positioned beneath a tube and the voltage of the GM tube is ramped up (slowly increased by small intervals) from zero, the tube does not start counting right away. The tube must reach the starting voltage where the electron "avalanche" can begin to produce a signal. As the voltage is increased beyond that point, the counting rate increases quickly before it stabilizes. Where the stabilization begins is a region commonly referred to as the knee, or

threshold value. Past the knee, increases in the voltage only produce small increases in the count rate. This region is the plateau we are seeking. Determining the optimal operating voltage starts with identifying the plateau first. The end of the plateau is found when increasing the voltage produces a second large rise in count rate. This last region is called the discharge region.

To help preserve the life of the tube, the operating voltage should be selected near the middle but towards the lower half of the plateau (closer to the knee). If the GM tube operates too closely to the discharge region, and there is a change in the performance of the tube. Then you could possibly operate the tube in a "continuous discharge" mode, which can damage the tube.

By the end of this experiment, you will make a graph similar to the one in Figure 2, which shows a typical plateau shape.
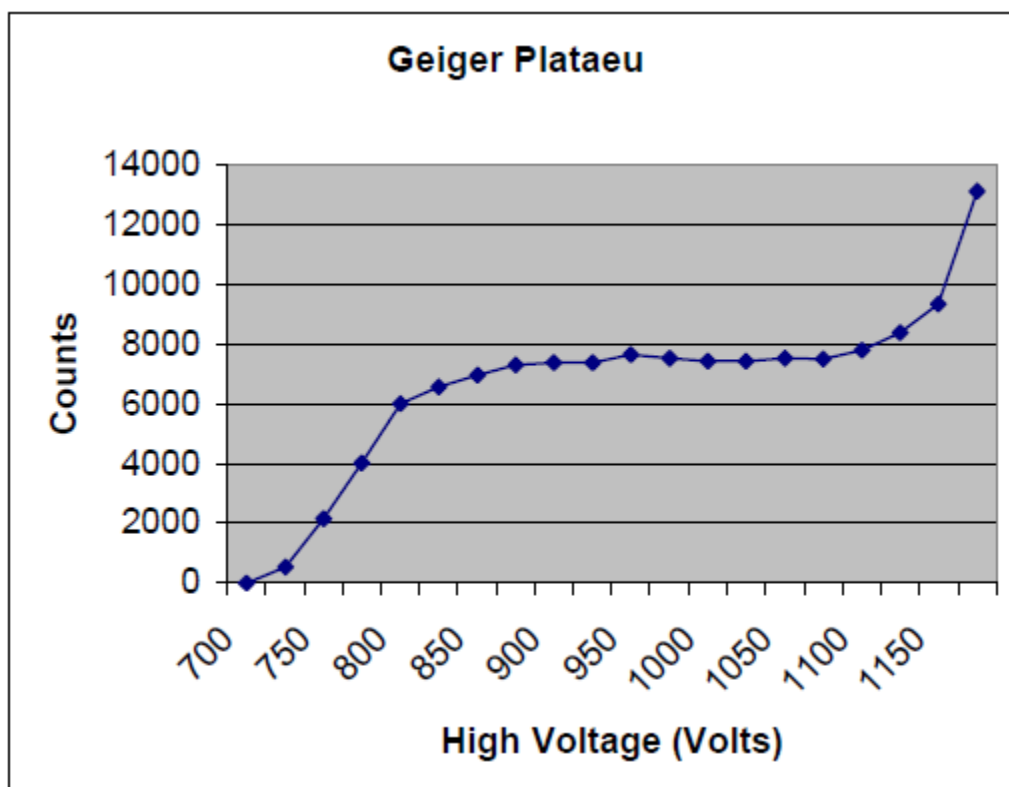

Figure 2: A plateau graph for a Geiger-Müller counter.

Q: What will your graph look like (what does the plateau look like)?

Answer: An "S" shape. Up from bottom left, leveling out for a bit, and up at top right. This would the "standard" plateau plot.

Q: Read the introduction section on GM tube operation. How does electric potential effect a GM tube's operation?

Answer: The electrical potential controls the electron multiplication, which affects the size of the signal. The size determines whether the pulse is detected or not. (The electric potential determines the size of the electric field, which actually does this).

Procedure:

1. Plug in the transformer/power supply into any normal electricity outlet and into the back of the ST-360 box. Next, remove the red or black end cap from the GM tube VERY CAREFULLY. (Do NOT touch the thin window!) Place the GM tube into the top of the shelf stand with the window down and BNC connector up. Next, attach the BNC cable to the GM tube and the GM input on the ST-360. Finally, attach the USB cable to the ST-360 and a USB port on your PC (if you are using one).

2. Turn the power switch on the back of the ST-360 to the ON position, and double click the STX software icon to start the program. You should then see the blue control panel appear on your screen.

3. Go to the Setup menu and select the HV Setting option. In the High Voltage (HV) window, start with 700 Volts. In the Step Voltage window, enter 20. Under Enable Step Voltage, select on (the default selection is off). Finally, select Okay.

4. Go under the Preset option and select Time. Enter 30 for the number of seconds and choose OK. Then also under the Preset option choose Number of Runs. In the window, enter 26 for the number of runs to make.

5. You should see a screen with a large window for the number of Counts and Data for all the runs on the left half of the screen. On the right half, you should see a window for the Preset Time, Elapsed Time, Runs Remaining, and High Voltage. If not, go to the view option and select Scaler Counts. See Figure below
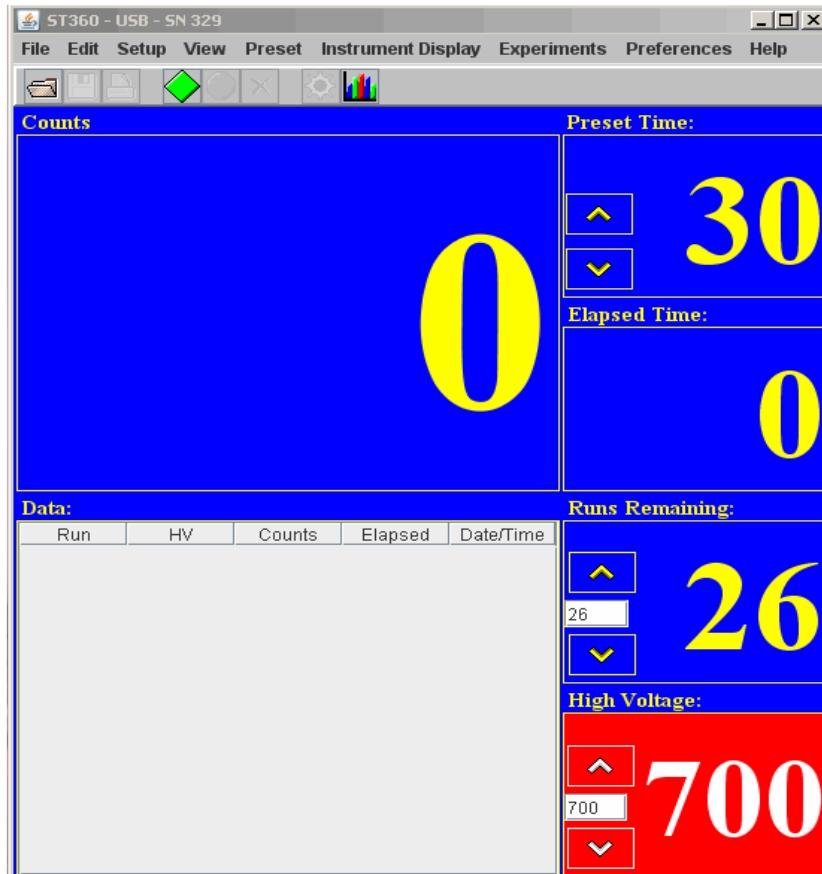
6. Make sure no other previous data by choosing the Erase All Data button (with the red "X" or press F3). Then select the green diamond to start taking data.

7. When all the runs are taken, choose the File menu and Save As. Then you may save the data file anywhere on the hard drive or onto a floppy disk. The output file is a text file that is tab delimited, which means that it will load into most spreadsheet programs. See the Data Analysis section for instructions in doing the data analysis in Microsoft Excel®. Another option is that you may record the data into your own data sheet and graph the data on the included graph paper.

8. You can repeat the data collection again with different values for step voltage and duration of time for counting. However, the GM tubes you are using are not allowed to have more than 1200 V applied to them. Consider this when choosing new values.

Observations and Calculations:

Tube #:_____

Voltage	Counts

Voltage	Counts

Graph Paper

Results and Discussion:

Precautions:

EXPERIMENT # 4

Object

To investigate and compare Poisson and Gaussian distribution related to measurement of radioactive decay with Geiger counter.

Equipment

- Set-up for ST-360 Counter with GM Tube and stand (Counter box, power supply – transformer, GM Tube, shelf stand, serial cable, and a source holder for the stand) as shown in Figure 1.
- Radioactive Source (e.g., Cs-137, Sr-90, or Co-60) – One of the orange, blue, or green sources shown above in Figure 1.

Figure 1: ST360 setup with sources and absorber kit.

Theory

Statistics is an important feature especially when exploring nuclear and particle physics. In those fields, we are dealing with very large numbers of atoms simultaneously. We cannot possibly deal with each one individually, so we turn to statistics for help. Its techniques help us obtain predictions on behavior based on what most of the particles do and how many follow this pattern. These two categories fit a general description of mean (or average) and standard deviation.

A measurement counts the number of successes resulting from a given number of trials. Each trial is assumed to be a binary process in that there are two possible outcomes: trial is a success or trial is not a success. For our work, the probability of a decay or non-decay is a constant every moment in time. Every atom in the source has the same probability of decay, which is very small (you can

measure it in the Half-life experiment). The Poisson and Gaussian statistical distributions are the ones that will be used in this experiment.

Q: List the formulas for finding the means and standard deviations for the Poisson and Gaussian distribution.

Answer:

$$\text{Poisson: } \bar{x} = \sum_i x_i \quad \text{and} \quad \sigma = \sqrt{\bar{x}} \text{ so } \sigma_{\bar{x}} = \frac{\sigma}{\sqrt{N}}$$

$$\text{Gaussian: } \bar{x} = \sum_i x_i \quad \text{and} \quad \sigma = \sqrt{\frac{\sum_i (\bar{x} - x_i)^2}{N - 1}} \text{ and } \sigma_{\bar{x}} = \frac{\sigma}{\sqrt{N}}$$

Q: A student in a previous class of the author's once made the comment, "Why do we have to learn about errors? You should just buy good and accurate equipment." How would you answer this student?

Answer: Check students' answers, but there should be some discussion about how every measurement contains some error. Obtaining 100% accuracy is impossible.

Procedure:

1. Setup the equipment as you did in the Experiment # 4, and open the computer interface. You should then see the blue control panel appear on your screen.

2. Go to the Preset menu to preset the Time to 5 and Runs to 150.

3. Take a background radiation measurement. (This run lasts twelve and half minutes to match the later measurements.)

4. When you are done, save your data onto disk (preferred for 150 data points).

5. Repeat with a Cesium-137 source, but reset the Time to 1 and the Number of Runs to 750 (again will be twelve and a half minutes.)

Data Analysis

1. Open Microsoft Excel®. Import or enter all of your collected data.
2. First, enter all of the titles for numbers you will calculate. In cell G10, enter **Mean**. In cell G13, enter **Minimum**. In cell G16, enter **Maximum**. In cell G19, enter **Standard Deviation**. In cell G22, enter **Square Root of Mean**. In cell H10, enter N. In cell I10, enter **Frequency**. In cell J10, enter **Poisson Dist.** Finally, in cell K10, enter **Gaussian Dist.**
3. In cell G11, enter =AVERAGE(C12:C161) – this calculates the average, or mean.
4. In cell G14, enter =MIN(C12:C161) – this finds the smallest value of the data.
5. In cell G17, enter =MAX(C12:C161) – this finds the largest value of the data.
6. In cell G20, enter =STDEV(C12:C161) – this finds the standard deviation of the data.
7. In cell G22, enter =SQRT(G11) – this takes a square root of the value of the designated cell, here G11.

8. Starting in cell H11, list the minimum number of counts recorded (same as Minimum), which could be zero. Increase the count by one all the way down until you reach the maximum number of counts.

9. In column I, highlight the empty cells that correspond to N values from column H.
    Then from the **Insert** menu, choose **function**. A window will appear, you will want to choose the **FREQUENCY** option that can be found under Statistical (functions **Spectrum Techniques Instructor Lab Manual** 25 listed in alphabetical order). Once you choose Frequency, another window will appear. In the window for **Data Array**, enter C12:C161 (cells for the data).
    In the window for **Bin Array**, enter the cells for the N values in column H. (You can highlight them by choosing the box at the end of the window.) **STOP HERE!!** If you hit OK here, the function will not work. You must simultaneously choose, the **Control key, the Shift key, and OK button** (on the screen). Then the frequency for all of your N values will be computed. If you did not do it correctly, only the first frequency value will be displayed.

10. In cell J11, enter the formula =G11^H11/FACT(H11)*EXP(-G11)*150 for the **Poisson Distribution**. (You must multiply the standard formula by 150, because the standard formula is normalized to 12.)

11. In cell K11, enter the formula =(1/(G20*SQRT(2*PI())))*EXP(-((H11-G11)^2)/(2*G20^2))*150 for the **Gaussian Distribution**. Note that in Excel the number $\square$ is represented by PI(). Again, you must multiply by 150 to let the function know how many entries there are. (*NOTE*: The formula this is derived from can be found in Appendix C.)

12. Next, make a graph of all three distributions: **Raw Frequency**, **Poisson Distribution**, and **Gaussian Distribution**. Start with the Chart Wizard either by choosing Chart 8 from the Insert Menu or pressing its icon on the top toolbar.

13. For your graph, select the N values in the H column and the Frequency values in the I column. Now add two more series, one for the **Poisson Distribution** and one for the **Gaussian Distribution**.

14. Print the graph to hand in to your instructor.

15. Repeat this whole data analysis procedure for your counts with Cs-137.

Observations and Calculations:

Tube #: _____

Source: _____

Run Duration: _____

(Time)

Tube #: _____

Source: _____

Run Duration: _____

(Time)

Run #	Counts

Run #	Counts

Data Set	Mean	Gaussian σ	Poisson σ
Background			
Cs-137			

Graph Paper

Questions:

1. Which distribution matches the data with the background counts? How well does the **Gaussian** distribution describe the Cs-137 data?

2. Why can't you get a value for the **Poisson** distribution with the data from the Cesium-137 source?

3. How close are the standard deviation values when calculated with the **Poisson** and **Gaussian Distributions**? Is one right (or more correct)? Is one easier to calculate?

Results and Discussion:

Precautions:

EXPERIMENT # 5

Object

To generate calibration curve of Helium source using spectrometer and diffraction grating.

Equipment

Spectrometer/goniom. w. vernier

Spectral lamp He, pico 9 base

Power supply for spectral lamps

Lamp holder, pico 9, f. spectral. lamps

Tripod base –PASS-

Theory

When light of wavelength A passes through a prism, it is devia- ted. The angle of deviation depends on the geometry of the prism and on the angle of incidence. The refractive index of a prism depends on the wavelength and thus also on the angle of deviation. Fig. 2 shows the calibration curve for the He spectrum (dispersion curve), obtained at the angle of mini- mum deviation.

Excitation of atoms results from electron impact. The energy difference produced when electrons revert from the excited state E0 is emitted as a photon with a frequency f.

$$hf = E_1 - E_0$$

where:

h = Planck's constant
= $6.63 \cdot 10^{-34}$ joule-seconds.

The Hamiltonian operator (non-relativistic) for the two elec- trons 1 and 2 of the He atom is:

$$H = -\frac{\hbar^2}{2m}\Delta_1 - \frac{\hbar^2}{2m}\Delta_2 - \frac{2e^2}{|\vec{r_1}|} - \frac{2e^2}{|\vec{r_2}|} + \frac{e^2}{|\vec{r} - \vec{r_2}|}$$

where $\hbar = \frac{h}{2\pi}$,

m and e represent the mass and charge of the electron respectively,

$$\Delta_i = \frac{d^2}{dx_i^2} + \frac{d^2}{dy_i^2} + \frac{d^2}{dz_i^2}$$

is the Laplace operator, and $\vec{r_i}$ is the position of the i-th elec- tron. The Spin-orbit interaction energy

$$E_{so} \propto \frac{Z^4}{4 \cdot (137)^2}$$

was ignored in the case of the nuclear charge Z = 2 of helium, because it is small when Z is small.

If we consider $\frac{e}{|\vec{r}_1 - \vec{r}_2|}$ as the electron-electron interaction

term, then the eigenvalues of the Hamiltonian operator without interaction are those of the hydrogen atom:

$$E^0_{n,m} = -\frac{me^4}{8h^2}\left(\frac{1}{n^2} + \frac{1}{m^2}\right)$$

$n, m = 1, 2, 3, \ldots .$

As the transition probability for simultaneous two-electron excitation is very much less than that for one-elecron excitation, the energy spectrum of the undisturbed system is:

$$E^0_{l,m} = -\frac{me^4}{8h^2}\left(1 + \frac{1}{m^2}\right) \quad m = 1, 2$$

The interaction term removes out the angular momentum degeneracy of the pure hydrogen spectrum and the exchange energy degeneracy. There results an energy adjustment:

$$E^1_{nl\pm} = <\phi^{\pm}_{nl\alpha} \,|\, \frac{e^2}{|\vec{r}_1 - \vec{r}_2|} \,|\, \phi^{\pm}_{nl\alpha} > = C_{nl} \pm A_{nl}$$

in which $\phi^{\pm}_{nl\alpha}$ are the anti-symmetrical undisturbed 2-particle wave functions with symmetrical $\phi^{\pm}_{nl\alpha}$ or anti symmetrical $\phi^{\pm}_{nl\alpha}$ position component, l* is the angular momentum quantum number, and alpha is the set of the other quantum numbers required.

In the present case, the orbital angular momentum of the single electron l is equal to the total angular momentum of the two electrons L, since only one-particle excitations are being considered and the second electron remains in the ground state (l = 0).

Cnl and Anl are the Coulomb and exchange energy respectively. They are positive. Coupling the orbital angular momentum L with the total spin S produces for S = 0, i. e. $\phi^{\pm}_{nl\alpha}$, a singlet

series and for S = 1, i. e. $\phi^{\pm}_{nl\alpha}$, a triplet series. Because of the lack of spin-orbit interaction, splitting within a triplet is slight. As the disturbed wave functions are eigen functions for S2 and as S2 interchanges with the dipole operator, the selection rule

ΔS = 0

(which is characteristic for 2-electron systems with a low nuclear charge number) results and forbids transitions between the triplet and singlet levels. In addition, independent of the spin-orbit interaction, the selection rule for the total angular momentum.

$$\Delta J = 0, \pm 1$$

applies except where

$$J = 0 \rightarrow J' = 0 .$$

If the spin-orbit interaction is slight, then

$$\Delta L = 0, \pm 1$$

Set-up and Procedure:

For Calibration of the prism spectrometer using the He spectrum. The experimental set up is as shown in Fig. 1. The spectrometer/goniometer and the prism must be set up and adjusted in accordance with the operating instructions. The spectral lamps attain their maximum light intensity after a warm-up period of approx. 5 min. The lamp housing should be set up so as to ensure free circulation of air through the ventilator slit.

Fig.1: Experimental set up for measuring the spectra of Helium
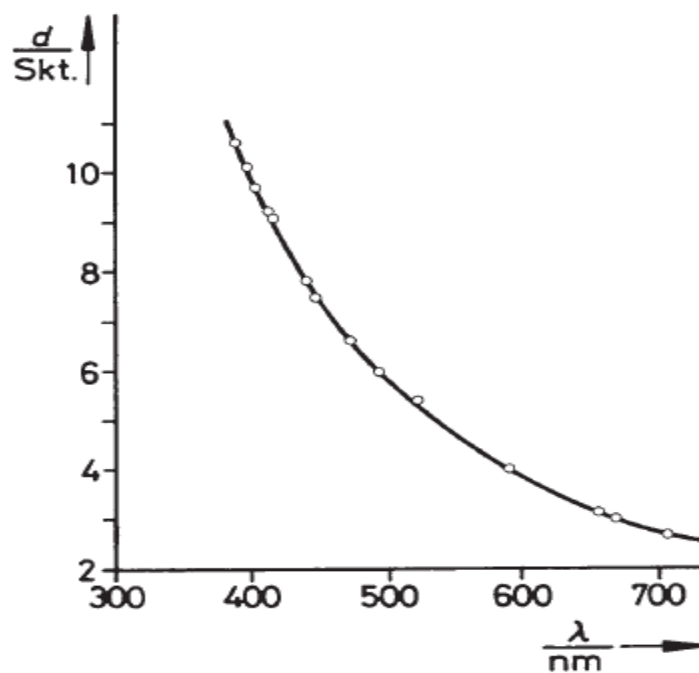
Fig. 2: Calibration curve of the prism spectrometer.

Observations and Calculations:

Graph Paper

Results and Discussion:

Precautions:

EXPERIMENT # 6

Object

To estimate the spectrums of the given sources using helium calibration curve.

Equipment

Spectrometer/goniom. w. vernier

Spectral lamp He, pico 9 base

Power supply for spectral lamps

Lamp holder, pico 9, f. spectral. lamps

Tripod base –PASS-

Theory

When light of wavelength A passes through a prism, it is devia- ted. The angle of deviation depends on the geometry of the prism and on the angle of incidence. The refractive index of a prism depends on the wavelength and thus also on the angle of deviation. Fig. 2 shows the calibration curve for the He spectrum (dispersion curve), obtained at the angle of mini- mum deviation.

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$$hf = E_1 - E_0$$

where:

h = Planck's constant
= $6.63 \cdot 10^{-34}$ joule-seconds.

$$H = -\frac{\hbar^2}{2m}\Delta_1 - \frac{\hbar^2}{2m}\Delta_2 - \frac{2e^2}{|\vec{r_1}|} - \frac{2e^2}{|\vec{r_2}|} + \frac{e^2}{|\vec{r} - \vec{r_2}|}$$

where $\hbar = \frac{h}{2\pi}$,

The Hamiltonian operator (non-relativistic) for the two elec- trons 1 and 2 of the He atom is:

m and e represent the mass and charge of the electron respectively,

$$\Delta_i = \frac{d^2}{dx_i^2} + \frac{d^2}{dy_i^2} + \frac{d^2}{dz_i^2}$$

is the Laplace operator, and $\vec{r_i}$ is the position of the i-th elec- tron. The Spin-orbit interaction energy

$$E_{so} \propto \frac{Z^4}{4 \cdot (137)^2}$$

was ignored in the case of the nuclear charge $Z = 2$ of helium, because it is small when Z is small.

If we consider $\frac{e}{|\vec{r}_1 - \vec{r}_2|}$ as the electron-electron interaction

term, then the eigenvalues of the Hamiltonian operator without interaction are those of the hydrogen atom:

$$E^0_{n,m} = -\frac{me^4}{8h^2}\left(\frac{1}{n^2} + \frac{1}{m^2}\right)$$

$n, m = 1, 2, 3, \dots$.

As the transition probability for simultaneous two-electron excitation is very much less than that for one-elecron excitation, the energy spectrum of the undisturbed system is:

$$E^0_{l,m} = -\frac{me^4}{8h^2}\left(1 + \frac{1}{m^2}\right) \quad m = 1, 2$$

The interaction term removes out the angular momentum degeneracy of the pure hydrogen spectrum and the exchange energy degeneracy. There results an energy adjustment:

$$E^1_{nl\pm} = \langle \phi^\pm_{nl\alpha} \mid \frac{e^2}{|\vec{r}_1 - \vec{r}_2|} \mid \phi^\pm_{nl\alpha}\rangle = C_{nl} \pm A_{nl}$$

in which $\phi^\pm_{nl\alpha}$ are the anti-symmetrical undisturbed 2-particle wave functions with symmetrical $\phi^\pm_{nl\alpha}$ or anti symmetrical $\phi^\pm_{nl\alpha}$ position component, l* is the angular momentum quantum number, and alpha is the set of the other quantum numbers required.

In the present case, the orbital angular momentum of the single electron l is equal to the total angular momentum of the two electrons L, since only one-particle excitations are being considered and the second electron remains in the ground state (l = 0).

Cnl and Anl are the Coulomb and exchange energy respectively. They are positive. Coupling the orbital angular momentum L with the total spin S produces for S = 0, i. e. $\phi^\pm_{nl\alpha}$, a singlet

series and for S = 1, i. e. $\phi^\pm_{nl\alpha}$, a triplet series. Because of the lack of spin-orbit interaction, splitting within a triplet is slight. As the disturbed wave functions are eigen functions for S2 and as S2 interchanges with the dipole operator, the selection rule

$\Delta S = 0$

(which is characteristic for 2-electron systems with a low nuclear charge number) results and forbids transitions between the triplet and singlet levels. In addition, independent of the spin-orbit interaction, the selection rule for the total angular momentum.

$$\Delta J = 0, \pm 1$$

applies except where

$$J = 0 \to J' = 0 .$$

If the spin-orbit interaction is slight, then

$$\Delta L = 0, \pm 1$$

Set-up and Procedure:

For Calibration of the prism spectrometer using the He spectrum. The experimental set up is as shown in Fig. 1. The spectrometer/goniometer and the prism must be set up and adjusted in accordance with the operating instructions. The spectral lamps attain their maximum light intensity after a warm-up period of approx. 5 min. The lamp housing should be set up so as to ensure free circulation of air through the ventilator slit. Before changing the spectral lamps they must be allowed to cool since the paper towels or cloths used for this operation might otherwise stick to the glass. The illuminated scale is used for recording the spectra.

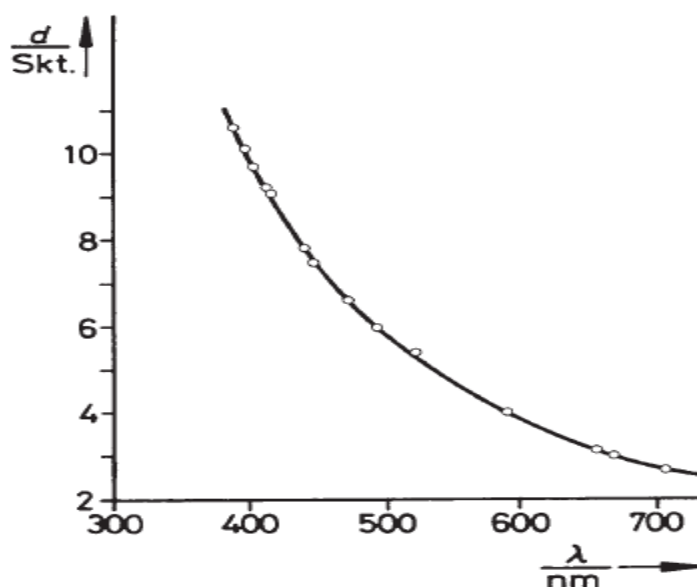Fig.1: Experimental set up for measuring the spectra of Helium

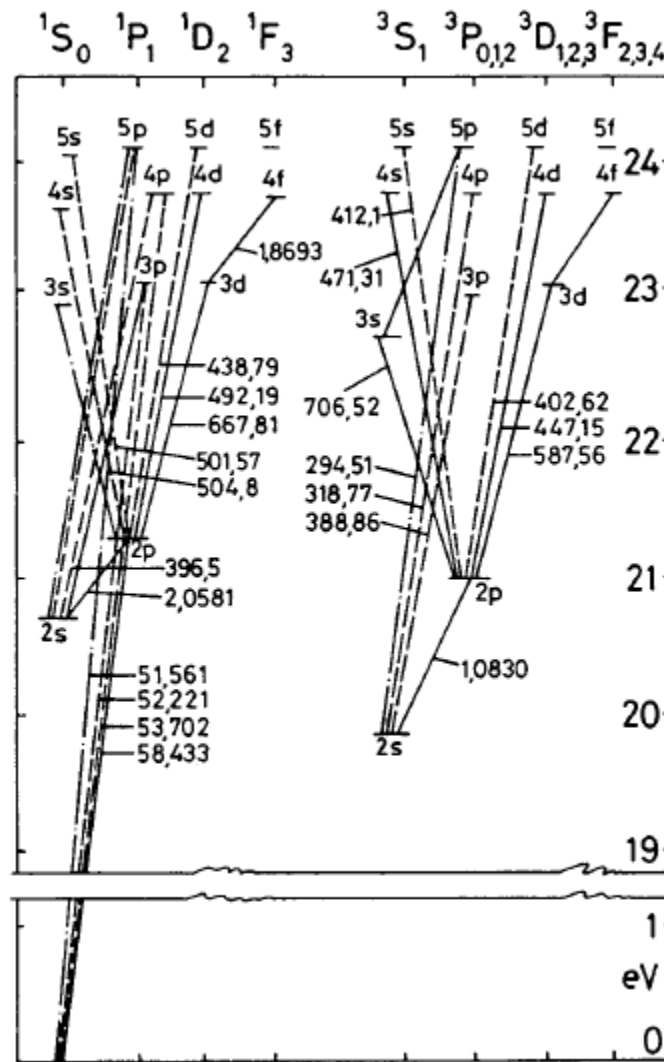Fig. 2: Calibration curve of the prism spectrometer.

Fig. 3: Spectrum of helium.

Colour	λ/nm	Transition	Relative intensity
red	706.5	$3\,^3S \rightarrow 2\,^1P$	5
red	667.8	$3\,^1D \rightarrow 2\,^1P$	6
red	656.0	He II	4–6
yellow	587.6	$3\,^3D \rightarrow 2\,^3P$	10
green	504.8	$4\,^1S \rightarrow 2\,^1P$	2
green	492.2	$4\,^1D \rightarrow 2\,^1P$	4
blue	471.3	$4\,^3S \rightarrow 2\,^3P$	3
blue	447.1	$4\,^3D \rightarrow 2\,^3P$	6
blue	438.8	$5\,^1D \rightarrow 2\,^1P$	3
violet	414.4	$6\,^1D \rightarrow 2\,^1P$	2
violet	412.1	$5\,^3S \rightarrow 2\,^3P$	3
violet	402.6	$5\,^3D \rightarrow 2\,^3P$	5
violet	396.5	$4\,^1P \rightarrow 2\,^1S$	4
violet	388.9	$3\,^3P \rightarrow 2\,^3S$	10

Table 1: He-I spectrum.

Observations and Calculations:

__Graph Paper__

Results and Discussion:

Precautions:

EXPERIMENT #07

OBJECT:

   To develop a computer program to compute the root of given equation using a bracketing numerical method.

PROGRAM CODE:

PROGRAM OUTPUT:

EXPERIMENT #8

To develop a computer program for the solution of ordinary differential equation (ODE) by second order numerical method (R-K method).

PROGRAM CODE:

PROGRAM OUTPUT:

What is Radiation?

This section will give you some of the basic information from a quick guide of the history of radiation to some basic information to ease your mind about working with radioactive sources. More information is contained in the introduction parts of the laboratory experiments in this manual.

Historical Background

Radiation was discovered in the late 1800s. Wilhelm Röntgen observed undeveloped photographic plates became exposed while he worked with high voltage arcs in gas tubes, similar to a fluorescent light. Unable to identify the energy, he called them "X" rays. The following year, 1896, Henri Becquerel observed that while working with uranium salts and photographic plates, the uranium seemed to emit a penetrating radiation similar to Röntgen's X-rays. Madam Curie called this phenomenon "radioactivity". Further investigations by her and others showed that this property of emitting radiation is specific to a given element or isotope of an element. It was also found that atoms producing these radiations are unstable and emit radiation at characteristic rates to form new atoms.

Atoms are the smallest unit of matter that retains the properties of an element (such as hydrogen, carbon, or lead). The central core of the atom, called the nucleus, is made up of protons (positive charge) and neutrons (no charge). The third part of the atom is the electron (negative charge), which orbits the nucleus. In general, each atom has an equal amount of protons and electrons so that the atom is electrically neutral. The atom is made of mostly empty space. The atom's size is on the order of an angstrom (1 Å), which is equivalent to $1\times10\text{-}10$ m while the nucleus has a diameter of a few fermis, or femto-meters, which is equivalent to $1\times10\text{-}15$ m. This means that the nucleus only occupies approximately 1/10,000 of the atom's size. Yet, the nucleus controls the atom's behavior with respect to radiation. (The electrons control the chemical behavior of the atom.)

Radioactivity

Radioactivity is a property of certain atoms to spontaneously emit particle or electromagnetic wave energy. The nuclei of some atoms are unstable, and eventually adjust to a more stable form by emission of radiation. These unstable atoms are called radioactive atoms or isotopes. Radiation is energy emitted from radioactive atoms, either as electromagnetic (EM) waves or as particles. When radioactive (or unstable) atoms adjust, it is called radioactive decay or disintegration. A material containing a large number of radioactive atoms is called either a radioactive material or a radioactive source. Radioactivity, or the activity of a radioactive source, is measured in unit equivalent to the number of disintegrations per second (dps) or disintegrations per minute (dpm). One unit of measure commonly used to denote the activity of a radioactive source is the Curie (Ci) where one Curie equals thirty seven billion disintegrations per second.

1 Ci = 3.7x1010 dps = 2.2x1012 dpm

The SI unit for activity is called the Becquerel (Bq) and one Becquerel is equal to one disintegration per second.

1 Bq = 1 dps = 60 dpm

Origins of Radiation

Radioactive materials that we find as naturally occurring were created by:

1. Formation of the universe, producing some very long lived radioactive elements, such as uranium and thorium.

2. The decay of some of these long lived materials into other radioactive materials like radium and radon.

3. Fission products and their progeny (decay products), such as xenon, krypton, and iodine.

Man-made radioactive materials are most commonly made as fission products or from the decays of previously radioactive materials. Another method to manufacture radioactive materials is activation of non-radioactive materials when they are bombarded with neutrons, protons, other high energy particles, or high energy electromagnetic waves.

Exposure to Radiation

Everyone on the face of the Earth receives background radiation from natural and man-made sources. The major natural sources include radon gas, cosmic radiation, terrestrial sources, and internal sources. The major man-made sources are medical/dental sources, consumer products, and other (nuclear bomb and disaster sources).

Radon gas is produced from the decay of uranium in the soil. The gas migrates up through the soil, attaches to dust particles, and is breathed into our lungs. The average yearly dose in the United States is about 200 mrem/yr. Cosmic rays are received from outer space and our sun. The amount of radiation depends on where you live, lower elevations receive less (~25 mrem/yr) while higher elevations receive more (~50 mrem/yr). The average yearly dose in the United States is about 28 mrem/yr. Terrestrial sources are sources that have been present from the formation of the Earth, like radium, uranium, and thorium. These sources are in the ground, rock, and building materials all around us. The average yearly dose in the United States is about 28 mrem/yr. The last naturally occurring background radiation source is due to the various chemicals in our own bodies. Potassium (^{40}K) is the major contributor and the average yearly dose in the United States is about 40 mrem/yr.

Background radiation can also be received from man-made sources. The most common is the radiation from medical and dental x-rays. There is also radiation used to treat cancer patients. The average yearly dose in the United States is about 54 mrem/yr. There are small amounts of radiation in consumer products, such as smoke detectors, some luminous dial watches, and ceramic dishes (with an orange glaze). The average yearly dose in the United States is about 10 mrem/yr. The other man-made sources are fallout from nuclear bomb testing and usage, and from accidents such as Chernobyl. The average yearly dose in the United States is about 3 mrem/yr

Adding up the naturally occurring and man-made sources, we receive on average about 360 mrem/yr of radioactivity exposure. What significance does this number have since millirems have not been discussed yet? Without overloading you with too much information, the government allows you 5,000 mrem/yr. (This is the Department of Energy's Annual Limit.) This is three times below the level of exposure for biological damage to occur. So just by living another year (celebrating your birthday), you receive about 7% of the government regulated radiation exposure.

The Geiger-Muller Counter

Geiger-Müller (GM) counters were invented by H. Geiger and E.W. Müller in 1928, and are used to detect radioactive particles ($\square$ and $\square$) and rays ($\square$ and x). A GM tube usually consists of an airtight metal cylinder closed at both ends and filled with a gas that is easily ionized (usually neon, argon, and halogen). One end consists of a "window" which is a thin material, mica, allowing the entrance of alpha particles. (These particles can be shielded easily.) A wire, which runs lengthwise down the center of the tube, is positively charged with a relatively high voltage and acts as an anode. The tube acts as the cathode. The anode and c When the radiation enters the GM tube, it will ionize some of the atoms of the gas*. Due to the large electric field created between the anode and cathode, the resulting positive ions and negative electrons accelerate toward the cathode and anode, respectively. Electrons move or drift through the gas at a speed of about 104 m/s, which is about 104 times faster than the positive ions move. The electrons are collected a few microseconds after they are created, while the positive ions would take a few milliseconds to travel to the cathode. As the electrons travel toward the anode they ionize other atoms, which produces a cascade of electrons called gas multiplication or a (Townsend) avalanche. The multiplication factor is typically 106 to 108. The resulting discharge current causes the voltage between the anode and cathode to drop. The counter (electric circuit) detects this voltage drop and recognizes it as a signal of a particle's presence. There are additional discharges triggered by UV photons liberated in the ionization process that start avalanches away from the original ionization site. These discharges are called Geiger-Müller discharges. These do not effects the performance as they are short-lived.athode are connected to an electric circuit that maintains the high voltage between them.

Now, once you start an avalanche of electrons how do you stop or quench it? The positive ions may still have enough energy to start a new cascade. One (early) method was external quenching which was done electronically by quickly ramping down the voltage in the GM tube after a particle was detected. This means any more electrons or positive ions created will not be accelerated towards the anode or cathode, respectively. The electrons and ions would recombine and no more signals would be produced,

The modern method is called internal quenching. A small concentration of a polyatomic gas (organic or halogen) is added to the gas in the GM tube. The quenching gas is selected to have a lower ionization potential (~10 eV) than the fill gas (26.4 eV). When the positive ions collide with the quenching gas's molecules, they are slowed or absorbed by giving its energy to the quenching molecule. They break down the gas molecules in the process (dissociation) instead of ionizing the molecule. Any quenching molecule that may be accelerated to the cathode dissociates upon impact producing no signal. If organic molecules are used, GM tubes must be replaced as they loss they permanently break down over time (about one billion counts). However, the GM tubes included in Spectrum Techniques® set-ups use a halogen molecule, which naturally recombines after breaking apart.