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DESCRIPTION

The Franck-Hertz Apparatus (FHA002) is designed for college students to demonstrate the existence of quantized states. The use of an argon tube allows the experiment to be performed at room temperature instead of in a heated oven as in the original mercury-based experiment. The argon tube is enclosed in a metal housing together with the necessary voltage supplies, current amplifier, and controls. The data can be recorded manually using the built-in digital meters, or viewed on a user-supplied oscilloscope (shown above), computer data acquisition system, or X-Y recorder.

SPECIFICATIONS

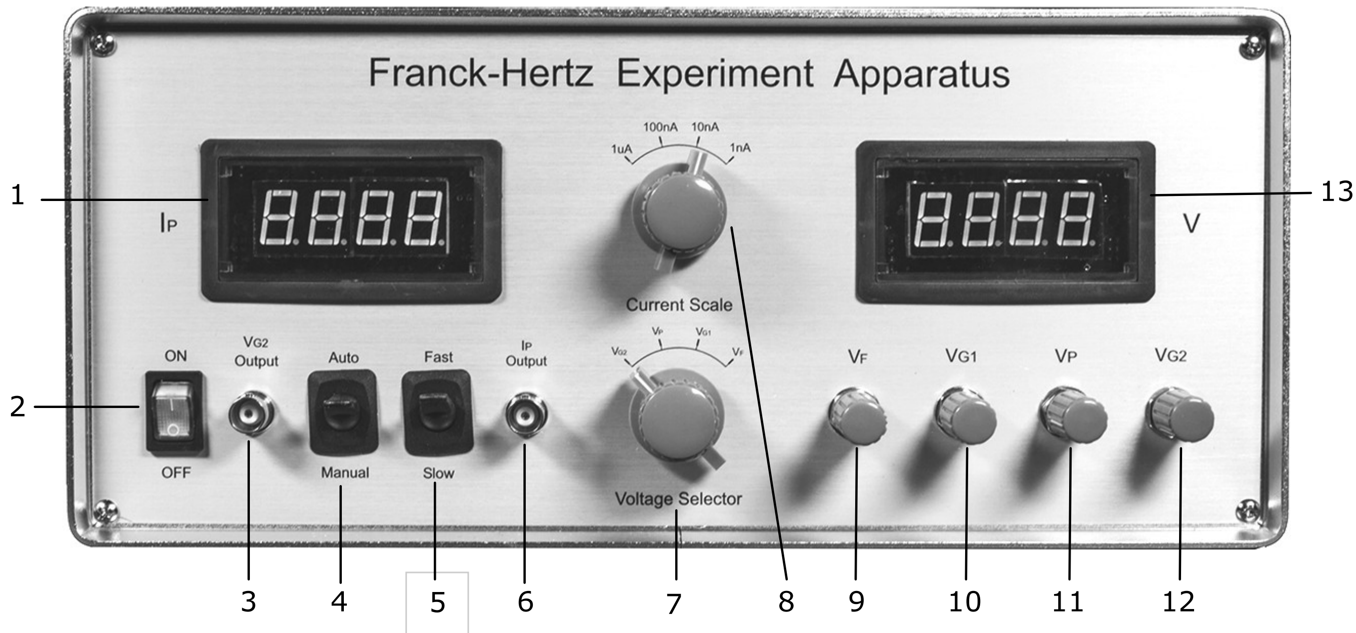
Number of observable peaks in spectrum:	
Point–by-point measurement	>6
Automatic observation on oscilloscope	>5
Voltages supplied to the Franck- Hertz tube:	
Filament heating voltage (V_F)	1.2 ~ 5V
Control grid voltage (V_{G1})	0 ~ 12V
Accelerating voltage (V_{G2})	0 ~ 95V
Plate reverse voltage (V_P)	0 ~ >20V
Scan for oscilloscope (X-Y mode):	
Scan Voltage at tube	0 ~ 90V
Scan duration	0 ~ 30ms
Scan repetition rate	33Hz
Scan output amplitude to oscilloscope	0 ~ 9V
Plate current measuring range:	0.02nA to 2.0µA in 4 range steps

Operating conditions

Operating power	110VAC ± 10%, 60Hz
Rated input power	21W
Preheating time for pattern to appear	≤1 min
Preheating time for stable current	≤5 min
Dimensions	32cm X 30cm X 15.5cm (l x w x h)

COMPONENT IDENTIFICATION

The controls and readouts on the front panel of the instrument are identified below:



1	Plate current display	2	ON/OFF Power switch	3	Acceleration voltage output
4	Scan mode selector	5	Scan speed selector	6	Plate current output
7	Voltage display selector	8	Plate current range selector	9	Filament voltage adjustment
10	Control grid adjustment	11	Reverse bias adjustment	12	Acceleration voltage adjustment
13	Voltage display				

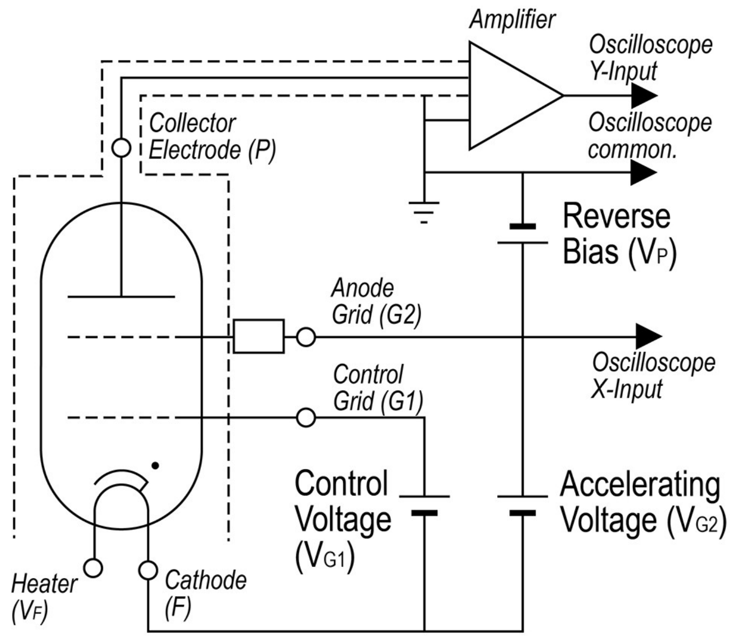
OPERATING PRINCIPLE

The Franck-Hertz tube in this instrument is a tetrode filled with argon. The schematic below illustrates the electrode configuration and shows the relations between their voltages.

Free electrons are generated at a heated cathode (F). The temperature of the cathode and so the quantity of electrons released are regulated by the applied heater voltage, V_F. A small voltage V_{G1} is applied between the cathode and the control grid G1 to control the scattering effect of the accumulating space charge at the cathode by extracting the electrons towards the anode plate (P) which serves as a collector.

Acceleration of the electrons towards the plate P is controlled by a second grid G2, where an adjustable voltage V_{G2} is maintained between G2 and F. A small decelerating voltage V_P (a reverse bias) between G2 and P ensures that only electrons that arrive at G2 with sufficient energy to overcome the deceleration can reach P and be registered.

An amplifier connected to P creates a large enough signal to register on the current display or an oscilloscope.



The electrons emitted by the cathode oxide are accelerated in the electric field generated by the voltage V_{G2} between the cathode and the second (anode) grid G2. As they travel though this field, their kinetic energy steadily increases. After passing through G2, the electrons encounter an opposing electric field. Those with insufficient kinetic energy do not reach the plate P and return to G2. On the path between G1 and G2, the electrons collide with argon atoms. The result of such collisions depends on the electrons' kinetic energy at the collision, which in turn depends on the magnitude of the voltage V_{G2} and the location of the collision along the path between the two electrodes.

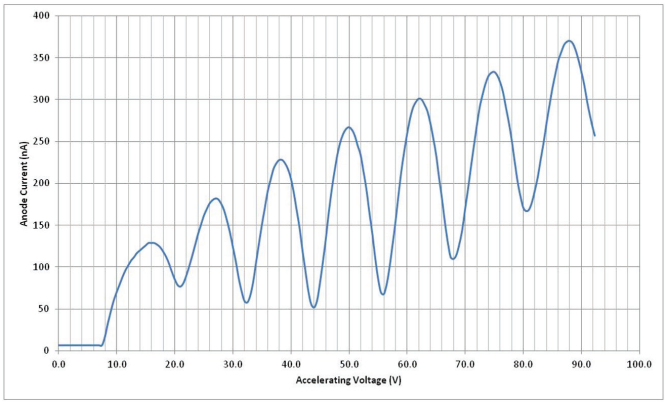
At the beginning of a scan of V_{G2}, because of a low accelerating voltage, the electron energy is low everywhere. Until the electron kinetic energy reaches the first excitation potential of the argon atoms, all the collisions are elastic So initially, the plate current I_P formed by electrons penetrating G2 with sufficient energy will increase with increasing V_{G2}.

When V_{G2} reaches the first excitation potential of the argon atom, electrons collide with argon atoms near G2 in an inelastic collision, and transfer the total energy obtained in the accelerating field to the argon atoms, exciting them from the ground state to the first excitation state.

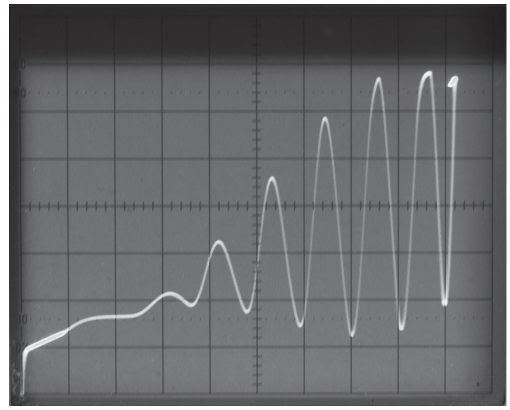
But after transferring all their energy to argon atoms, the electrons cannot overcome the reverse field between G2 and the anode plate P. They are drawn back to G2, even if some of them have penetrated it. So the plate current I_P decreases noticeably (to just those electrons that have not encountered an argon atom). Then, with a further increase of $V_{G2,}$ the electron energy also increases. There is now enough energy left after a collision with an argon atom to overcome the reverse field and reach the anode plate P once more.

At this stage, the current I_P begins to increase again, until V_{G2} reaches twice the argon atom's first excitation potential. Electrons between G1 and G2 can now lose energy to argon atoms twice, but electrons undergoing a second inelastic collision cannot reach the anode, so the current I_P decreases once more.

We can plot the amplitude curve of I_P vs. V_{G2} to obtain a spectrum of the transitions:



I_P vs. V_{G2} plot—Manual Operation



I_P vs. V_{G2} plot—Oscilloscope in X-Y Mode

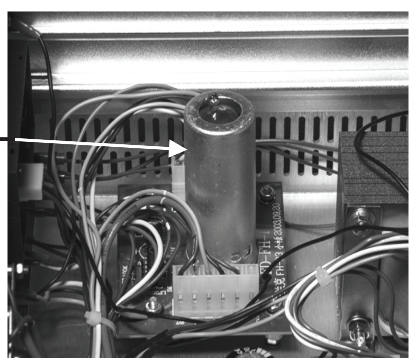
The voltage difference between two consecutive valley points (or peak points) is the first excitation potential of the argon atom.

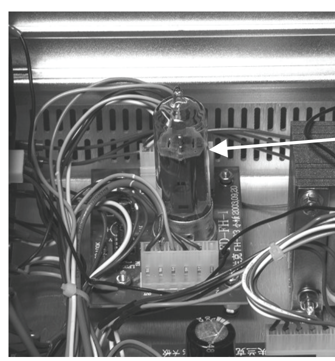
This experiment demonstrates that when the slow electrons in Franck-Hertz tube collide with argon atoms, either the collision is strictly elastic or an exact amount of energy is transferred, exciting the atoms from a lower energy level to a higher one. By measuring the voltage separation of the successive minima and verifying that it is constant, we can show that the energy transmitted is discrete, not continuous and estimate argon's first excitation potential (13.1V).

OPERATION

The unit is shipped with the argon tube in place internally:

Shield





Unshielded tube

MANUAL OPERATION

- Manual operation only requires the unit to be connected to 110VAC power. The built-in displays are used to record voltage and current values.
  - Voltage display: **actual voltages** at the tube are **same as the display value, except V_{G2}, which is 10X the displayed value**
  - Current display: **actual currents** at the tube are **2X the display value** for all ranges set on the range selector (8, illustration page 2)
- Set up: Turn the "Manual-Auto" switch (4) to "Manual", rotate the four control knobs (9),(10), (11),& (12) counter-clockwise to minimum, set the current range selector to 1nA and turn on the power (2)
- Choose initial settings: Using the voltage display selector and the corresponding

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control knobs, set V_F = 2.00V, V_{G1} = 1.00V, V_P = 8.00V, and V_{G2} = 5.0V ("0.50" on display.)

- Wait at least 5 minutes for the tube to warm up and the current to stabilize before making measurements.
  (These initial parameters set the tube in the range where the typical Franck-Hertz curve is readily visible without saturating the amplifier. You can explore the effect of other settings, but avoid increasing the filament voltage beyond about 3.5V. At high filament voltage settings, the large electron supply rate can promote breakdown and establish a gas discharge in the argon filling. This is characterized by a sudden large increase in the plate current. Immediately reduce V_{G2} sharply to extinguish the discharge, which can damage the tube.)
- Slowly increase V_{G2} and record V_{G2} & I_P pairs at suitable V_{G2} intervals (1V works well). The amplifier driving the I_P display saturates at a display reading of 11.40 (22.80 actual), so it is recommended to select the next higher setting of the current range selector (8) when a display of about 10.00 is reached.
- A plot of I_P vs. V_{G2} displays the characteristic maxima and minima and allows the first excitation potential of argon to be estimated from the V_{G2} separations of neighboring minima (or maxima).
- When finished measuring, reduce all the applied voltages to minimum before turning off the unit.

OSCILLOSCOPE OPERATION

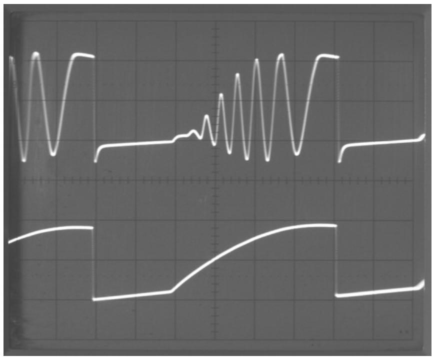
- Turn the "Manual-Auto" switch (4) to "Auto", and the "Fast-Slow" switch (5) to "Fast".
- Using the supplied shielded cables, connect the instrument's V_{G2} output to the oscilloscope's CHANNEL 2 (X) input and the I_P output socket to the CHANNEL 1 (Y) input. Set up the Franck-Hertz apparatus voltage parameters as described above for manual operation.

X-Y OPERATION

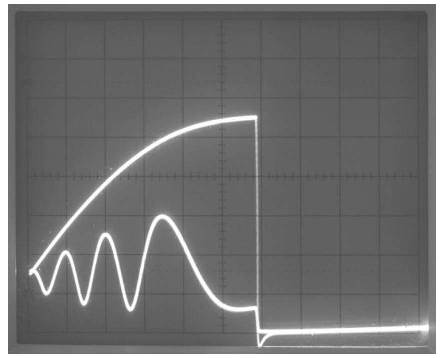
- Set the oscilloscope to X-Y mode and switch on the power of oscilloscope. Rotate the V_{G2} knob of the Franck-Hertz apparatus and observe the waveform on the oscilloscope screen. As the scan range increases with increasing V_{G2}, the successive maxima and minima appear. If necessary, adjust the amplifier range (knob 8) to yield a large trace without saturation.

TWO-CHANNEL OPERATION

- Set the oscilloscope to two-channel operation, triggered on Channel 2 (X) in chopped mode. Adjust the timebase setting appropriately for the 33Hz scan rate (5ms/div or 2ms/div usually works well). Slowly increase V_{G2} and observe the oscilloscope traces.



Upper trace: I_P
Lower Trace: V_{G2}



V_{G2} set to a minimum

- The I_P trace shows the maxima and minima and the V_{G2} trace shows the corresponding accelerating voltage. Adjust the current range setting (8) to avoid saturation, if necessary. (You can also increase V_P to achieve this)
- Adjust the Y and X positions on the oscilloscope as well as the timebase to show a single scan across the width of the screen. Slowly increase V_{G2} from zero and stop when the I_P trace is set to finish exactly at a minimum. Flip the scan mode selector switch (4) to "Manual" and read the value of V_{G2}. (= display value X10) Flip the switch back to "Auto", increase V_{G2} to the next minimum, and read the voltage again. Repeat until 5 or 6 minima have been determined. Estimate the argon first excitation potential from the voltage intervals between minima.
- When finished measuring, reduce all the applied voltages to minimum before turning off the unit.

X-Y RECORDER OPERATION

- When using an XY recorder with this unit, set the scan speed selector switch (5) to "Slow" then proceed as for oscilloscope X-Y mode.

PRECAUTIONS

During the experiment, pay particular attention to the output current indicator when the V_{G2} voltage is over 60V ("3.00" on display). If the I_P reading increases suddenly, decrease the accelerating voltage at once to avoid the damage to the tube.
The recommended filament voltage for this tube is 2V. There will be small variations in electron output at this voltage from tube to tube and you may need to adjust the filament voltage. However, do not exceed 3.5V. If distortion occurs on the top of the waveform, as the filament heats up, this indicates that the anode output current is too large and is causing the amplifier to saturate. The filament voltage should be decreased.