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Instruction Manual
and Experiment Guide
for the PASCO scientific
Model SE-9640 Franck-Hertz Tube
Model SE-9641 Franck-Hertz Oven
Model SE-9642 Franck-Hertz Control Unit

Franck-Hertz Experiment

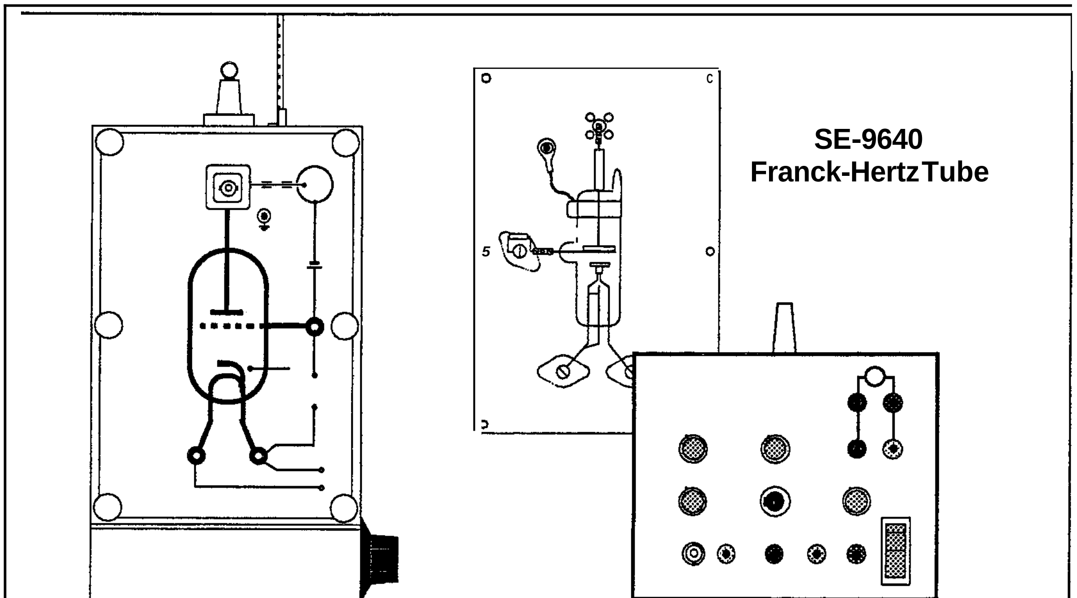

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Table of Contents

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LIMITED WARRANTY

PASCO scientific warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. **PASCO** will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by **PASCO** scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment, after repair, will be paid by **PASCO** scientific.

Equipment Return

Should this product have to be returned to **PASCO** scientific, for whatever reason, notify **PASCO** scientific by letter or phone BEFORE returning the product. Upon notification, the return authorization **and** shipping instructions will be promptly issued.

> **NOTE: NO** EQUIPMENT **WILL** BE **ACCEPTED FOR** RETURN WITHOUT *AN* **AUTHORIZATION.**

When returning equipment for repair, the **units** must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

1. The carton must be strong enough for the item shipped.
2. Make certain there is at least two inches of packing material between **any** point on the apparatus and the inside walls of the carton.
3. Make certain that the packing material *can* not shift in the **box,** or become compressed, thus letting the instrument come in contact with the edge of the **box.**

Introduction

In 1914, J. Franck and G. Hertz performed a landmark experiment, providing important empirical support for *Max* Planck's quantum theory and for the model of the atom suggested by Niels Bohr. Through the study of collisions between electrons and gas molecules, Franck and Hertz demonstrated that energy is indeed quantized in atomic interactions. For this work, they shared the1925 Nobel Prize in physics. Because of the importance of their experiment, and because of its conceptual simplicity, it has become an important experiment in the undergraduate laboratory.

A simplified diagram of the Franck-Hertz experiment is shown in Figure 1. In an oven-heated vacuum tube containing mercury gas, electrons are emitted by a heated cathode, and are then accelerated toward a grid that is at a potential Va relative to the cathode. Just beyond the grid is an anode, which is at a slightly lower potential than that of the grid (V_p = Va - AV; **AV = 1.5 V;** where V_p is the anode potential, and Va is the grid potential,).

If the accelerated electrons have sufficient energy when they reach the grid, some of them will pass through and will reach the anode. They will be measured as current Ic by the ammeter. If the electrons don't have sufficient energy when they reach the grid, they will be slowed by **AV,** and will fall back onto the grid.

Whether the electrons have sufficient energy to reach the anode depends on three factors: the accelerating potential **(V_a)**, the opposing potential **(AV),** and the nature of the collisions between the electrons and the gas molecules in the **tube. As** long as the electron/molecule collisions are elastic, the collector current depends only on Va and **AV,** because the electrons lose no energy to the gas. However, Franck and Hertz discovered that Ic went through a series of maxima and minima as the accelerating potential was varied. This implies that the gas molecules absorb energy from the electrons only at specific electron energies (resonant energies).

For example, the first excited state of mercury is 4.9 eV above the ground state. This is the minimum amount of energy that the mercury atoms can absorb in collisions with the accelerated electrons. When **Va** is less than 4.9 V, the electron/molecule collisions are therefore elastic, so the electrons loose no energy to the gas and arrive at the grid with kinetic energy equal to eVa. If **Va > AV,** the electrons Rave sufficient energy to overcome the opposing voltage, and many of them will pass through the grid and reach the anode, to be measured as current. However, if **Va** equals 4.9 **V,** the electrons gain enough kinetic energy to collide inelastically with the mercury atoms just as they reach the grid. In these collisions, the mercury atoms absorb the **full** 4.9 eV

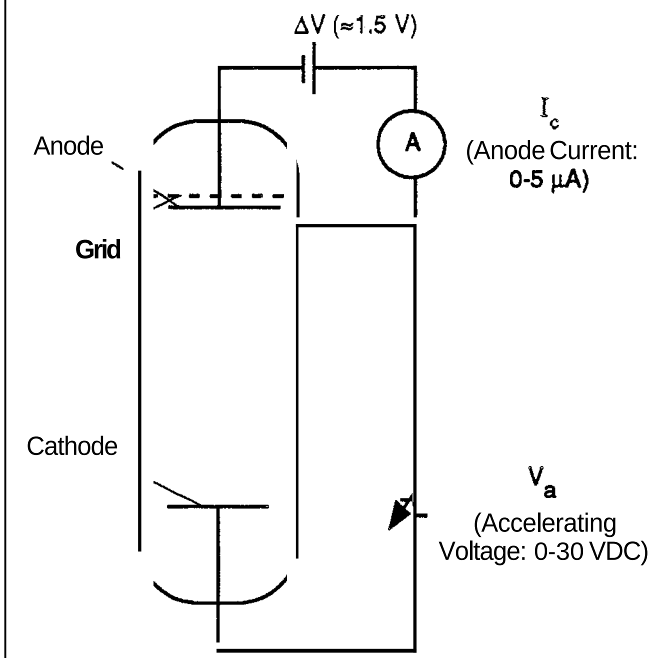

Figure 1 Simplified Diagram of Franck-Hertz Experiment

carried by the electrons. The electrons no longer have sufficient energy to overcome **AV,** and they fall back onto the grid. Ic is then a minimum.

As Va is raised beyond 4.9 V, I, increases again. However, when **Va** reaches 9.8 V, the electrons can lose all their energy to the gas molecules in two collisions. One collision is likely to occur midway between the cathode and the grid, the other will occur just as the electrons reach the grid. Again, the electrons loose all their kinetic energy in the inelastic collisions, so they fall back onto the grid, and Ic again falls to a minimum. Because of multiple inelastic collisions between the accelerated electrons and the mercury atoms, current minima are found whenever Va is a multiple of 4.9 V.

> **Note:** The above description is somewhat simplified. Due to contact potentials, the total energy gain of the electrons is not quite equal to eVa. Therefore, **Va** will be somewhat higher than 4.9 **V** when the first current minimum occurs. However, the contact potentials are a constant in the experiment, so at successive current minima **Va** will always be a multiple of 4.9 V higher than it was when the first current minimum occured.

If the accelerating voltage is too high, the electrons can still gain excessive energy before striking Mercury atoms, even if the temperature is correct, and the same problem *can* occur.

How the Tube *Should* Look During the Experiment

When the tube is properly heated and the accelerating voltage is within the proper range, there will be a deep blue cloud between the cathode and the grid (as opposed to the blue-green glow caused by ionization). **You** should *see* dark bands forming near the grid and moving towards the cathode as the accelerating voltage is increased. These bands are the regions in the tube where the electrons are colliding inelastically with the gas, raising the mercury atoms to their first level of excitation. The blue light is caused by the emission of a photon as the atoms return to the ground state (E_{photon} = **4.9** eV; λ_{photon} = 254 nm).

The Experiment: Setup, Operation, and Analysis

The Franck-Hertz experiment *can* be performed using three different setups:

A. Using the Control Unit and an Oscilloscope

B. Using the Control Unit and Voltmeters

C. Without the Control Unit (using separate power supplies and an ammeter or voltmeter)

The procedure for each setup is described below. Data tables and information on how to analyze the experiment are provided at the end of the manual.

A Using the Control Unit and an Oscilloscope

1. Remove the six thumbscrews that secure the front panel of the Franck-Hertz Oven. Replace the front panel with the Franck-Hertz **Tube as** shown in Figure 4.
2. Insert a centigrade thermometer (0-200 degrees) into the hole in the top of the oven. Insert it *so* the tip of the thermometer is near the center of the **tube.**
3. Check the label and plug the oven into an appropriate AC power outlet, then turn the thermostat dial to 180 °C. Let the oven heat up for 10-15 minutes. Keep an eye on the thermometer. Do **not let the oven temperature exceed 205 °C.**
4. Connect the tube, control unit, and oscilloscope **as** shown in Figure **4.** (The voltmeters that are shown in the figure are not needed when **an** oscilloscope is used.)
5. Switch on the control unit, but only AFTER the tube has warmed up for 10-15 minutes. Set the controls as follows:

Heater:	midrange (about 5.5 V)
Amplifier:	Gain–midrange Zero–midrange
Va:	Adjust–not applicable Switch–ramp ( )

6. Wait about 90 seconds for the cathode to warm up, then adjust **the** gain controls on the oscilloscope to get a trace as shown in Figure 4. (The x-channel gain should be approximately 0.5 volts/cm; the y-channel gain should be approximately 0.5 volts/cm.)
7. From the oscilloscope trace, measure the values of Va for which the collector current (I_c) is a minimum.

   Note: The input **to** the y-channel of the oscilloscope is proportional to Ic. The input to the x-channel of the **oscilloscope** is **equal** to Va/10.
8. **See** Analyzing the Experiment at the end of the manual for details about manipulating and analyzing your **data.**

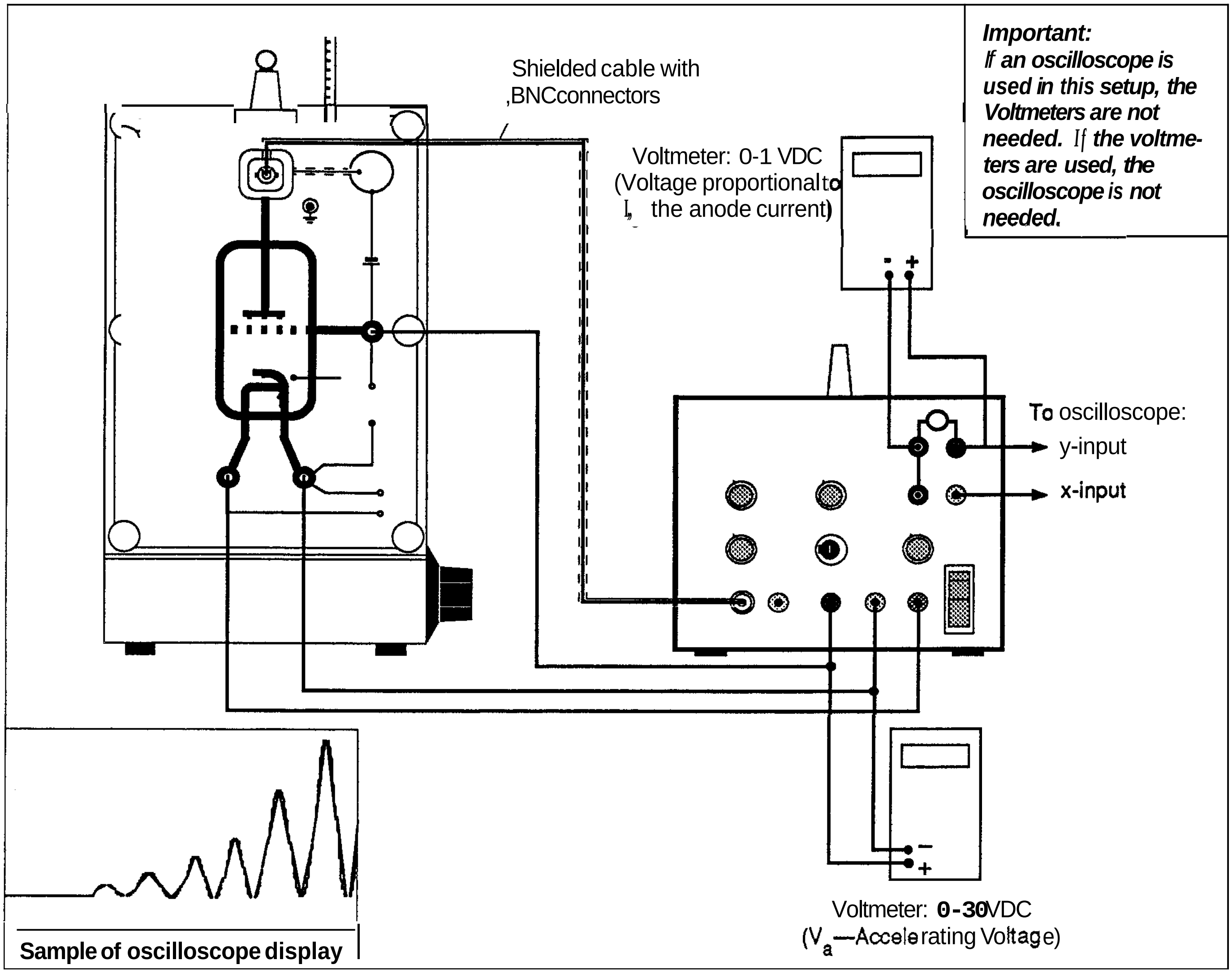

Figure 4 Franck-Hertz Experiment Using the Control Unit

B. Using the Control Unit and Voltmeters

1. Remove the six thumbscrews that secure the front panel of the Franck-Hertz Oven. Replace the front panel with the Franck-Hertz **Tube** as shown in Figure **4.**
2. Insert a centigrade thermometer (0-200 degrees) into the hole in the top of the oven. Insert it so the tip of the thermometer is near the center of the **tube.**
3. Check the label and plug the oven into an appropriate AC power outlet, then **turn** the thermostat dial to 180 °C. Let the oven heat up for 10-15 minutes. Keep **an** eye on the thermometer. Do **not let the oven temperature exceed 205 °C.**
4. Connect the **tube,** control **unit,** and voltmeters as shown in Figure **4** (the oscilloscope connections that are shown in the figure **are** not necessary when using voltmeters).
5. Switch on the control unit, but only AFTER the **tube** has been allowed to warmp up for 10-15 minutes. Initially, set the controls **as** follows:

Heater:	midrange (about 5.5 **V)**
Amplifier:	**Gain** – maximum gain (fully clockwise) Zero – midrange
Va:	Switch–Man. (→) Adjust – zero (fully counterclockwise)

6. Allow at least 90 seconds for the cathode to heat up.
7. Adjust the Amplifier Zero so that the amplifier output is zero volts (if it won't go to zero, just adjust it **as** close to zero **as** possible).
8. Increase the accelerating voltage in increments of about 0.5 volts, by turning the **Va** Adjust knob clockwise. At each value of **Va,** record **Va** and the corresponding value for the amplifier output.

   Note: The amplifier output is not equal to **Ic.** It is **a** voltage that is proportional to **Ic.**
9. **See** ***Analyzing*** the Experiment at the end of the manual for details about manipulating and analyzing your **data.**

C. Without the Control Unit

1. Remove the six thumbscrews that secure the front panel of the Franck-Hertz Oven. Replace the front panel with the Franck-Hertz Tube as shown in Figure **4.**
2. Insert a centigrade thermometer (0-200 degrees) into the hole in the top of the oven. Insert it so the tip of the thermometer **is** near the center **of** the tube.
3. Check the label and plug the oven into an appropriate AC power outlet, then turn the thermostat dial to 180°C. Let the oven heat up for 10-15 minutes. Keep an eye on the thermometer. **Do not let the oven temperature exceed 205 °C.**
4. Connect the tube, power supplies, and ammeter* as shown in Figure 5.

   Important: *All* power supplies must be floating with respect to ground.

6. Set all the power supplies to zero volts. Then turn them on and set the heater voltage to 5.5 **volts,** the accelerating voltage to zero volts, and the opposing voltage to 1.5 volts. **DO** NOT **LET** THE HEATER VOLTAGE **EXCEED** 7 VOLTS, or the tube may be damaged.

17. Increase the accelerating voltage, V_a, in increments of about 0.5 volts. At each value of **Va:** record Va and the corresponding value for the anode current, I_c. Repeat your measurements, but this time **try** to locate the exact values of Va for which current minima occur. Record these values of Va and the corresponding values of I_c.
18. See *Analyzing the Experiment* at the end of the manual for details about manipulating and analyzing your **data.**

***Note:** If **you** don't have a sufficiently sensitive ammeter to accurately measure the anode current, you *can* use **a** voltmeter instead. The voltmeter must have 0.1 mV resolution and a 10 MΩ input impedance. Connect it just as the ammeter is connected in Figure 5. The voltage reading of the voltmeter will then be **equal** to the anode current, in units of 10^{-11} amperes.

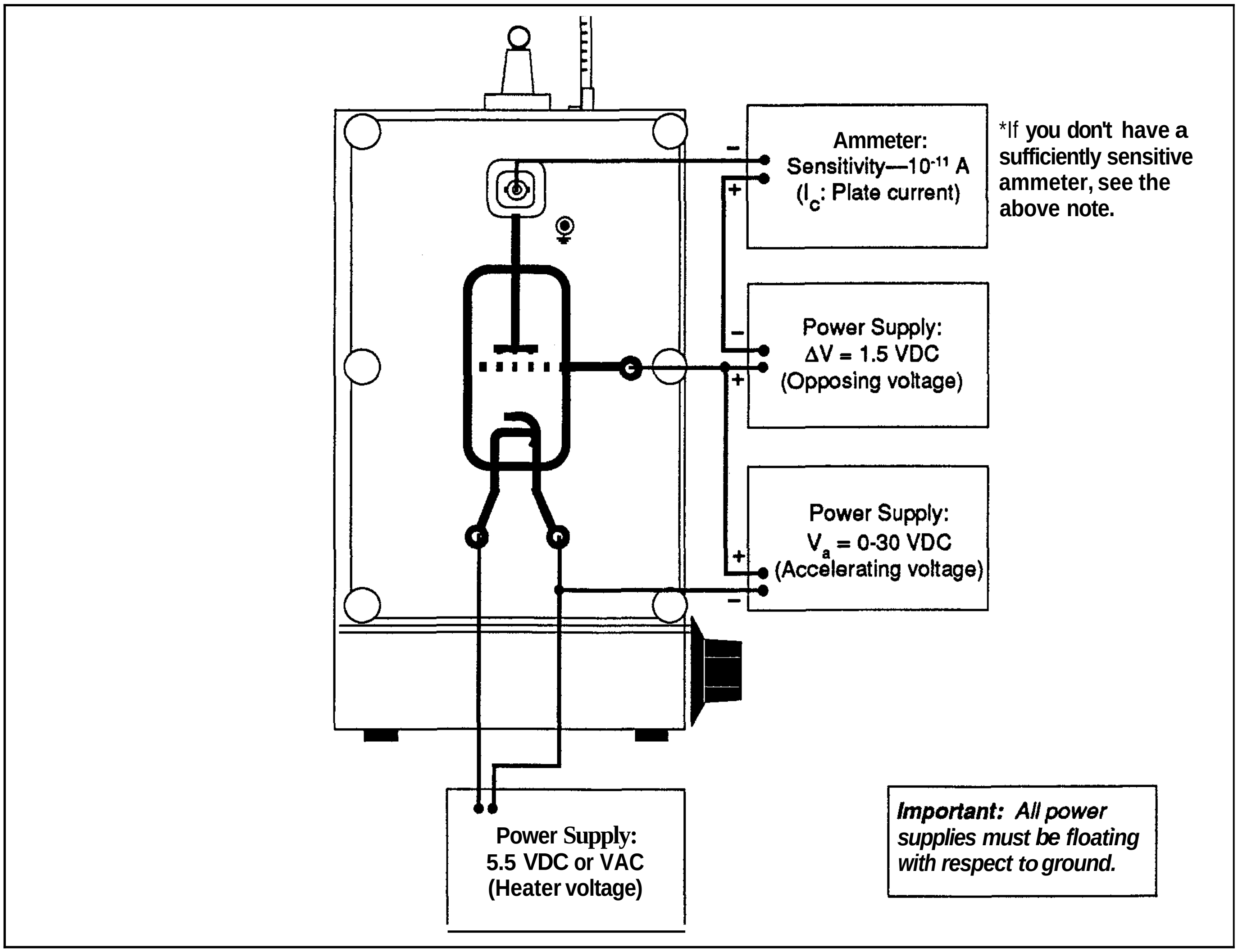

Figure 5 Franck-Hertz Experiment Without the Control Unit