Classical justification of the Franck-Hertz experiment

Hamid V. Ansari
Department of Physics, Isfahan University, Isfahan, IRAN
Personal address: No. 16, Salman-Farsi Lane, Zeinabieh Street, Isfahan, Postal Code 81986, IRAN

September 19, 2007

Abstract

By increasing the voltage in the Franck-Hertz experiment we reach a breakdown voltage in which the current existent between the grid and anode is canceled. This breakdown voltage will be repeated at equal intervals by increasing the voltage.

1 Introduction

As an evidence that even absorption of kinetic energy by an atom is quantized the Franck-Hertz experiment is cited. It is said that this experiment shows clearly that the kinetic energy of an electron colliding with an atom will be absorbed by the atom only when the magnitude of it is at least equal to the distance between the energy levels of the electron in the atom, and the amount of absorption will be equal to this energy distance. In other words, only when the kinetic energy has some definite magnitudes it'll be absorbed by the atom completely. What this paper is going to show is that what occurs in this experiment is not really a quantum process but a simple electric (or electronic) one: By increasing the current between the cathode and grid in the lamp of this experiment the heat of the gas between the grid and anode will be increased to such extent that, due to the inverse voltage existent between the grid and anode, an inverse current will flow between these two in the lamp. The voltage creating this sufficiently high current is in fact a kind of breakdown voltage. The inverse current, related to this inverse (breakdown) voltage, will cancel the main current and will cause the gas to become cold again. Again, by increasing the voltage to the extent of the breakdown voltage, the main current, and consequently the heat created by it, will increase and, again, the inverse voltage will create an inverse current which will make the gas cold by canceling the main current. And this process will be repeated in this manner.

2 Analysis of the Franck-Hertz experiment

In the Franck-Hertz experiment, as shown in Fig. 1, the grid G is located near the Anode A while the high potential difference V between G and the cathode C is variable but the low potential difference between A and G is constant. The gas under experiment is in the lamp containing C, G and A. When C is warmed up (electrically), the experiment starts. Variation of I, the current of A, with V is something like what is shown in Fig. 2 in which the horizontal distance between each two adjacent tops is the same. The curve falls abruptly after each top.

Electric current is a continuous process, in which an electron train is moving (ie as if the electrons, taking part in the current, are in touch with each other in a train of themselves each exerting force on the next), not a colliding one.

Now, we consider two suppositions. According to the first one let's remove the grid G temporarily. In this state, when the cathode C has not yet been warmed no current flows in the circuit. But when as a stimulation C is warmed, a current of electrons will flow in the circuit in the direction from C to A. Why? Because, magnitude of the constant (inverse) voltage V' is smaller than V and then the situation is as if the source of potential in the circuit is a single battery which its negative pole is connected to C and its positive pole is connected to A. Thus, certainly we shall have an electron current from C to A when the cathode is warmed. This current will also be flowing in the wire connected to C and we call it as I_C here. Now as the second supposition let's use a solid metallic plate, which completely separates the space containing A from the space containing C, instead of the perforated grid G. In this state by warming the cathode C an electron current will flow in the left circuit. Practically no portion of this current will enter the right circuit because this circuit is separated from the left circuit by the above-mentioned solid plate. Also for a constant voltage V in both of the above suppositions, the current in the wire connected to C, ie I_C, is more in the second supposition than in the first one since in the second supposition not only the voltage V has not decreased by the inverse voltage V' but also the distance between the cathode and anode in the second supposition (ie the distance between C and G) is less than this distance in the first supposition (ie the distance between C and A) and then the resistance in the second supposition is less than one in the first supposition.

Now consider the real state of the experiment, ie instead of lack of G or solidness of it let it be a perforated grid G as shown in Fig. 1. Clearly, in this state, the electron current entering the right circuit will be neither as large as in the first supposition nor as small as in the second supposition. Namely, in this state, only a part of the electron current of the cathode will flow via the grid toward the point a and the rest of it still flows toward A (through the holes in the grid). The state we described here is one of possible states for discharging of electron current from the cathode in the lamp of Fig. 1 and is the one having the most possibility for occurrence. But as we know there are several possible states in which electric discharge can occur. Most of these states are other than the state(s) having the most possibility for occurrence, but if, under certain conditions, one of them is chosen for discharge, the act of discharge will continue in this chosen state without shifting of this state to the (mentioned) most possible one during the discharge even if the mentioned certain conditions are removed. So, although that a considerable part of the electron current of C in Fig. 1 reaches A through the grid G and the rest reaches a through the wire connected to G is the most possible state for discharging of the electron current of C, if, under certain conditions, the whole electron current of C is made to descend only on the grid G and to reach a through the wire connected to it (without any portion of it reaching A through the holes of G), such current of discharge will continue in such state without any shifting to the first state. (In other words the electron current will have been canalized through a new path and will continue through the same path.)

Now let's consider the right circuit consisting of G, A and V' before warming the cathode up, ie before causing any current to flow in the circuit. In this state, what can cause an electron current to flow in this (sub)circuit from A to G? Just the same factor that causes an electron current in the main circuit from C to A, ie (the stimulation caused by) heat. But we have not given any external (electric) heat to the space between A and G as done in the main circuit when warming C up. That's right, but such a heat can be provided by the electric current flowed in the space between G and A. Such a heat should be sufficient if it is to cause freedom of the electrons of the atoms of the gas from these atoms and an electron current in the right (sub)circuit from A to G, otherwise there won't be such a current even though the space between G and A is warmed (insufficiently).

Thus, if the total current in the circuit, from C to G, is sufficiently intense (which this occurs when V is sufficiently high), sufficient heat, due to passing of the electron current from G to A, will be produced to cause freedom of the electrons of the atoms ie stimulation of the right circuit to cause an electron current to flow from A to G. But this recent electron current from A to G will cancel the main electron current in the main circuit from G to A, and the result is that there will be no current practically. When there is no current in the space between G and A, there won't be any heat produced due to it, and then there won't be any stimulation to cause any electron current (in the right circuit) to flow from A to G, and then the story can be repeated, ie by increasing the voltage V, the electron current is again increased until when the heat produced due to it stimulates the voltage V' to cause an equal but oppositely directed electron current to flow causing a renewed fall in the curve of I against V just at a point as far from the previous point of fall as the next point of fall.

Of course, in the real curves, each (new) peak is (a little) higher than the previous one. What presented above excluded this aspect of the experiment as an unimportant thing for the general justification of the main result of the experiment (ie existence of repeated falls in the curve at equal distances). What can be said at present for the probable cause of this effect is that by increasing the voltage there may be some electrons flowing from Cathode to Anode due to field emission. These electrons themselves make a ground current having no relation to the current produced by displacing of the valence electrons of the atoms of the gas in the tube. Only this recent current (ie one due to displacing of the valence electrons of the gas atoms) can give heat to the atoms (causing separation of their electrons if this heat is sufficiently big), because the electrons of only this current are in direct contact with the atoms. This suggestion can probably be tested by study on any alteration in the results of the experiment when we try to eliminate as many causes for the field emission as possible.

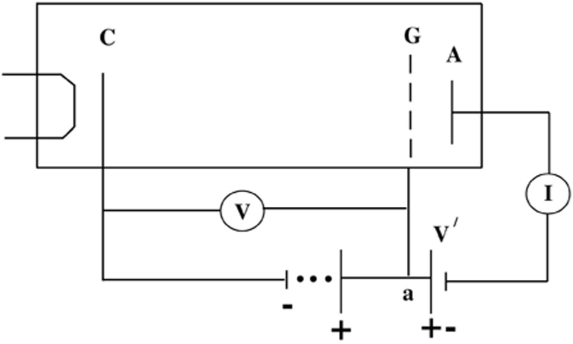

Fig. 1

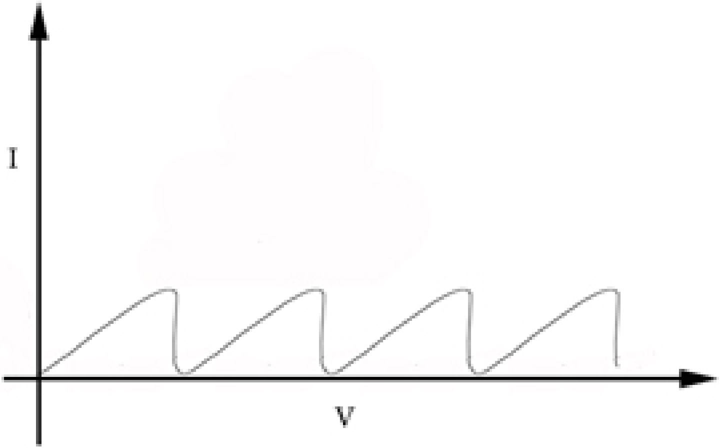

Fig. 2