

Measurement of Relativistic Effects with a CRT Oscilloscope

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In 2025 Prof. Jorma Jormakka and Wolfgang Sturm published the paper: "Can relativistic mass or weakening of force be measured with a vacuum tube?" This paper develops a mass spectroscopic measurement method using an oscilloscope vacuum tube that answers this question.

1. Introduction

In the paper "Can relativistic mass or weakening of force be measured with a vacuum tube?" [1] the question was discussed whether and how relativistic electron effects can be detected with a normal oscilloscope vacuum tube.

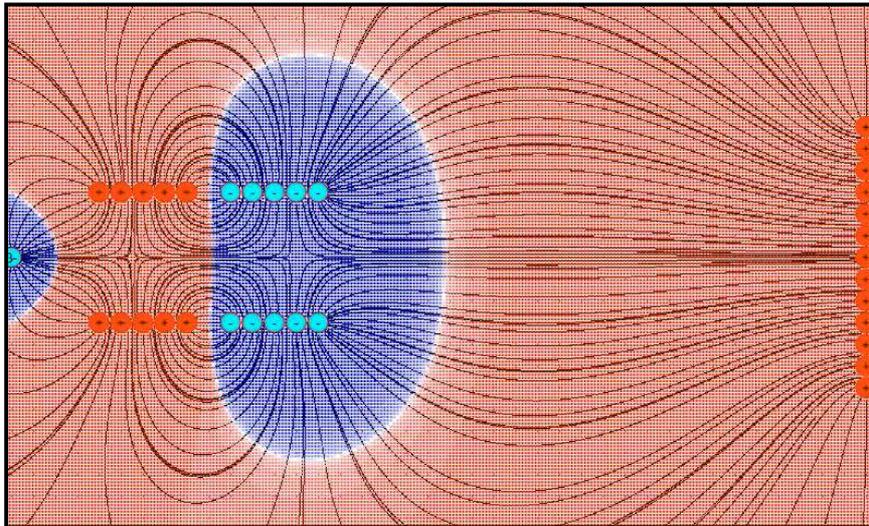
It was recognized that the relativistic effects are too small to be measured directly.

In this paper, a differential measurement method is proposed and tested using a data sheet and real measurements.

The measured values are very stable, so that the method can be used for electron mass spectroscopy at very low velocities.

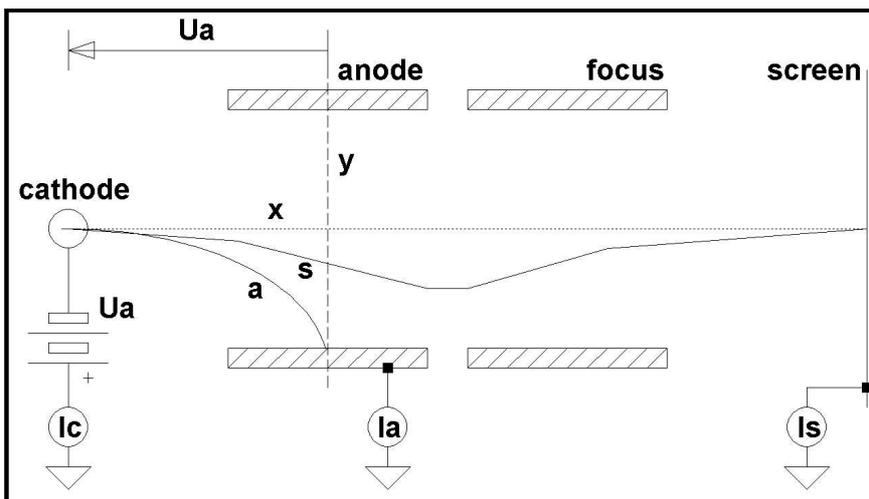
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2. Differential two-beam measuring method



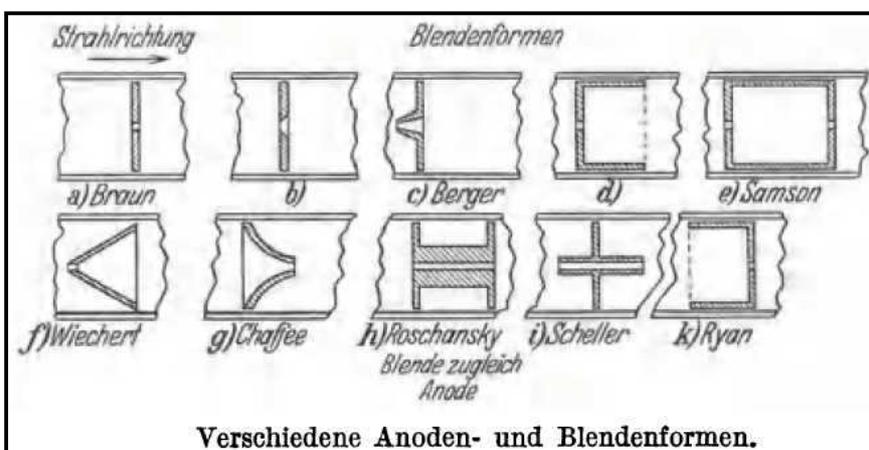
Even the simulation of an idealized CRT (only cathode, phosphor screen, anode and focus cylinder) shows complex field lines.

Fig. 1: Simulation ^[2]



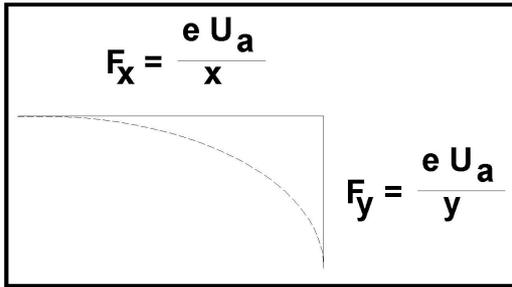
Based on this simulation, the paths of three electrons **a**, **s** and **x** are sketched. **s** and **x** fly through the anode and form I_s . **a** hits the anode and forms I_a .

Fig. 2: Beam paths



In reality, the electrode shapes and beam paths are more complicated.

Fig. 3: Electron optics ^[3]

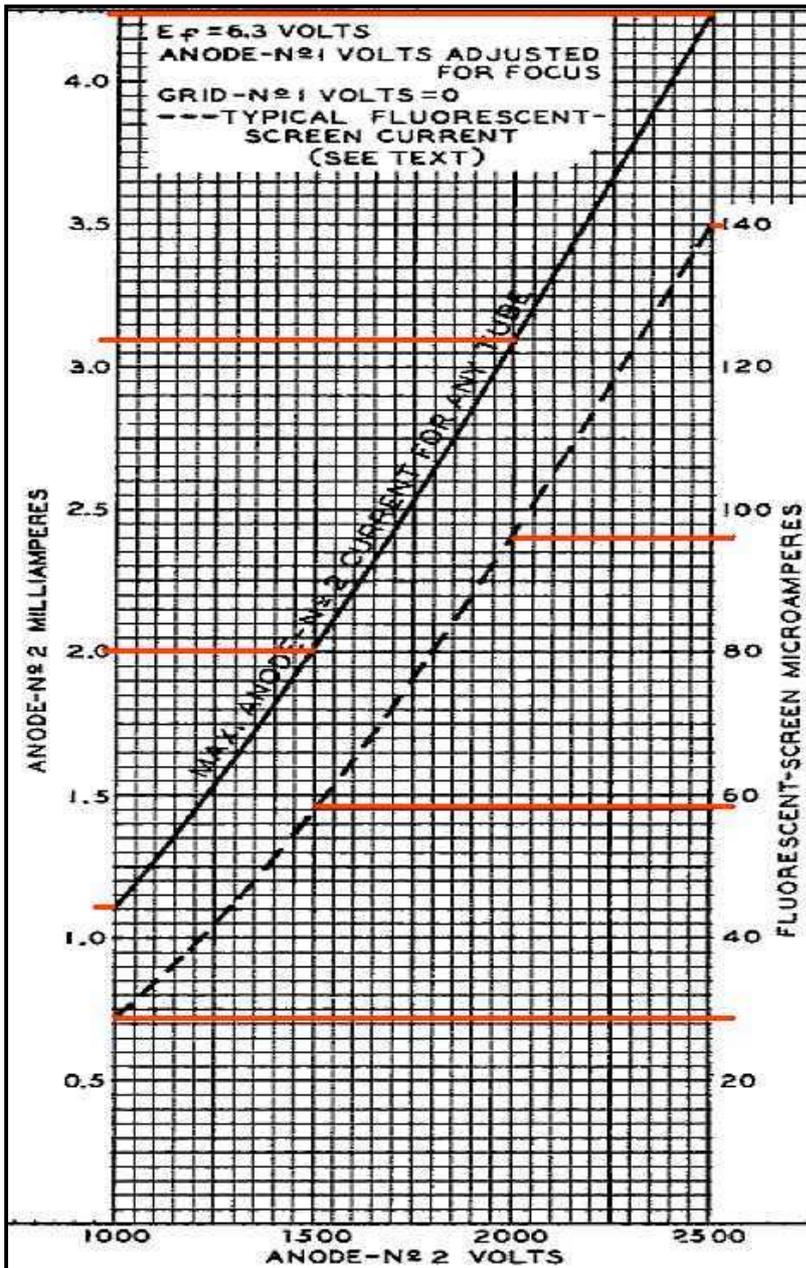


The force F_x accelerates all cathode electrons horizontally. A small proportion then flies unaccelerated to the screen and causes I_s .

Most of the electrons are **additionally** accelerated with the perpendicular F_y and cause I_a .

Fig. 4: Anode forces

Since the electron optics is unknown, the total force must be estimated. In formula (2), U_a is therefore multiplied by 2.



The differential two-beam method calculates the ratio of cathode and anode current

$$\Gamma = \frac{I_c}{I_a} = \frac{I_a + I_s}{I_a} \quad (1)$$

as a function of U_a

The values for I_a and I_s at

$U_a = 1 \text{ to } 2.5 \text{ kV}$ and

$$\gamma = \frac{1}{\sqrt{1 - \frac{2 e 2 U_a}{m_e c^2}}} \quad (2)$$

complete the table.

Fig. 5: Data sheet 5UP1 [4]

Table 1

U_a [kV]	γ	I_a [mA]	I_s [μ A]	Γ
1.0	1.004	1.11	29	1.026
1.5	1.006	2.02	58	1.029
2.0	1.008	3.10	96	1.031
2.5	1.010	4.24	140	1.033

Results

Despite the rough estimate of the anode forces, both the Lorentz factor γ and the Γ calculated from the data sheet increase by approx. 0.6% if U_a is increased from 1kV to 2.5kV.

The behavior of Γ can be due to a disproportionately high increase of I_s or a disproportionately low increase of I_a . Since I_a and I_s are accelerated in the same way in the x-direction, only the additional vertical acceleration of I_a can explain the behavior of Γ . I_a therefore shows a weaker increase compared to I_s . An increasing mass or a decreasing force in the y-direction could be the cause.

Relativistic effects can therefore be demonstrated in the data sheet.

Notes

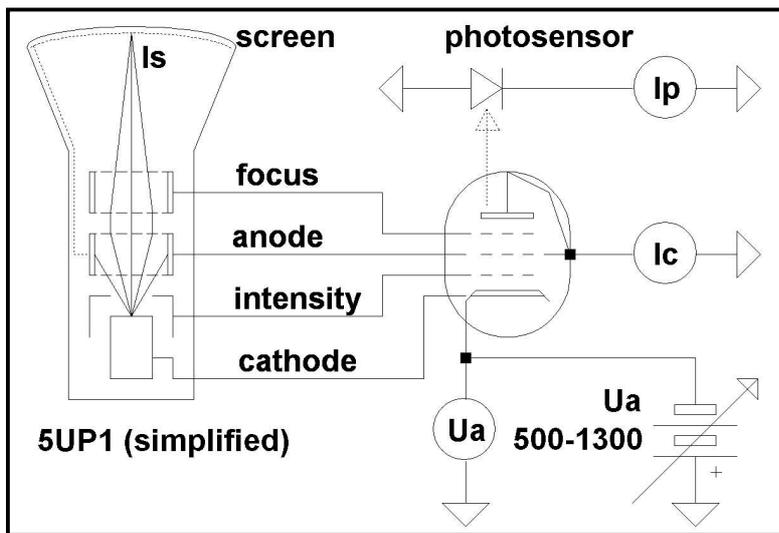
This measuring method cannot say anything about relativistic effects in the x-direction, because they compensate each other.

The data sheet at $U_a=2\text{kV}$ and $U_{g1}=0\text{V}$ plot currents of $I_a=3.1\text{mA}$ and $I_s=96\mu\text{A}$. I_a is a maximum value. On the following page of the data sheet, a current of $I_a=1.94\text{mA}$ is plotted for the same U_a , U_{g1} and I_s , which is probably the typical current.

3. Dual-beam method in practice

In contrast to the data sheet, a direct I_s measurement is not possible because the fluorescent screen and anode are connected inside the tube. It applies $I_a = I_c - I_p$

The I_s electrons hitting the screen generate photons. These can be converted back into I_p electrons using a photodiode. However, losses occur in this conversion chain. $I_s = 2 I_p$ is assumed.



The tube is located in an oscilloscope. Its components limit the maximum voltage to $U_a=1.3\text{kV}$. The data sheet specifies a minimum voltage of $U_a=1\text{kV}$. However, this tube still works down to $U_a=500\text{V}$. $U_a=0.7, 1.0$ and 1.3 kV are used.

Fig. 6 : Setup

The use of the measured values in formula (1) and (2) confirms relativistic effects.

Table 2

U_a [kV]	γ	I_p [μA]	I_c [μA]	I_a [μA]	Γ
0.7	1.003	0.15	140	$I_c - 2 I_p$	1.002
1.0	1.004	0.35	200	$I_c - 2 I_p$	1.0035
1.3	1.005	0.7	275	$I_c - 2 I_p$	1.005

Note

The 10-fold smaller I_a compared to the data sheet is due to the reduced brightness in the experiment in order to avoid non-linearities of the phosphor layer or the photosensor.

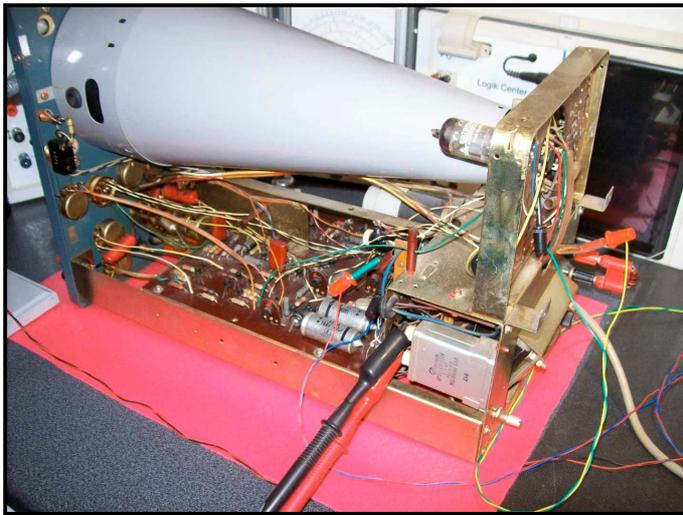
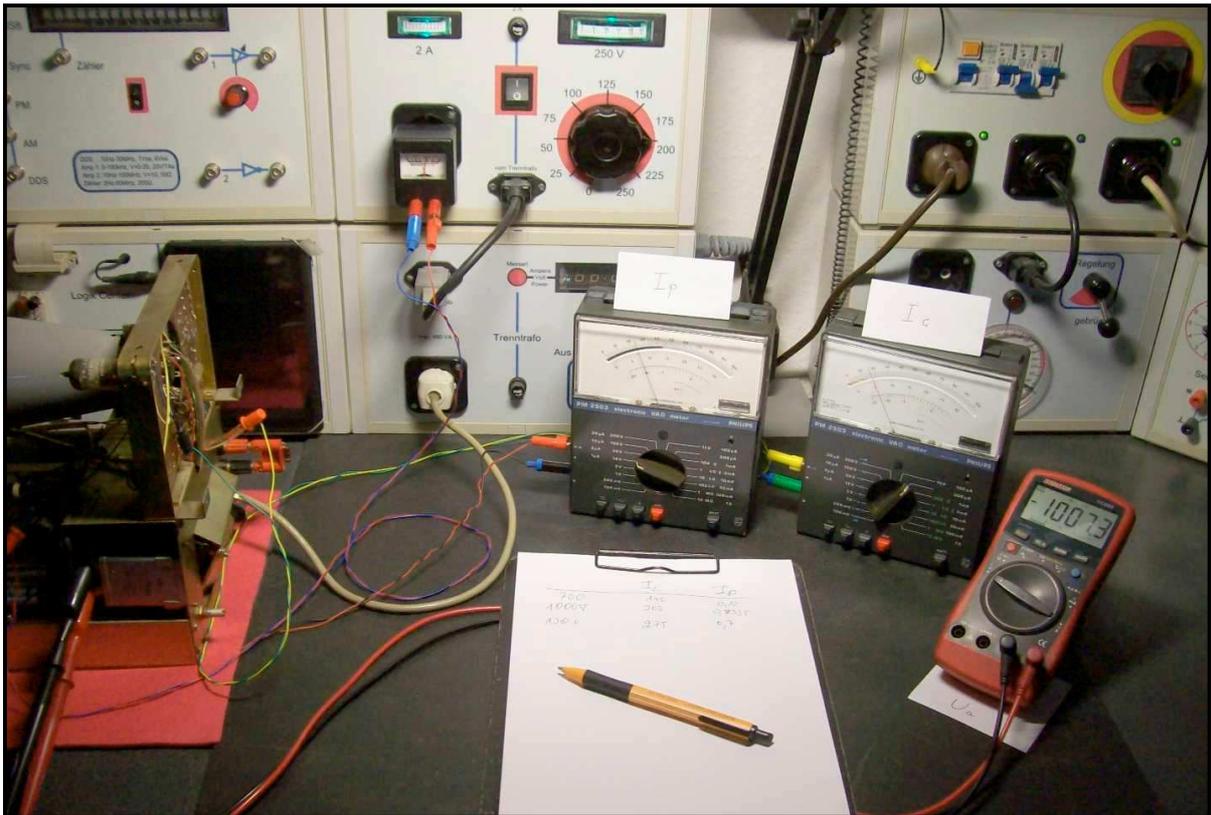


Fig. 7: Setup impressions

¹ Jormakka J., Sturm W.: Can relativistic mass or weakening of force be measured with a vacuum tube?, 2025. Available at the ResearchGate. Also at vixra

² Simulator from Prof. Raimund Girwidz, LMU München at <https://www.leifiphysik.de>

³ Alberti E.: Braunsche Kathodenstrahlröhren und ihre Anwendung, 1932, Springer, Berlin

⁴ 5UP1, Oscilloscope tube data sheet. RCA