THE GAS DISCHARGE PHYSICS IN THE 20th CENTURY (PART I)

– by Julia Cipo, Holger Kersten –

Peter Joseph William Debye


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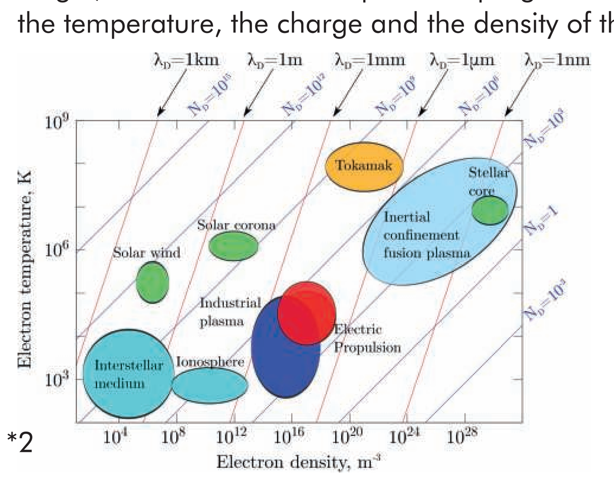
* March 24th, 1884 in Maastricht, Netherlands
† November 2nd, 1966 in Ithaca, New York, U.S.A

Peter Joseph William Debye was a dutch-american chemist, physicist, a student of Arnold Sommerfeld and winner of the Nobel Prize in Chemistry in 1936 "for his contributions to the study of molecular structure". His name comes up in the plasma physics in terms like the Debye length, the Debye shielding and the Debye sphere. When a test charge is brought into a plasma, their electrical field is shielded by the opposite charges of the plasma. This phenomenon was called "Debye shielding". The characteristic length, which describes the potential progression during the shielding is called the "Debye length" and depends on the temperature, the charge and the density of the particles.



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Bildunterschrift

For electrons it has the form: $\lambda_D = \left(\varepsilon_0 k_B T / n e^2\right)^{1/2}$
Based on the electron density in space and technical plasmas, the Debye-length varies and can reach huge values in solar winds and intergalactic medium. The Debye-sphere is a spherical volume having the same radius as the Debye-length. The number of the charged particles inside of a Debye-sphere is important for the classification of a particularly ionized gas as a plasma. When the number of the particles is high, their thermic kinetic energy is dominant towards the electrostatic interaction energy. By high values of it, it can be almost be considered as an ideal Debye plasma.

Rudolf Seeliger

* November 12th, 1886 in München, Germany
† January 20th, 1965 in Greifswald, Germany


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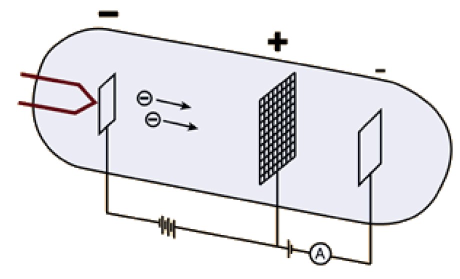
Rudolf Seeliger was a german physicist and a colleague of the Nobel Prize winner Johannes Stark. Seeliger established the "Institute for gas discharge physics" in Greifswald, what became the predecessor of the "Leibniz-Institute for plasma science and technology", also known as the "Institute for Low Temperature Pressure Plasmas". His first work in the gas discharge physics was his dissertation thesis in 1909 "The theory of conduction of electricity in densed gases", absolved under the known theoretical physicist Arnold Sommerfeld. In 1912 he made some observations "About the lightning of gases under the influence of cathode rays". He noticed that the needed energy for the excitation of spectral lines through a current flow is portioned. So he proved the existence of discrete energy levels, later being introduced more exactly in the "Franck-Hertz experiment".


Accelerating Apparatus
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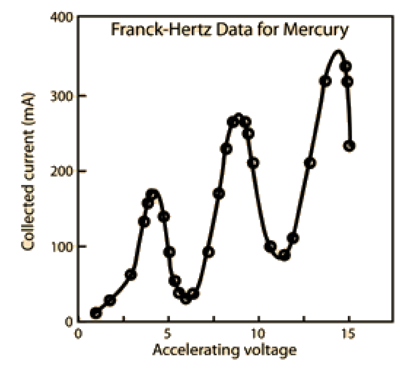
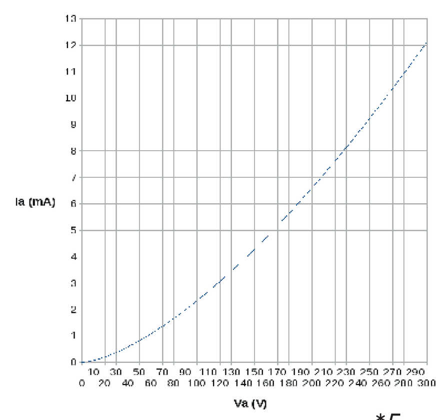


The Franck-Hertz experiment as successor of Seeliger's experiment

Clement Dexter Child

* 1868 in Madison, Ohio, USA
† July 15th, 1933 in Rochester, New York, USA

Clement Dexter Child was an american physicist and colleague of J.J.Thomson. Child conducted a lot of experiments studying the discharge effects in glass tubes as he published 1913 in his book "Electric Arcs: Experiments upon arcs between different electrodes in various environments and their explanation". In his electrodes he varied the metal of the electrodes, the filling gas and the pressure of the gas. His greatest achievement was still the work "Discharge from hot CaO" published in May 1911. There he solved the Poisson Equation and found a correlation between the voltage and the current among two electrodes in vacuum. The cathode, maintained at the potential zero, is heated. Then the excited atoms within the cathode emit electrons, which are headed to the anode. After a while a steady state with a constant current is reached. Child precludes the electron emission process as the reason for a current limit. Instead he refers the limitation to a space charge, a continuum of electrons near to the cathode. He also calculated this current density in terms of the anode voltage: $J = \frac{I_a}{S} = \frac{4\varepsilon_0}{9}\sqrt{2e/m_e}\,\frac{V_a^{3/2}}{d^2}$ where J is the current density, meaning the current divided through the anode surface, d is the distance between the electrodes and Va the anode voltage. This relation is called "Child's Law" and sometimes also the "Child-Langmuir-Law" because Child's calculations based on the values for the current of positive ions, while Langmuir studied the electrons.



Child-Langmuirl-Law *5

Sir John Sealy Edward Townsend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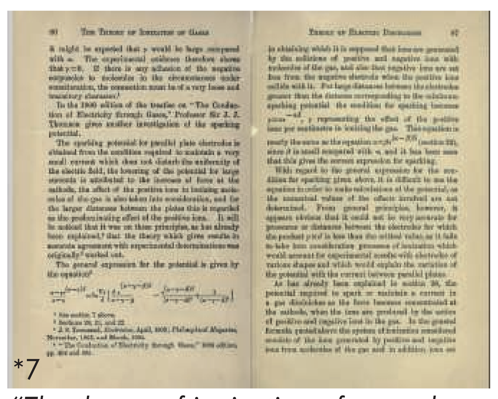
* June, 7th 1868 in Galway, Ireland
† February, 16th 1957 in Oxford, England

John Sealy Edward Townsend was an irish mathematician, physicist, fellow of the Royal Society and a student of J.J.Thomson. Between the years 1897 and 1901 Townsend worked on the avalanche ionisation effect of gases and published his work in 1910 under the title " The theory of ionization of gases by collision". In 1915 he extended his results in the book "Electricity in gases". There he shows, that the motion of an electron in an electrical field can generate new electrons through collision. This leads to a multiplication of charges by forming the "avalanche effect", which takes place in low pressure discharges, known as the "Townsend discharges". For his work, he studied different ways of ionising a gas such by cosmic rays or by the electromagnetic X-rays (Röntgen rays). It resulted that the different methods of generating the ions did not have an influence on the ionizing power of positive or negative ions. He also noticed that the multiplied ionisation process happened between the two electrodes. This process is linked with the emission of electrons. Only if the electric field is strong enough, the free electrons can gain the needed velocity to cause the emission of other electrons by colliding with the gas molecules. He refined his work by using different shaped electrodes or even by separating his results in ionisation processes caused by positive ions and those caused by negative ones. For each case he calculated the conditions for the minimum sparking potential establishing the "Townsend ionisation coefficients" αn and αp which express the number of anions or cations per unit length.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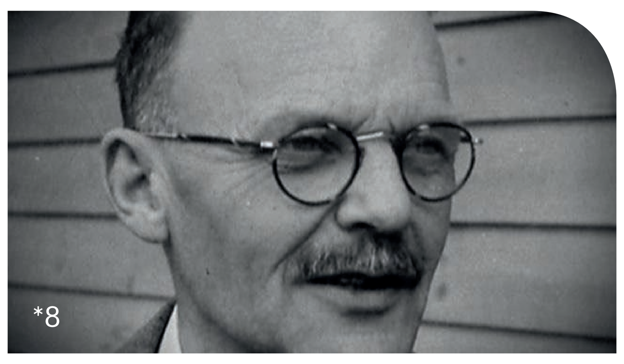
"The theory of ionization of gases by collision" in 1910

Johannes "Hans" Wilhelm Geiger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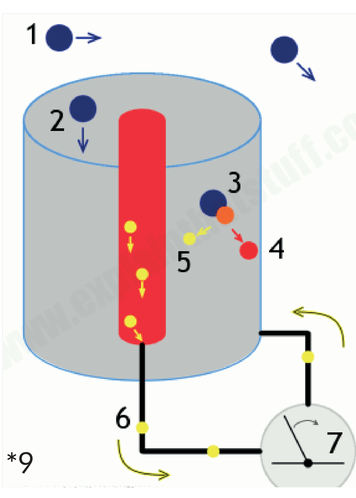
* September 30th, 1882 in Neustadt an der Haardt, Germany
† September 24th, 1945 in Potsdam, Germany

Johannes "Hans" Wilhelm Geiger was a german physicist, who worked together with Ernest Rutherford and James Chadwick. His most established discovery is the "Geiger counter" developed in 1928 by him and his assistant Walther Müller as they worked at the "Christian-Albrechts-University" in Kiel, Germany. For the construction of this device they used the "Townsend avalanche discharges". The Geiger counter is a device for measuring the ionising radiation like alpha, beta and gamma radiation. The device consists of a metal cylinder filled with a low pressure gas and a tungsten wire in the center, connected to a high positive voltage outside. The radiation that has to be detected, enters the cylinder through its opening and collides with the gas molecules within. This causes the ionisation of the gas by splitting the gas molecules in electrons and in positive ions. The ions abandon the cylinder, while the electrons are attracted to the wire. While moving to the wire, they collide with other gas molecules generating new electrons and causing this way a continuous avalanche discharge. The current of electrons travels down the wire deflecting the needle on the circuit outside. If a loudspeaker is connected, a loud click can be heard every time an electron is detected. The quantity of the radiation inside of the Geiger counter is measured by the quantity of the clicks heard.



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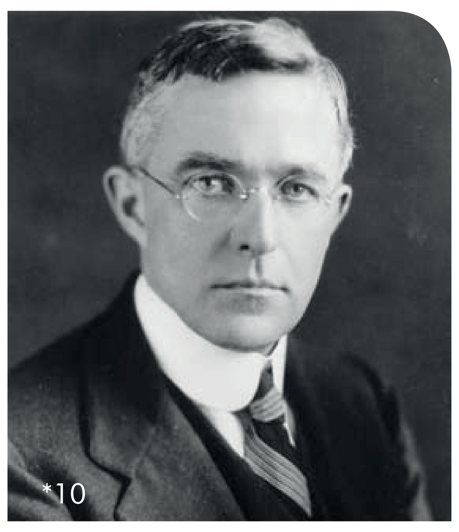
The principle of the Geiger-Müller counter

Irving Langmuir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* January 31st, 1881 in Brooklyn
† August 16th, 1957 in Woods Hole, Massachusetts, USA

Irving Langmuir was an american physicist, chemist and winner of the Nobel Prize for Chemistry in the year 1932. He was a pioneer of the gas discharge physics, since he was the name finder for the fourth aggregation state, calling it "plasma". Before then his colleagues came up with suggestions like "equilibrium discharge" or "uniform discharge". Langmuir compared in 1927 the 'equilibrium' part of the discharge, which acted as a layer carrying charged and neutral particles with the blood plasma, which carried the blood corpuscles around. In 1929 Langmuir first used the term "Quasi-Neutrality" to describe the same density of positive and negative charges in a plasma granting its total neutrality. Wanting to learn more about the plasma, Langmuir developed in 1924 the Langmuir probe with its help he could obtain a current-voltage-characteristic. From the curve different plasma parameters can be determined, such as the density and the temperature of the electrons, the floating potential and the plasma potential. During more detailed investigations Langmuir noticed collective periodical oscillations of the charge densities, caused by temporary displacements of electrons towards the positive ions. Wanting to revoke this displacement, the charged particles begin to move up and down their balance position. The propagation of this oscillations in plasma causes the "Langmuir waves". As a continuation of his dissertation thesis, which he wrote under supervision of the german Nobel Prize winner Walther Nernst, Langmuir invented a gas-filled light bulb. While he before invented a high-vacuum pump for the lamps, Langmuir now experimented by placing nitrogen in a tungsten lamp, noticing that this slowed the evaporation of the tungsten filaments. He then used thin filaments instead of thick filaments, because the thin ones radiated heat faster. So he improved the tungsten light bulbs by increasing their lucency. Langmuir's work opened new ways in understanding astrophysical processes, in creating technical plasmas as using them for controlled thermonuclear fusion.

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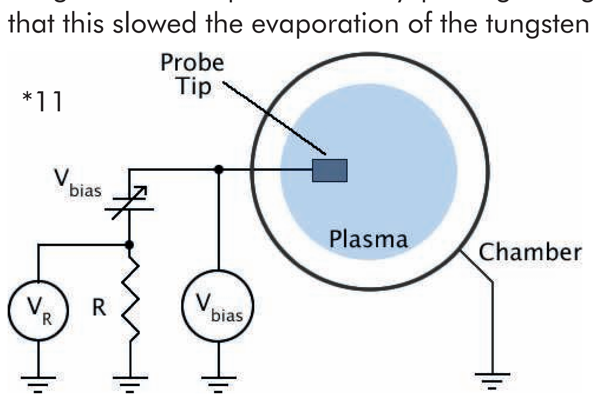
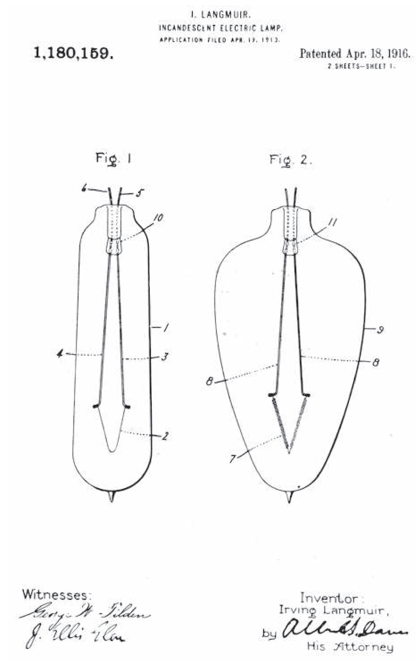


Application of a Langmuir probe



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The new gas filled incandescent lamp, designed by Langmuir in !916

Lewi Tonks

* 1897 † July 1971


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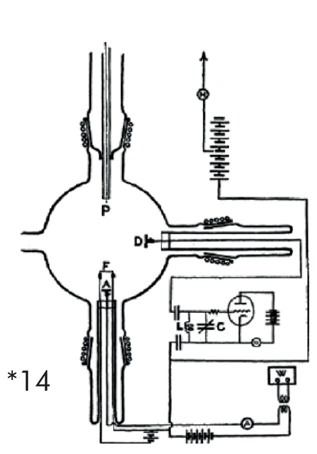
Lewi Tonks was an american quantum physicist and a colleague of Irving Langmuir. During the period 1926-41 he published 29 papers, mostly about electrical discharges in gases. Later he became the head of a theoretical physics group, working on designs for nuclear reactors. Tonks also assisted as a consultant for the Stellarator Project at the Princeton University. In 1929 he published together with Langmuir two papers about the plasma oscillations and the general theory of plasmas. There they investigated the plasma sheath potential for planar, cylindrical and spherical plasmas.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Device used by Tonks and Langmuir for studying the plasma oscillations

1- Sächsiche Akadamie der Wissenschaften zu Leipzig (Saxon Academy of Sciences in Leipzig), 2- Plasma Dynamics Modeling Laboratory, Texas A&M University, 3- Leibniz Institut für Plasmaforschung und Technologie e.V. Greifswald (Leibniz Institute for Plasma Science and Technology in Greifswald), 4- hyperphysics.phy-astr.gsu.edu, 5- Wikimedia, work by Miroslav Cika, 6- Biographical Memoirs of Fellows of the Royal Society Vol. 3 (Nov., 1957) by A. von Engel, 7- Archive.org, 8- SWR (SüdWestRundfunk) Fernsehen Online - (South West Broadcast)TV Online, 9- www.explainthatstuff.com, 10- Encyclopedia Britannica, 11- David Pace- mostly fusion, 12- University of Houston, 13- Grems-Doolittle Library and Archives, 14- Research gate