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Crookes' Radiometer and Geissler's Light-Mill - Cooperation or Competition?

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Scientific instruments provide crucial historical information about the research process, and are valuable sources for historians of science and technology. The design of the radiometers, which William Crookes constructed for his own use in experimentation in the mid-1870's, show technical features originally developed by the German instrument maker Heinrich Geissler in the construction of his "lightmills". Further analysis reveals a myriad of connections between scientists and instrument makers. Members of this group such as Geissler or his former apprentice and co-worker Goetze participated in the discussion of radiometer effects and their place within the kinetic theory of gasses, going beyond a passive role as invisible technicians to actively intervene in the research process.

These technological improvements contributed both to basic and applied scientific knowledge, and the proliferation of their instruments created a network of cooperation and competition which lay the foundations for a new field of research.

In the second half of the 19th century , the development of classical physics took off quickly . The discovery of X-rays and the description of the electron were both the high points of this phase and the starting point for new developments ; they underlined that physicists would have to rethink their concepts . Of the artistic glass instruments that accompanied or made possible these eventful decades , two have survived the passage of time and found their way into living rooms : the tried and tested liquid thermometer and the Crookes radiometer invented in 1875. The instrument makers who were reliable and often congenial partners to scientists are exemplified by the Bonn glass technician Heinrich Geisler (1814-1879) and his students. The history of the creation and interpretation of the radiometer, which with its errors, misunderstandings and contradictions reflects the difficult path of establishing the kinetic gas theory and the understanding of electrical phenomena, is also shaped by this partnership and interaction - far more than previously perceived. The attempt made here to include this aspect in the description of the processes at that time is about more than a more comprehensive presentation of the facts. It turns out that the more complex picture that is now emerging also opens up many new perspectives on the long-established international research network of the late 19th century .

Prehistory

When the chemist William Crookes (1832-1919) presented his research on the atomic weight of thallium [Crookes 1873] to the Royal Society in London on June 20, 1872, he looked back with justifiable pride. Ten years earlier, in June 1862 and February 1863, he had reported in the same place on his discovery of the metal thallium, its occurrence, extraction, properties and relationship to other elements . After the discovery of cesium and rubidium by Robert Wilhelm Bunsen (1811-1899), [redacted]

[redacted]

[redacted]

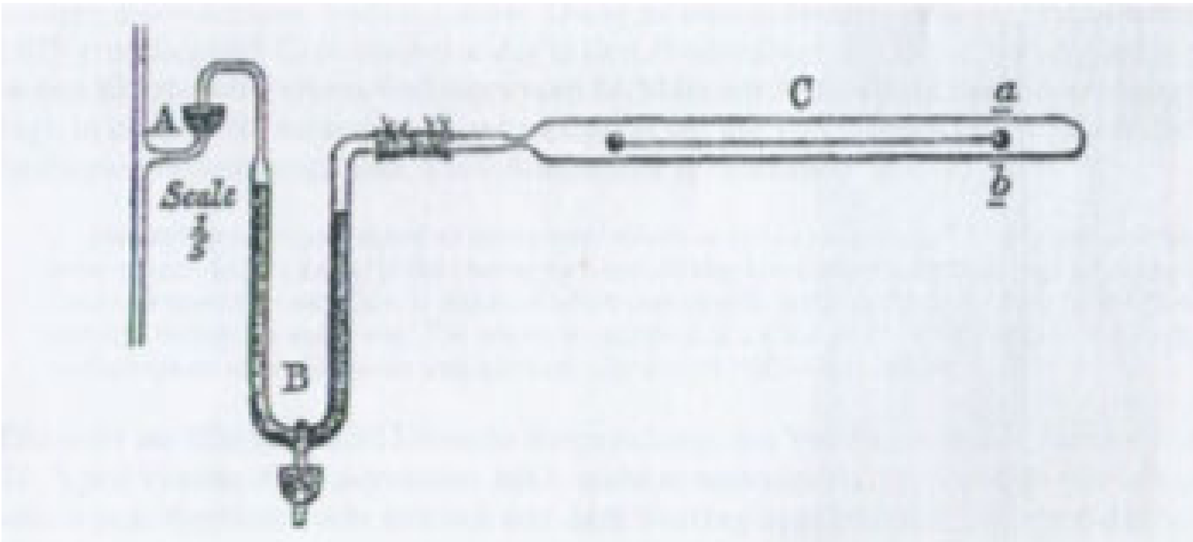

Fig. 1. Crookes balance for demonstrating thermally induced repulsion and attraction (after Crookes 1874b)

Crookes had done quite extensive research in preparation for his lecture. He cited more than a dozen previous clues and experiments that seemed to be explained by the effect he was now cultivating . The experiments of Augustin Jean Fresnel (1788-1827) came closest to his own. He had attached a disc made of opaque and transparent material (mica) vertically to the ends of a magnetic needle suspended on a silk thread and placed it opposite a solid metal disc.2 And he had evacuated the system to about [redacted]

[redacted]

[redacted]

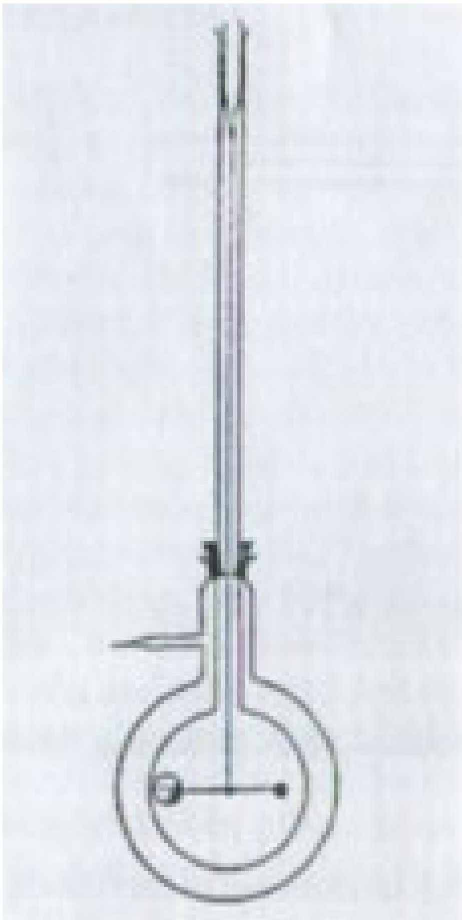

Fig. 2 One of many forms of Crookes torsion pendulum (after Crookes 1875a).

James Dewar (1842-1923) and Tail in Edinburgh, Scotland [N. N.(b) 1875] formulated the idea that the mean free path of the gas molecules in relation to the geometry of the apparatus plays a decisive role Crookes, however, supported his opposing viewpoint with a series of further apparatus and experiments, which he presented to the Royal Society on March 22, 1875 [Crookes 1875 a]. They differed from earlier ones in that he no longer used the balance beam as the radiation-sensitive element , but rather pendulums , in particular various forms of symmetrical and asymmetrical rotating pendulums (Fig. 2). As far as the terminology is concerned , Crookes had meanwhile adopted Maxwell 's concept of light and heat radiation and only spoke of " radiation " . Here and elsewhere , Crookes mentioned his " friend and student Mr. C H. Gimingham", who was his assistant from 1870 to 1882.

Crookes' radiometer and Geissler's Lightmill

We can assume that the discussion that had taken place up to that point, despite its intensity, had not caused a great stir in the public . After all, the scientific basis of the arguments exchanged - the theory of electromagnetic phenomena on the one hand and the kinetic theory of gasses on the other - was not yet common knowledge, and the effects discussed could only be understood with careful observation.

This situation changed fundamentally in the early summer of 1875. Crookes had added a supplement to the short version of his lecture of March 22nd, which appeared in the Proceedings of the Royal Society, on April 20th, in which he described a new type of device for detecting the thermally induced attraction and repulsion effects he was pursuing

“” the Author has constructed an instrument which he calls a radiometer*. [redacted]

[redacted]

[redacted]

[redacted]

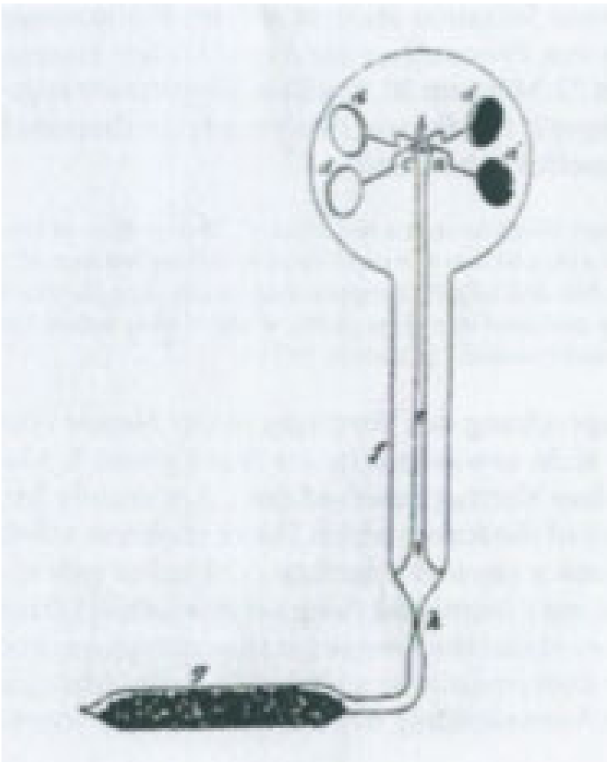

Fig. 3.
Early form of a rotating Crookes radiometer (after Crookes 1876b).

the 3rd axiom of Newtonian mechanics - action equals reaction - and carry out a slow countermovement.

The instrument best fitted for an experimental investigation of this kind is the one which has been called “radiometer" by Mr. Crookes. These instruments have been made in great perfection by Dr. Geissler, of Bonn, under the name of .light-mills'." [Schuster 1876a].

[redacted]

Fig. 4.
Early radiometer construction by Heinrich GeiGler (after Reynolds 1876b).

German perceptions

Carl Friedrich Zollner (1834-1882), an astrophysicist in Leipzig and member of the local Royal Saxon Society of Sciences, was received by Crookes in his laboratory in September 1875 .

“”On this occasion I saw for the first time the remarkable rotation phenomena in the radiometers constructed by Mr. Crookes and immediately decided, with the permission of Professor Crookes, to interest Dr. Geissler in Bonn in the construction on my return journey. [redacted]

[redacted]

Zollner, the initiator of this scientifically fruitful debate had himself temporarily withdrawn from it . Evidently strongly impressed by Crookes' personality and willingness to compromise, he became an unwavering and polemical advocate of his views at the time . At least we owe his efforts to provide historical evidence for the existence of the effects demonstrated by Crookes the reference to the investigations of Georg Wilhelm Muncke (1772-1847) in Heidelberg. Like Crookes, he had observed disturbing effects triggered by thermal radiation on a Coulomb torsion balance [Muncke 1829, 1830a] and had not ruled out thermoelectric effects [Muncke 1830b]. Muncke, like Fresnec before him, worked with negative pressure. At that time, there was a dispute over the causes of the disturbances with Emil Lenz (1804-1864) , who was working in St. Petersburg. He assumed that they were caused by air currents driven by heat [Lenz 1832], [Muncke 1833]. Zollner also referred to the now forgotten amateur researcher and writer Adolf August Bergner. He had - possibly uninfluenced by the scholars mentioned here , although he did not cite them - tested a rotating system in addition to a large number of rotating pendulums operated at normal pressure . He had mounted a cross made of light spring ribs on an agate sleeve so that it could rotate, and attached to the ends of the cross "four discs made of tinsel gold, each of which is coated on one side with pine soot ". Also interesting is the parallel drawn between one of his experiments and Crookes' later rotating pendulums (see Fig. 2) and the technology used :

[redacted]

[redacted]

Despite a wide range of activities , it seems that a similarly concentrated and systematic pursuit of the phenomenon as that of Crookes in England did not take place in Germany. Geisler was largely left to his own devices. On November 8, 1875, he gave a lecture to the Natural History Society of the Prussian Rhineland and Westphalia, of which he was a member, and demonstrated the light mill invented by Crookes "Councillor Professor Clausius added explanatory remarks about the new experiment , which, however, does not yet allow a sufficient explanation given our current state of knowledge about light ." [redacted]

[redacted]

Towards conclusive explanations

Schuster's experiment with Geisler 's light mill initiated a change in direction in attempts to interpret the radiometer effect . Crookes did indeed strike back with his answer to Reynolds ' polemical remark in Nature on May 6th:

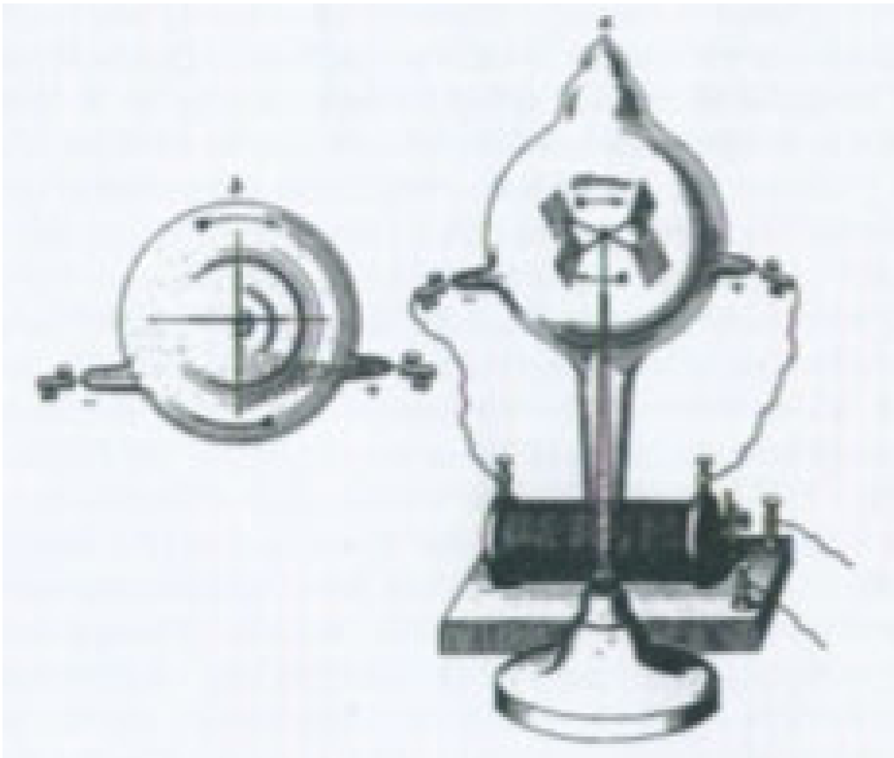

Fig. 5
Replica by Robert Goetze of the apparatus demonstrated by Heinrich Geisler in Hamburg in 1876 to detect the mechanical impulse of gas discharges (i.e. of moving charge carriers). The sketch given by Zdllner in 1877 is almost certainly a simplified representation. It can be assumed that Goetze became acquainted with Geisler's construction for securing the impeller, which is suppressed in the sketch, in Bonn and took it with him to Leipzig.

..Prof. Reynolds goes far when he says that my experiments are …the only direct proof that has ever been [redacted]

[redacted]

[redacted]

[redacted]

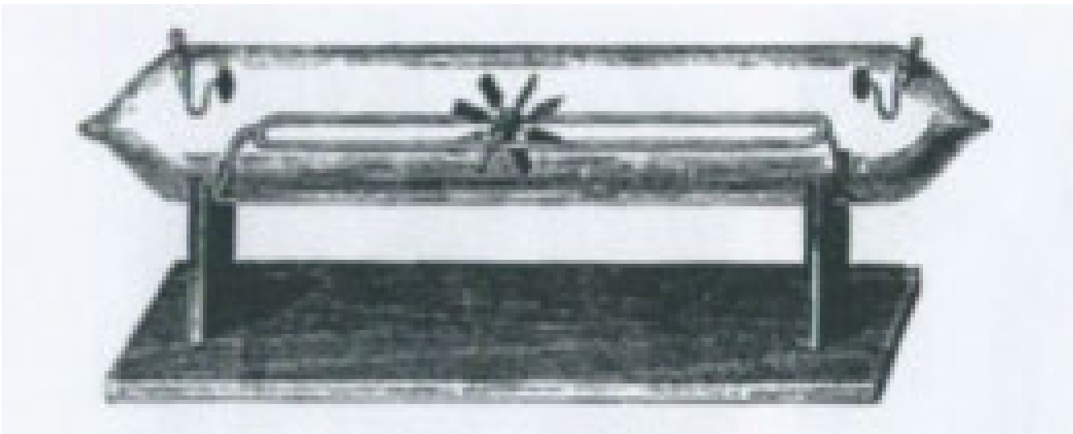

Abb. 6.
Impeller for demonstrating the mechanical effect of gas discharges (after Crookes 1879).

…I have proposed for this instrument the name of the .Radiometer", as it serves to measure the amount of radiation falling upon it by the velocity with which it revolves. It may also be called the, Light-Mill"." [Crookes 1876b].

In his subsequent works he no longer made this claim. This episode corresponds in some way to a note from Zollner - which he had added to his above - quoted thank you to Crookes

[redacted]

[redacted]

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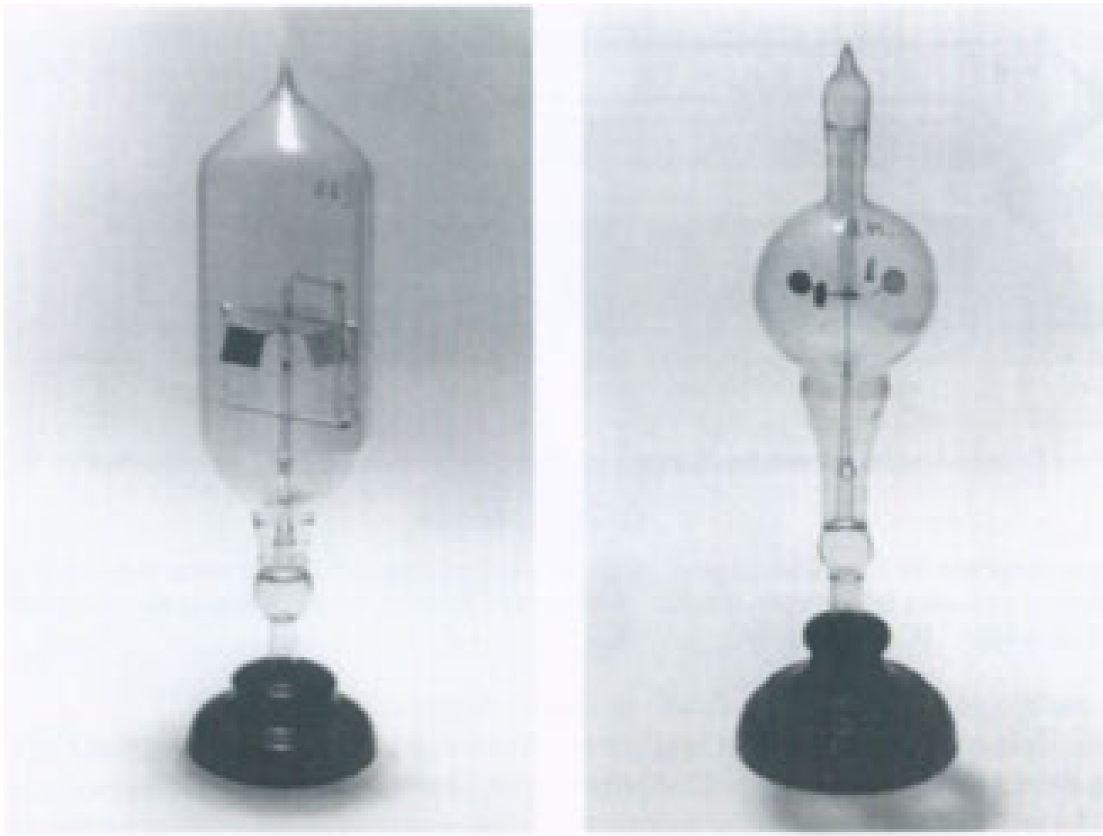

Fig. 7
Two early light mills from Geisler's workshop ; Physical Institute of the Rheinische Friedrich-Wilhelms-Universität Bonn (Photograph : Photographik Rauchfuß Dresden). The cylindrical instrument is Geisler's design of Kundt's "friction apparatus" [Kundt 1876a,b]. The variety of constructions for securing the wings is an indication of the creative independence of Geisler's employees.

[redacted]

[redacted]

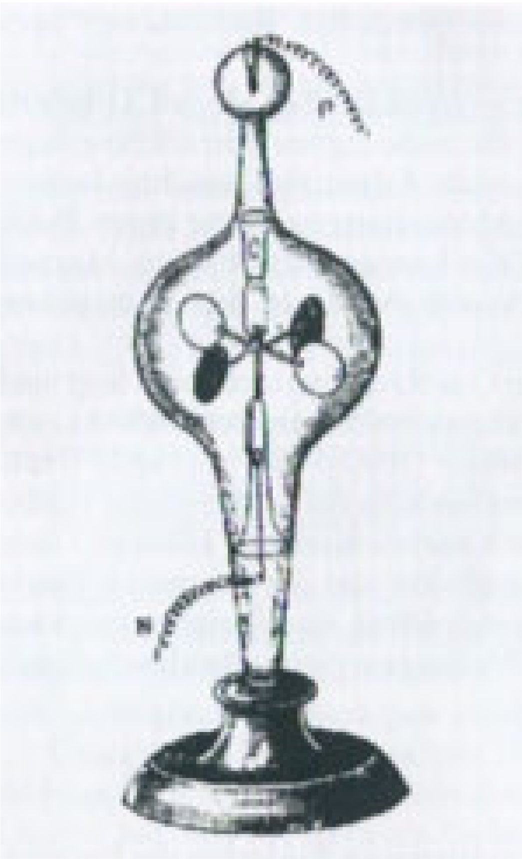

Fig. 8 Radiometer with axial electrode arrangement
(after Crookes 1879).

gas, which should be large compared to the wings. But this was only roughly approximated. This unsatisfactory situation prompted Maxwell to carry out a mathematical analysis, which he presented to the Royal Society on April 11, 1878. This showed that the pressures depend on the higher spatial temperature gradients. In the published version of this work in the Transactions [Maxwell 1879], Maxwell included an appendix to a work by Reynolds in which he had described the migration of gas molecules from the cold side of a porous plate to the warm side - an effect which Reynolds called "thermal transpiration" [Reynolds 1879]. [redacted] the technological perfection and production of this special radiometer (Fig. 7) [Kundt 1876b].

Maxwell praised Reynolds' discovery and his physical model, but criticized his mathematical treatment and contrasted it with his own view . It was unusual that Maxwell, who had become acquainted with Reynolds' work as a reviewer [Garber 1995], discussed and used Reynolds' paper before it was published . This meant that there was no scandal . Maxwell died in November 1879 , at the time when Reynolds ' paper appeared in the Transactions

[redacted]

Summary and Outlook

The controversies surrounding the radiometer greatly promoted the development of the kinetic gas theory . In particular, the work of Kundt, Warburg, Reynolds and Schuster supported Maxwell 's theoretical work and predictions . [redacted]

[redacted]

“”When I first showed the Radiometer to my friends some of them thought that it would become a very popular toy and I was advised to patent it as it would only be fair that some of the pro-fit arising from the sale should come to me instead of all being adsorbed by the instrument makers. I find however that these anticipations are not likely to be realized.'"'13

Among the patent documents issued by the English Office of the Commissioners of Patents for Inventions [redacted]

[redacted]

[redacted]hese pioneers, i.e. in Thuringia, it has remained a profitable branch of industry up to the present day

Thanks to

During their research and deliberations , which were initially carried out without knowledge and independently of each other , the authors found a knowledgeable and committed discussion partner in Klaus Hentschel, Göttingen . It was he who then also encouraged the joint preparation of the manuscript . Karlheinz Althoff, Bonn, made historical radiometers from the collection of the Physics Institute of the University of Bonn available to us . Ernst Weihreter, Berlin, was a well- informed guide through the old French literature. Demonstrations and explanations of today's radiometer production, which Wolfgang Linschmann, Cursdorf , gave, were also beneficial to our understanding of the historical and technological processes . We would like to express our sincere thanks to all of the gentlemen mentioned.

Notes

1 In Crookes' initial experiments, the effect of his (torsion) balances stopped at one point with increasing evacuation and started again with further evacuation . (See also Maxwell 's description of Crookes ' experiment quoted below .) The existence of this " neutral point " was his reason to rule out any activity of the residual gas , since beyond this point the effect of other factors was assumed .

This " neutral point" was mentioned by Crookes as early as 1872 in letters to his assistant Charles Gimingham. Such and other neutral or reversal points occurred in a wide variety of experiments and authors , depending on the test conditions ; see also [Munke 1830 a| and [Stokes 1877]. It is obvious that different, sometimes opposing effects overlap depending on the experiment. For example , when making today 's decorative radiometers , the glassblower can temporarily reverse the direction of rotation of the impeller by heating the radiometer vessel in an open flame during melting , i.e. at a corresponding negative pressure.

2 The latter feature gained importance a hundred years later as a design principle for highly sensitive technical radiometers (see [Hettner 1928)).

3 During Crookes' long business trips, Gimingham ran the laboratory and the research work largely independently, with Crookes giving instructions and receiving reports by letter. As a thank you for his effective support , Crookes allowed him to report to the Royal Society on technical improvements to the Sprengel vacuum pump [Gimingham 1877]. The mention of the assistant in the publications is also an expression of special appreciation. The special relationship between Crookes and Gimmingham was described by Ilannah Gay in a study " on Crookes' invisible resources" [Gav 1996).

4 The emphasis here and in the following verbatim quotations was added by the authors.

5 Schuster later pointed out in a more general context that the experiment was also successful at normal pressure [Schuster 1876 c)

6 A vivid description of his views on this can be found in [Euler 1769/1983). 17.. 18. u. 19. Letter.

7 For the intellectual and experimental environment in which Zollner worked, see also [Meinel 1991] and [Staubermann 2001].

8 Züllner reported this in 1877 and 1879 (see also legend to Fig. 5). The event in question is not mentioned in the reports on the natural scientists' meeting available to the authors . However, the list of participants published in the daily newspaper of the 49th meeting of German natural scientists and doctors in Hamburg from September 11th to 24th , 1876 , confirms Geisler's presence. Reference is also made to a "collective exhibition" which primarily showed natural history objects from outstanding private collections , but also exhibits "from scientifically interesting industrial enterprises . "

9 Given the vacuum pump at his disposal , Crookes assumed that he had reduced the pressure in the radiometer vessel to (almost) one millionth of normal pressure , which for a chemist at that time was an extremely low level of " contamination ". (It is highly doubtful that he could actually achieve this final pressure , given the complex apparatus equipped with many strontium resistors and connections .) However , for the physicist who adhered to the kinetic gas theory , it had to be taken into account that there were still around 10'^ of residual gas molecules moving around the radiometer blades

10 The blackened (heated) side of the radiometer vane imparts a higher energy in the form of increased speed to the residual gas molecules touching it . The sum of the " recoils" drives the wing. This interpretation based on George Jonstone Stoney (1826-1911) [Stoney 1876] is tied to the (not readily fulfilled) assumption that the mean free path of the residual gas molecules is large compared to the radiometer dimensions and does not explain the radiometer effects observable at higher pressures - up to atmospheric pressure . Descriptions of the radiometers of that time and the corresponding development of scientific views can be found , for example , in Woodruff [1966], Brush and Everitt [1969], DeKosky [1976] and Heckenberg [1995]. The dispute over the mechanisms of action flared up, triggered by an article by William B. Carpenter (1813-1885) in Nature [Carpenter 1877 b], once again . Carpenter formally opposed the misinterpretation of his radiometer article in The Nineteenth Century [Carpenter 1877a] by George Carey Foster (1835-1919), Section Director of the British Association. In substance , however, he expressed scientific and behavioral doubts about Crookes ' competence for the interpretation of the radiometer effect . In the sometimes very sharp and personal debate in Nature 17 (1877), the following people participated - in addition to Carpenter and

Foster - W. Crookes, G. Johnstone Stoney, Alfred R. Wallace (1823-1913) on the one hand and O Reynolds and A. Schuster on the other hand.

11 Geisler's instruments were imported and valued in England . Klaus Hentschel, Göttingen , refers in this context to a passage in the correspondence of the instrument dealer T. Cooke and Sons in York dated November 9 , 1877, according to which the spectral tubes supplied by Geisler were described as the best of those available . A note in [De La Rue and Müller 1878] proves that Geisler also visited his customers in England . This visit to England was probably connected with the exhibition of scientific apparatus in the South Kensington Museum in London . 1876. The exhibition report (Biedermann 1877) mentions radiometers from Geissler (Bonn), Weinhold (Chemnitz) and Browning (London). It is possible that special radiometers also came to Crookes in this way . As early as April 1876 , he reported to George Gabriel Stokes (1819 1903): "1 asked Dr. Geissler some time ago, if he would make me a Radi exhausted as he calls 'perfectly ' and having platinum wires sealed in. to show that the induction spark would not pass. He has recently sent the instrument and I have tried many experiments with it." In this context he also mentioned other Geissler radiometers that were in his possession (Cambridge University Library, Correspondence of George Gabriel Stookes. Add . MSS 7656 C109], Geisler's efforts to respond to Crokkes's request may have been the trigger for the discovery of the effect he demonstrated in 1876 (Fig. 5). Zollner 1877.1879]).

12 The extraordinary development of interest in the radiometer effect is reflected , for example , in the reporting in the supplements to the Annalen der Physik and Chemistry . In the first year, 1877, they devoted a separate chapter to the keyword "radiometer" . In terms of citations, the chapters are more extensive than comprehensive classical chapters such as "acoustics" or " theory of heat". The development was in decline in 1878 and 1879. In 1890 the separate chapter "Radiometer " was abandoned. The same trend is followed by the reporting in the yearbooks Repertorium für Experimentalphysik, Munich, and Die Fortschritt auf dem Gebiet der Physik, Cologne and Leipzig.

13 Cambridge University Library, Correspondence of George Gabriel Stokes Add. MSS 7656, CI 115.

14 Archives of the Edison National Historic Site, Letterbook Series - General Letterbook: LB 00667 LTAEM 80:438.

15 Archives of the Edison National Historic Site. D8104C;TEAM 57:33.

16 In collaboration with the Frankfurt physicist Walter Konig (1859-1936) , Goetze had produced tubes for studying the thermal effects of cathode rays before the discovery of X-rays , which then proved to be particularly suitable for producing X -ray images and influenced subsequent designs of X - ray tubes [Dorfel 2000]. However, he expressly renounced the acquisition of intellectual property rights [Dorfel 2003].

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