Photoelectric Photometry — The First Fifty Years

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Abstract

This historical review covers the first fifty years of the electrical measurement of starlight, which saw its beginnings in August 1892 when William Monck used a Minchin photovoltaic cell on his refractor in Dublin. The work of Stebbins using photoconductive cells from 1907 and of Guthnick, Stebbins and others using photoelectric cells from 1912 is also discussed. The advances brought about by thermionic amplification and the red-sensitive Cs-O-Ag photocathode in the early 1930s by respectively Whitford and Hall enabled new astrophysical problems to be tackled. Although many observers attempted photoelectric photometry, relatively few were successful during the 1920s and '30s. It was not until the introduction of the 1P21 photomultiplier tube that astronomers had a reliable and sensitive detector for photometric observations.

An Irish beginning

This colloquium is to celebrate the centenary of the first electrical measurement of starlight [1] on 28 August 1892 by William Monck, at his private observatory in Earlsfort Terrace, Dublin. The detector was a primitive photovoltaic cell comprising a selenium photocathode on an aluminium substrate immersed in acetone. A quartz window admitted light from Monck's $7\frac{1}{2}$-inch refractor and a quadrant electrometer recorded the emf produced. Ironically the real hero of the occasion, George Minchin, had returned to London from his native Ireland before the weather had cleared; he was not therefore a participant in the historic first observations which were made by Monck (a notable Dublin amateur astronomer and former philosophy professor) with the help of Professors Stephen Dixon and George Fitzgerald. Monck reported that although they failed to obtain any certain results from fixed stars, nevertheless the effects from the moon were 'of a striking character' (Monck 1892), while Dixon noted measurable deflections from Jupiter and Venus (Dixon 1892).

[1]Thermocouple observations had been made in astronomy as early as 1868 but are not considered in this article

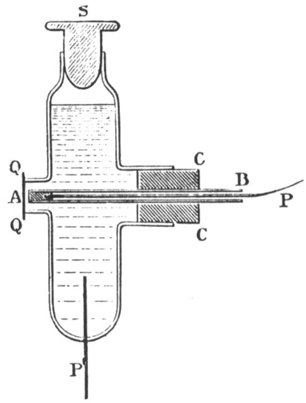

Figure 1 Minchin photovoltaic selenium cell.

Minchin was a genial professor of mathematics at the Royal Indian Engineering College at Cooper's Hill, who evidently enjoyed experimenting in his physical laboratory at the college. Here he developed photovoltaic cells from 1890 for astronomical use (Minchin 1895). From 1894–96 he made three visits to the Daramona House Observatory, Co. Westmeath, where more successful observations were made on the 24-inch reflector (Minchin 1896). Observations of at least ten stars and three planets were made, and Minchin concluded that '... there is little difficulty in obtaining fairly accurate measurements of the light of the stars of the first and second magnitudes' (Minchin 1895).

Stebbins' photoconducting cell at Illinois

The Irish photovoltaic observations had created practically no interest in electrical photometry in the astronomical community. Indeed the next electrical observations in 1907 involved a completely different type of detector, a photoconductive selenium cell made by F.C. Brown at the University of Illinois for Joel Stebbins, using the property of a decreased resistance of this element when under illumination. The earliest photoconductive cells were of low sensitivity and demanded great patience from the observer with a continuous stable current flow and short intermittent exposures to light. Stebbins found that the sensitivity improved at least twenty-fold on cooling, and by 1909 he was able to achieve $0\overset{m}{.}02$ precision on the 12-inch telescope. This was the first truly quantitative electrical photometry, and the device was used to produce the classical paper on the light curve of Algol, which showed the shallow secondary eclipse for the first time (Stebbins 1910). Other results for eclipsing binaries were published in 1910–11 as well as photometric observations of Halley's comet.

From 1907 we can say that a new era in photometry had been launched by Joel Stebbins. Yet the astronomical usefulness of this detector was as short-lived as Minchin's photocells. For in turn they were overtaken by the photoelectric cell, to which Stebbins himself, from 1912, quickly turned his attention. However Stebbins

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was not the only observer to employ the photoconductive cell. Stebbins referred to unpublished attempts by Pickering at Harvard to use such a detector, possibly as early as 1877. In Germany Ernst Ruhmer observed solar and lunar eclipses with a selenium photoconductive cell in 1902–03, and Fournier d'Albe used one to record star transits in his meridian telescope in Birmingham in 1913.

Early photoelectric photometry in Germany

The true photoelectric era in astronomical photometry began in 1912. Julius Elster and Hans Geitel had experimented with the photoelectric effect from 1889 using alkali metals. By 1910 they showed that the hydrides of potassium and sodium had significantly higher sensitivities than the metals themselves, and it was a KH photocell that was used in the earliest observations by Paul Guthnick at the Berlin Observatory in the summer of 1912. He can be regarded as the father of photoelectric photometry in astronomy. Guthnick's photocell was one made commercially by the firm of Günther and Tegetmeyer on the 31-cm Berlin refractor. He was able to demonstrate that the ratio of the cell's responses for α Lyrae to α Cygni was in accord with the ratio from visual photometry.

The photoelectric observations were continued on the 30-cm telescope of the new Berlin-Babelsberg Observatory from 1913. From 1914 Richard Prager collaborated in this work. The light curve of β Cephei was the first variable star observed, and in fact the first variable to be discovered by photoelectric means (Guthnick and Prager 1914). The Ap star α CVn was observed soon afterwards, as well as Nova Aquilae in 1918.

The German KH photocells were operated with 100 V across the cell and were filled with low pressure argon, which increased the sensitivity as a result of collisional ionization. A delicate string electrometer suspended from gimbals was used to collect the charge from the anode, the string being deflected sideways in an electric field. The rate of deflection was measured with a microscope and a stop-watch, and this was proportional to the brightness of the star.

By 1917 Guthnick and Prager had amassed 67 000 photoelectric measures on 50 stars and planets (Guthnick and Prager 1918), in the best cases with probable errors as small as $0^{\mathrm{m}}.005$. A yellow filter was used to define a colour index as the difference between filtered and unfiltered magnitudes and the relationship between colour and spectral type was explored for 67 stars.

The fine Berlin tradition of photoelectric photometry was continued by Guthnick and his collaborators right up to the early 1940s. Most notable were Kurt Bottlinger, who made the first 2-filter (440 and 460 nm) colour-index observations in 1920–22 and who applied the results to astrophysical problems including interstellar reddening (at that time a controversial subject); Wilhelm Becker, who used filters at 425 and 475 nm for his colour indices in 1930–31 to obtain colour temperatures and Margarethe Güssow from 1931 to the early years of the Second War.

Hans Rosenberg with Edgar Meyer in Tübingen also attempted photoelectric photometry from 1912 (Meyer and Rosenberg 1913); although the cell was their design, their productivity was much less — in fact no useful photometry was reported by the time Rosenberg left Germany in 1933 for Chicago. However in 1920 Rosenberg pioneered the technique of thermionic valve d.c. amplification. His triode valve gave an amplification of at least 6×10^5, enabling the very low anode currents ($\sim 10^{-14}$ A) to be detected with a galvanometer off the telescope, instead of the delicate suspended string electrometer. These experiments were not generally copied at the time, although Bengt Strömgren in Copenhagen was using an amplifier to record star transits photoelectrically in 1925. Widespread use of d.c. amplifiers in photoelectric photometry only came after their introduction by Whitford at the Washburn Observatory from 1932.

Joel Stebbins and photoelectric photometry

Meanwhile Joel Stebbins had taken sabbatical leave from Illinois in 1912–13 and was able to witness at first-hand the installation of the photoelectric apparatus by Guthnick in Berlin in 1912. This good fortune, together with the arrival in 1911 of Jakob Kunz in the Physics Department at Illinois were the events which set Stebbins off on his illustrious career as a photoelectric photometrist. Kunz came originally from Switzerland, but in Germany he had learnt the techniques of KH photocell production. In the absence of Stebbins, Kunz and Schulz at Illinois constructed a photoelectric photometer and made successful stellar observations on Capella from December 1912 (Schulz 1913).

The photocells by Kunz were helium-filled and operated at about 300 V. They were far more sensitive than the selenium photocells used earlier by Stebbins (the peak quantum efficiency for the KH photocells was about 10 per cent), but suffered from a small bandwidth, the useful response being only 380 to 500 nm. A series of papers on the photometry of eclipsing binary stars appeared in the *Astrophysical Journal* by Stebbins and his associates (*e.g.* Stebbins (1920) on λ Tau). Perhaps the outstanding feature which distinguishes the Illinois publications from those of Stebbins' photometric contemporaries was his concentration on astrophysical problems of the stars themselves rather than the technical difficulties of operating a photoelectric photometer.

When Stebbins moved to the University of Wisconsin in 1922 he had access to the larger 15.6-inch telescope of the Washburn Observatory (see Stebbins (1928)). However the close collaboration with Kunz in Urbana (Illinois) continued. In fact Kunz supplied Stebbins with his best photocells throughout the 1920s and '30s, and provided cells for several other American observatories as well (including Edith Cummings and later Kron at Lick, Elvey at Yerkes, Smith at Mt Wilson, Calder at Harvard and Baker in Urbana). Two significant developments at Wisconsin were the change to a sensitive Lindemann electrometer in 1927 (this instrument had a needle on a torsion wire which rotated when charged, and was much more robust than the string electrometer used earlier), and the introduction of thermionic amplification in 1932 by Whitford, which therefore dispensed with the electrometer altogether. The amplifier was placed in an evacuated chamber to avoid problems with cosmic rays. It

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had a gain of over two million and enabled ninth magnitude stars to be reached.

Using two filters (426, 477 nm) Stebbins defined a colour index and tackled problems in interstellar reddening, intrinsic star colours and the colours of the globular clusters during the 1930s. During these years Morse Huffer, Albert Whitford and Gerry Kron were the outstanding photometrists that graduated from Wisconsin under Stebbins' tutelage. Kron obtained his doctorate at Berkeley after leaving Wisconsin. He worked at Lick where Stebbins had fostered close relations through his annual summer observing expeditions, to Lick from 1915 and later to Mt Wilson.

Stebbins lent his technical expertise to other institutions to enable them to set up photoelectric apparatus. Kron at Lick was one example of an outstanding instrumental innovator in his own right, but Christian Elvey at Yerkes also built a photometer in 1929 based closely on the Washburn design.

Other photoelectric photometrists before 1940

Stebbins was sometimes cited as the leader of the only successful photometric observers before the Second War. He was certainly the most productive, but many other observers attempted photoelectric work. Guthnick and his collaborators were nearly as successful as Stebbins and if it were not for political intervention they may well have become equally as productive.

In Britain the photometer of Adolph Lindemann and his son Frederick (professor of physics at Oxford and later Lord Cherwell) was especially notable, at least for its independent design and the fact that even the photocells were home-made, although extensive published observations were not forthcoming. Adolph Lindemann was a German civil engineer who settled in Devon in 1884, where he established his private observatory. The first Lindemann photometer was built in 1918 (Lindemanns 1919). The paper is remarkable for its foresight in design and in identifying the potential for photometry to solve astrophysical problems.

The robust Lindemann quadrant electrometer was described in 1924. This became a feature of the new Lindemann photometer in 1926, and the electrometer design was copied widely by many other observers, including Stebbins, Kron and John Hall.

By 1940 as many as 38 observers had attempted stellar photoelectric photometry at 22 observatories in 7 countries, and they had published either photometric results or instrumental descriptions in over 100 papers in the literature. The order in which these countries entered the arena was Germany (1912), USA (1912), United Kingdom (1918), France (1925), Canada (1929), Italy (1930) and the Soviet Union (1934), where the years are those of first involvement in photoelectric observing (see Table 1). In North America Kunz cells were used almost exclusively until the mid-1930s, while in Europe commercial cells from Günther and Tegetmeyer predominated. For example Smart in Cambridge, Maggini in Italy at the Collurania-Teramo Observatory and Nikonov with Kulikovsky from Leningrad all used the German cells for their early experiments. In addition Maggini acquired two Kunz cells. Only the last two of these observers produced successful results; at first they used a German built photometer on the 13-inch Abastumani Observatory in Georgia, but by 1936–37 a new Russian-built photometer had been installed. It featured a d.c. amplifier and a Fabry lens, the first photoelectric photometer to employ a Fabry lens to focus the primary onto the photocathode.

The Cs-O-Ag red-sensitive photocathode

A new red-sensitive photocathode was developed by Lewis Koller at the General Electric Company in 1929. It consisted of a caesium layer deposited on an oxygenated silver substrate and gave a broad spectral sensitivity to beyond 1μm in the near infrared, but very low quantum efficiency at all wavelengths. The new cathode (now designated S1) was incorporated into photocells by Charles Prescott at Bell Labs, and some of these were acquired by John Hall, then a graduate student at Yale, in 1930. Hall became the pioneer of near infrared photoelectric stellar photometry. By 1931 he had introduced cooling with dry ice to reduce the high dark current, enabling sixth magnitude stars to be observed on the 15-inch Loomis telescope (Hall 1934). Between 1934 and '42 a classical series of *Astrophysical Journal* papers were written from successively Yale, Columbia, Sproul and Amherst. Wratten filters enabled IR colour indices to be defined, and then coarse objective gratings and diffraction gratings were used for multicolour spectrophotometry. The power of the wide wavelength sensitivity allowed new astrophysical problems to be tackled, notably a new study of the interstellar extinction law, and studies of stellar continua and colour temperatures. By 1935 he had photoelectric photometry to support a $1/\lambda$ interstellar law, which was confirmed by Stebbins and Whitford using their 6-colour $UVBGRI$ photometry some eight years later, again using a Cs-O-Ag (S1) cell on a photometer at Mt Wilson (the U filter at 353 nm represented the first use of the ultraviolet in photoelectric photometry).

Arthur Bennett at Yale (from 1934), Kron at Lick (1939) and Nikonov at Abastumani were other early observers with the new red cell. In the U.S. the Western Electric cells were generally used, while Nikonov had one of Russian manufacture.

Undoubtedly the Cs-O-Ag photocathode added a new dimension to photoelectric photometry in the days before the photomultiplier, and in spite of its high dark current (when uncooled) and low efficiency, much valuable work was accomplished by a few diligent observers — mainly Hall and Whitford — on stellar colours and interstellar reddening.

Concluding remarks

The most successful early photoelectric photometrists were those who persevered with the intricacies of electronics at a time when electronic apparatus was generally absent from astronomical observatories. Guthnick and Rosenberg both commented on the reluctance of astronomers to acquire the necessary skills and know-how to operate electronic instruments.

The three most successful photometrists in terms of their output of photometric results were Stebbins, Guthnick and Hall (including their collaborators). It is note-

Table 1 Observatories engaged in photoelectric photometry before 1940

Observatory	Observers	Year
Berlin	Guthnick, Prager, Hügeler, Bottlinger, W.Becker, Güssow	1912
Tübingen	Rosenberg, Meyer	1912
Urbana, Illinois	Stebbins, Schulz, Kunz, Dershem, Wylie	1912
"	Baker	1928
Lick	Stebbins	1915
"	Cummings	1920
"	Fath	1931
"	Kron	1937
Sidholme, Devon	A.F. and F.A. Lindemann	1918
Washburn, Wisconsin	Stebbins, Whitford, Huffer	1922
Strasbourg	Rougier	*c*.1925
Yerkes	Elvey, Stebbins, Mehlin	1929
Dominion, Ottawa	Henroteau	*c*.1929
Cambridge, U.K.	Smart, Green	1929
Mt Wilson	Stebbins, Whitford	1930
"	Smith	*c*.1933
Collurania-Teramo	Maggini	1930
Goodsell, Minnesota	Fath	1931
Harvard	Calder	1931
Yale	Hall	1931
"	Bennett	1935
Rutherfurd, Columbia	Hall	1933
Pulkova	Nikonov	1933
Sproul, Swarthmore	Hall, Delaplaine	1934
Abastumani, Georgia	Nikonov, Kulikovsky	1934
Potsdam	Hassenstein	1938
Amherst	Hall	1938
Steward	Roach, Wood	1938

Notes:

1. observers separated by commas were collaborators
2. the year is the year of initial involvement
3. from 1913 the Berlin Observatory was resited at Berlin-Babelsberg

worthy that all three had the close collaboration of physicists to advise them on the operation of their photocells, namely of Kunz, of Elster and Geitel and of Charles Prescott respectively. Those who ventured into this new field without such help were often unproductive in their efforts. It should be remembered too that photometry in the 1890s and early twentieth century was principally photographic or even visual — techniques which required very different skills to those demanded by the photocell.

The principal technical developments in photoelectric instrumentation were hydrogenated photocathodes (1910), the Lindemann electrometer (1924), thermionic valve amplification (1920, 1932), the Cs-O-Ag photocathode (1929) and photocell cooling (1931). In 1936 P. Görlich in Dresden produced the Cs-Sb photocathode with a response to 580 nm and higher sensitivity than the KH cell. This was used by V. Zworykin at RCA in the earliest photomultiplier tube from 1936. The photomultiplier was used by Whitford and Kron as early as 1937 as the detector for an autoguider. The RCA 931-A photomultiplier was developed during the war years and was a precursor to the famous 1P21 that revolutionized photoelectric photometry and which allowed the first pulse-counting photometers to be constructed by Yates at Cambridge and Blitzstein at Pennsylvania from 1948. These developments belong to the second fifty years in the history of the electrical measurement of starlight.

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