

## August Kirschmann and the Material Culture of Colour in Toronto's Early Psychological Laboratory

Erich Weidenhammer

Volume 38, numéro 2, 2015

URI : <https://id.erudit.org/iderudit/1037945ar>

DOI : <https://doi.org/10.7202/1037945ar>

[Aller au sommaire du numéro](#)

Éditeur(s)

CSTHA/AHSTC

ISSN

1918-7750 (numérique)

[Découvrir la revue](#)

Citer cet article

Weidenhammer, E. (2015). August Kirschmann and the Material Culture of Colour in Toronto's Early Psychological Laboratory. *Scientia Canadensis*, 38(2), 1–19. <https://doi.org/10.7202/1037945ar>

Résumé de l'article

Entre 1893 et 1908, le psychologue August Kirschmann (1860-1932) né en Allemagne, a dirigé le laboratoire de psychologie qui avait été récemment créé à l'Université de Toronto. Formé par le fondateur de la psychologie expérimentale Wilhelm Wundt (1832-1920) Kirschmann faisait partie d'une première génération de psychologues ayant contribué à la création de nouveaux laboratoires en Europe et en Amérique du Nord. Le domaine d'étude principal de Kirschmann était la perception de la couleur, un domaine dynamique pendant une période où la technologie de la couleur et de l'éclairage se développait rapidement. Cet article explore la contribution de Kirschmann à partir de la culture matérielle de sa recherche à Toronto et en particulier à partir des instruments basés sur la technologie des disques rotatifs. Il traite de l'échange de technologie expérimentale entre l'Allemagne, où la fabrication à des fins commerciales d'instruments de laboratoire était courante, et Toronto. Il explore aussi la contribution de Kirschmann à son domaine sur le plan technologique. Il cite, dans la mesure du possible, les objets et le matériel ayant survécu jusqu'à aujourd'hui.

# August Kirschmann and the Material Culture of Colour in Toronto's Early Psychological Laboratory

Erich Weidenhammer

**Abstract:** *Between 1893 and 1908, the German-born psychologist August Kirschmann (1860-1932) led the University of Toronto's newly founded psychological laboratory. Trained by the founder of experimental psychology, Wilhelm Wundt (1832-1920) Kirschmann was among an early generation of psychologists who helped to establish new laboratories across Europe and North America. Kirschmann's main area of study was colour perception—a vital field during a period in which the technology of colour and illumination was advancing rapidly. This paper explores Kirschmann's contribution through the material culture of his research in Toronto—especially instruments based on the technology of disc mixture. It discusses the exchange of experimental technology between Germany, where commercial manufacture of laboratory instruments was underway, and Toronto. It also explores Kirschmann's technological contribution to his field. It cites, where possible, surviving objects and materials.*

**Résumé :** *Entre 1893 et 1908, le psychologue August Kirschmann (1860- 1932) né en Allemagne, a dirigé le laboratoire de psychologie qui avait été récemment créé à l'Université de Toronto. Formé par le fondateur de la psychologie expérimentale Wilhelm Wundt (1832-1920) Kirschmann faisait partie d'une première génération de psychologues ayant contribué à la création de nouveaux laboratoires en Europe et en Amérique du Nord. Le domaine d'étude principal de Kirschmann était la perception de la couleur, un domaine dynamique pendant une période où la technologie de la couleur et de l'éclairage se développait rapidement. Cet article explore la contribution de Kirschmann à partir de la culture matérielle de sa recherche à Toronto et en particulier à partir des instruments basés sur la technologie des disques rotatifs. Il traite de l'échange de technologie expérimentale entre l'Allemagne, où la fabrication à des fins commerciales d'instruments de laboratoire était courante, et Toronto. Il explore aussi la contribution de Kirschmann à son domaine sur le plan technologique. Il cite, dans la mesure du possible, les objets et la le matériel ayant survécus jusqu'à aujourd'hui.*

---

**Keywords:** August Kirschmann, University of Toronto, History of Psychology, Material Culture, Scientific Instruments

---

WHEN THE STUDY OF EXPERIMENTAL PSYCHOLOGY first took hold in Canada in the 1890s, its development was fostered by a German-born psychologist, August Kirschmann (1860-1932) whose main interest was colour and its relation to human perception. Kirschmann's tenure as the head of the psychological laboratory at the University of Toronto from 1893 to 1908 created a well-equipped laboratory dedicated to the study of "psychological optics." This work represents an important and early Canadian experimental program that is only dimly remembered today. An overall account of Kirschmann's stay in Toronto has been provided elsewhere.<sup>1</sup> While a great deal of research remains to be done on

© The Author, 2015. Published by Érudit on behalf of the Canadian Science & Technology Historical Association. All rights reserved.

Erich Weidenhammer, "August Kirschmann and the Material Culture of Colour in Toronto's Early Psychological Laboratory," *Scientia Canadensis* 38, 2 (2015): 1-19.

Kirschmann's time in Canada, this short paper is only peripherally concerned with biography.

Rather, this paper explores Kirschmann's contribution by focussing on a particularly rich vein within the material culture of early experimental psychology. This is a technology, based on the optical blending effects of a spinning disk, which was incorporated into early instantiations of several key instruments including the colour mixer, the episcotister, and the photometer. Within the domain of philosophical optics, "disk mixture" was then the fundamental experimental technology. The underlying principle is relatively straightforward: when two or more sectors of different colour are placed on a disk, and that disk is spun with sufficient speed, the human eye will perceive an even blend of the sectors on the disk's surface—an aspect of what is referred to as the "flicker effect."

This technology provided a critical means to obtain accurate colours at a time when the development of calibrated colour, and the technology of colour calibration itself, was in the earliest stages of its development. This is the area in which Kirschmann made his most important technical contribution. Surviving objects from the psychological laboratory based on this principle offer a valuable perspective from which to study this Canadian node in an international network of instrument development and technological exchange, then centered on Germany, dedicated to understanding colour. They are especially important to understanding the materials, technology, and instrumental skills that characterized this early stage in the development of colour research when the involvement of the human eye and judgement was essential to measurement and to calibration.<sup>2</sup>

Kirschmann's technological contribution to experimental psychology, and his adaptation of existing tools and materials, evokes for us one of the most fruitful investigations of recent time: the search for a means of measuring and understanding the mechanisms of visual perception. For historians of science and technology, the research carried out by Kirschmann and his students illuminates the shifting landscape of colour and lighting at the turn of the century. The proliferation of artificial lighting, along with the ongoing development of colour standards following decades of improvement in commercial chemical pigments, provided both the backdrop and the material basis for the quantitative exploration of the human sense of sight: all emerged together in an interrelated series of technologies.<sup>3</sup>

Finally, to fin-de-siècle psychologists engaged in the study of colour, this process of rapid change raised questions about the extent to which longstanding "aesthetical laws" could be re-evaluated according to new standards obtained through psychological experiment. One of Kirschmann's students cited his mentor's belief that:

All of these obsolete ideas of primary, secondary and tertiary colours are based on laws about colour mixture which were once approximately correct, when the decorative art had at its disposal only a few mineral colours of great purity, but which are, in the light of modern colour chemistry, absolutely incorrect.<sup>4</sup>

Consequently, this instrumental investigation, which sought an empirical understanding of the human experience of colour, opens onto a broader debate about art, its description, and the possibility that basic assumptions underlying fields such as philosophical aesthetics and art criticism might be overturned by experimental psychology.



Figure 1



Figure 2

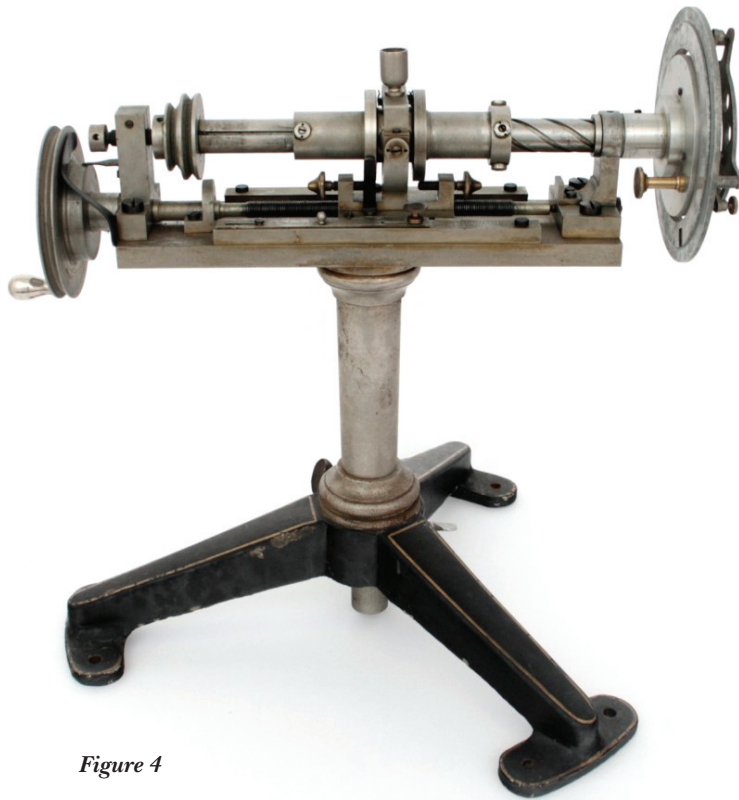


Figure 4



Figure 3

Clockwise from top left: **Figure 1.** A simple apparatus for disk mixture from the collection of the University of Toronto Department of Psychology (2012.psy.162). This, and other objects cited by accession number in this article, can be found in an online catalogue at [utsic.org](http://utsic.org). **Figure 2.** The Hipp Chronoscope (2012.psy.82). **Figure 3.** Gravity Chronometer (2012.psy.91). **Figure 4.** One version of the Marbe Colour Variator, manufactured by Zimmermann, which survives in the Department of Psychology collection (2012.psy.73).

### The Movement of People, the Exchange of Instruments

The history of experimental psychology in Canada begins in 1889, when the University of Toronto chose, amidst considerable controversy, to hire the American psychologist James Mark Baldwin (1861-1934) to fill a vacant position within the Department of Philosophy.<sup>5</sup> Born in South Carolina, Baldwin had studied philosophy at the College of New Jersey (renamed Princeton University in 1896). Having finished his Bachelor's degree, Baldwin had travelled to Germany where he studied for a year in several psychological laboratories.<sup>6</sup>

During his travels, he had visited the laboratory at the University of Leipzig run by Wilhelm Wundt (1832-1920) a figure widely considered to be the founder of experimental psychology. Baldwin subsequently returned to New Jersey where he completed his doctoral thesis. Before coming to the University of Toronto, he had taught German and French at Princeton and, beginning in 1887, had worked as a professor of philosophy at Lake Forest College in Illinois.<sup>7</sup>

The renovations that followed a disastrous fire, which gutted much of the University College building in February 14, 1890, likely made it easier for Baldwin to obtain space for teaching and experiment. By the spring of 1891, Baldwin had been allocated \$1,100 to equip a laboratory. He described the new space in the pages of *Science*, as "the first in the British Dominion as far as my information goes," though a temporary laboratory had previously been established by one of Wundt's former students, the American James McKeen Cattell (1860-1944) in the Cavendish Physics Laboratory of the University of Cambridge in 1887.<sup>8</sup>

The University of Toronto Psychological laboratory, like other newly founded laboratories across North America, was stocked with German-made instruments. For example, the Hipp Chronoscope, a precision timing instrument, made possible the measurement of reaction time and consequently formed the centrepiece of the early psychological laboratory. Wundt's early experimental program, focussed on timing reactions to various sensory stimuli, was fundamental to establishing the methodology and material culture of the new discipline.<sup>9</sup> Throughout the early development of experimental psychology, local manufacturers, such as the Zimmermann workshop in Leipzig, transformed the instruments developed by Wundt and his students into commercial objects that supplied the new laboratories.

This technology typically demanded considerable skill and experience to operate. In 1893, on the advice of contacts in Germany, Baldwin hired August Kirschmann, then a key figure in Wundt's laboratory. As Wundt's assistant, Kirschmann had largely controlled the laboratory's day-to-day operations, and, in that capacity, had explored key apparatus.<sup>10</sup> In 1892, for instance, Kirshmann, along with his colleague and collaborator, Oswald Külpe (1862-1915) had published a paper on the calibration of the Hipp Chronoscope.<sup>11</sup> Kirshmann's students in Toronto used this timing equipment, along with kymographs and other apparatus, to measure the estimation of time intervals and to explore the rhythms of poetical meter.<sup>12</sup>

The technology of disc mixture was especially important to the research that took place in Kirschmann's laboratory. Kirschmann had worked with this technology to a considerable extent in his graduate research at Leipzig during which he had studied the phenomena of simultaneous optical contrast.<sup>13</sup> Among the most important instruments of this type was the Marbe apparatus, introduced around 1894 by Karl Marbe (1869-1953) of the University of Würzburg. Marbe's apparatus (improved using a new



mechanism developed by O. Lummer and E. Brodhun in 1896) gave the experimenter control over the relative proportion of two sectors of a spinning disc. This allowed the operator to fluidly change the blend of colour without having to stop the instrument, and, consequently, to obtain more precise judgements from the subject. The Marbe apparatus was used extensively in Kirschmann's laboratory.<sup>14</sup>

Kirschmann's arrival in Canada consequently represents the parallel exchange of people that accompanied the exchange of instruments. Wundt directed 186 theses over his career, training a generation of expert technicians and researchers who spread the instrumental practices of experimental psychology.<sup>15</sup> The University of Toronto was one of many institutions eager to assimilate this novel product of the much-admired German university research system.

Kirschmann, who, upon his arrival in Toronto spoke little English, was hired to assist the well-established American. However, by the time Kirschmann had accepted the offer of a position as a "Lecturer and Demonstrator of Philosophy", Baldwin had left for a better paying position at his alma mater, Princeton. Baldwin's departure meant that Kirschmann was obliged to perform the role of a professor and a demonstrator while being paid a lecturer's salary. He was not promoted to Associate Professor until 1899. Even then his salary remained relatively low.<sup>16</sup>

Kirschmann's position in Toronto notably permitted him to develop new apparatus building on his earlier work in Germany. It also provided a specialised space in which to work. In the period before his departure, the University of Toronto psychological laboratory had been established according to the conventions, developed under Wundt in Germany, which would have become familiar to those, like Baldwin and Kirschmann, who had spent time in the early psychological laboratories.<sup>17</sup>

### Light and Dark Spaces

When Kirschmann arrived in Toronto, he would have found a recently equipped laboratory space that had been consciously developed to permit the investigation of visual perception. The space in which an experiment took place and its lighting was typically mentioned as part of the experimental apparatus in the published accounts of

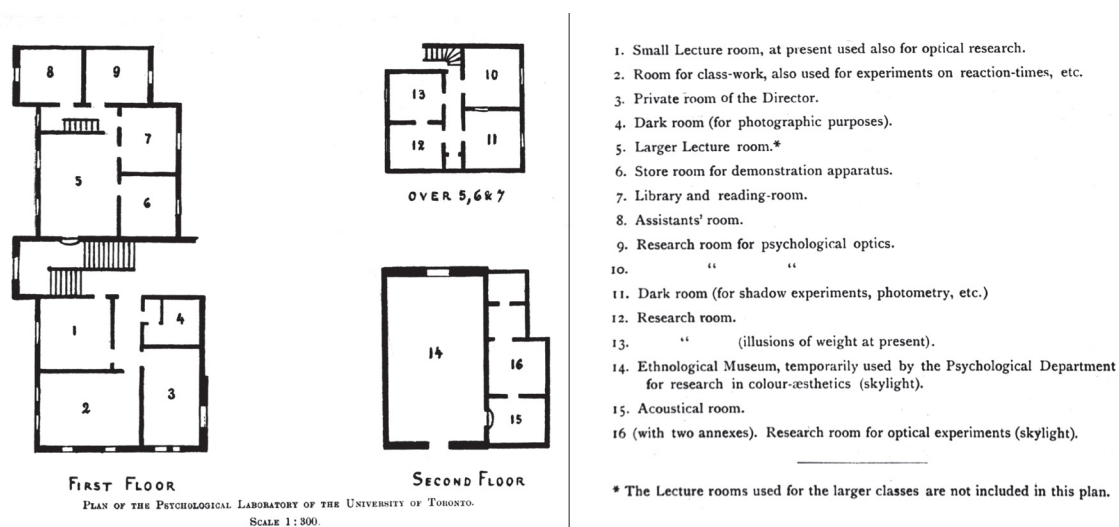


Figure 5. A map of the Psychological Laboratory circa 1900. It is adapted from August Kirschmann, ed., *University of Toronto Studies: Psychology Series*, Vol. 1, (1900), i-iii..

Kirschmann's students. In an early description of the psychological laboratory, published in 1892, James Mark Baldwin had noted:

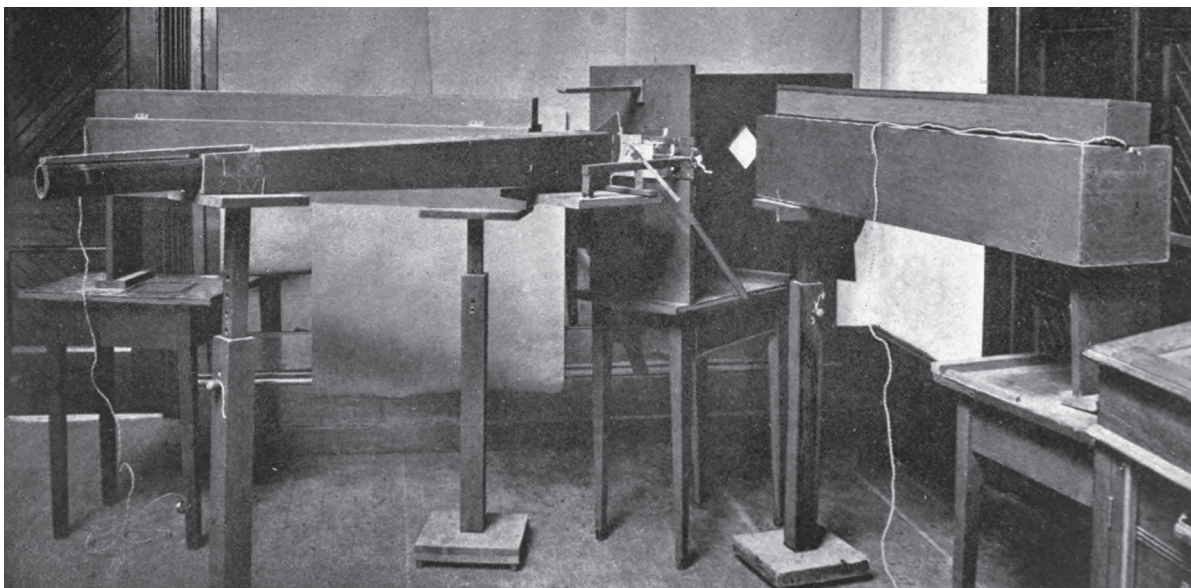
The work-tables of the research rooms (II. And III.) get light from the east, south, and west, a variety of which is of great value, especially as the east exposure (Room III.) has reflected light from the walls of the main building (this is also partly the case with the light from the west windows, Rooms I. and II.). The rooms are artificially lighted by a combination of gas and electric chandeliers from the ceiling, and have besides movable incandescent lamps over the work-tables. The dark room is also furnished with incandescent lights...The walls and ceilings are finished in dull white and the woodwork in dark walnut, colors being avoided in order to keep the physiological conditions of sight normal. Natural and colored light can be let into the dark room through the south wall. The central hall is lighted through glass panels in the doors.<sup>18</sup>

Throughout Kirschmann's tenure, spaces lit by natural light provided the brightest illumination, which made it possible to study the full range of colour vision. Following Kirschmann's arrival, he secured the use of several new rooms, including a space on the top floor of the University College Building (the old ethnological museum) possessing skylights (**Figure 5**). This large and sunny room was used for investigations of aesthetic judgement using pigment colours.<sup>19</sup> A nearby annex housed an elaborate apparatus for presenting colour (**Figure 6**).

Among the important areas of exploration for early investigators of vision was the phenomenon of "Purkinje:" the eye's differing sensitivity to different colours under varying levels of illumination.<sup>20</sup> Quantifying this phenomenon promised insight into the fundamental mechanisms of colour vision. One such experiment, carried out under Kirschmann's supervision, involved the use of the Marbe colour mixer made by Zimmermann shown (see **Figure 4**).

In this case, the instrument was set up with a ring of coloured paper surrounded by black and white sectors attached to the instrument's variable mechanism. The operator adjusted the proportion of white to black until the subject perceived the grey and the coloured ring to be of the same intensity. Ambient light was adjusted by placing sheets of translucent tissue paper over a window opening. Up to 60 sheets were used to reduce a small square of window opening from full daylight to the lowest visible intensity.<sup>21</sup> In the associated tables giving the angle of the black and white disk sectors relative to the level of illumination, the lighting conditions were described as ranging from "Very Bright" to "Dull and Hazy." Difficulties included the ambiguity of matching the intensity of coloured and uncoloured light and the inconsistencies in illumination that resulted from periods of intermittent cloud.<sup>22</sup>

Kirschmann also developed a second apparatus for studying variable illumination. In this case, the window opening was reduced to two points of light, each about one inch in diameter. One of these was covered with a combination of gelatine filters to create a colour of relatively narrow spectral band. In front of these openings was placed a locally made instrument incorporating the variable mechanism of the Marbe apparatus. Rather than shifting differently coloured sectors, this varied the size of two openings in a blackened disc. Just as one can perceive the space beyond the blades of a spinning fan, the proportional blend of a darkened-disk surface to open space produced a field of varying opacity, or, to put it another way, reduced the level of light reflected from a source according to the proportion of void to disk. The instrument was a "double episcotister," a version of a common optical instrument.



*Figure 6. Kirschmann's apparatus for presenting colour.*

The two points of light admitted through the small window openings were layered with tissue papers until they appeared to match in brightness when viewed through the disc of the fully opened spinning episcotister. When the size of the wheel's opening was incrementally decreased, the Purkinje effect could be observed through the perceived difference in the intensity of the two lights as indicated by the adjustment in the number of tissue layers needed to again make them match.<sup>23</sup>

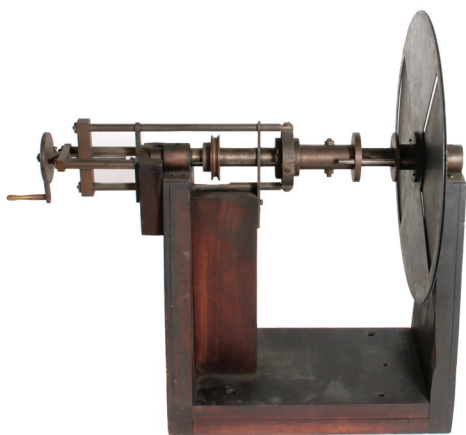
### **The Material Culture of Colour**

The experiments of Kirschmann and his colleagues reveal a shifting material technology of colour. Traditional dyes and pigments—such as indigo, graphite, and India ink—appear alongside newer products, for instance gelatine sheets, dyed with synthetic aniline colours, developed initially to tint the coloured lights of the theater. Such materials were studied using the spectroscope since it was by then understood that pigments, which appear similar to the eye, might have very different physical properties.<sup>24</sup> Kirschmann was critical of earlier researchers in this area who had lacked a sophisticated understanding of the nature of colour or the properties of their materials.<sup>25</sup>

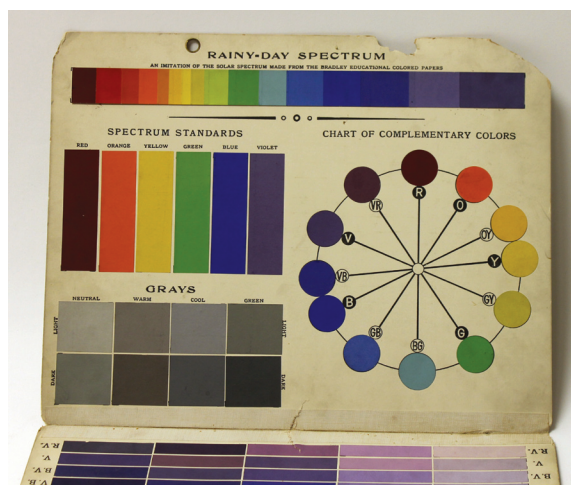
Kirschmann's graduate work had involved recently developed technology that could provide near-monochromatic colour stimulus for experimental purposes.<sup>26</sup> In 1891, while working at Wundt's laboratory in Leipzig, he had published a paper on a practical means of obtaining such colours by layering gelatine sheets and/or coloured glasses with different absorption properties. Transmitted light from back-lit transparent surfaces could also be employed in darkened spaces free from unwanted visual stimuli.<sup>27</sup>

No internationally recognized colour standard existed at this time, though several companies (notably Milton Bradley, Prang, and the Hering laboratory) provided colour sets meant to represent increments along the visible spectrum as well as the complements of these colours.<sup>28</sup> When an experiment required the presentation of several colours at once, there was little practical alternative to the use of pigmented papers. This technology was far from perfect. Pigmented cardboards could fade over time, and at different rates, making it difficult to achieve consistent results.<sup>29</sup>





**Figure 7.** A double episcotister incorporating a variable opening made at the University of Toronto (2016.psy.161).



**Figure 8.** Part of the Milton Bradley colour chart in the UTSIC Collection (2013.psy.142).

Such material typically required a high degree of knowledge, preparation, and adjustment before it could be applied to experimental purposes—a kind of shared tactile expertise that one sees communicated throughout experimental accounts related to colour research. For instance, Edward Bradford Titchener (1867-1927) a student of Wundt and an important figure for developing experimental psychology in North America, cited his correspondence with Kirschmann on the preparation of Kirschmann's disk for representing saturation. (This disc is discussed below and shown in **Figure 10**.<sup>30</sup>)

Much as experimental psychology had required new instruments to produce an accurate measure of small time intervals, the subfield of colour research likewise demanded specialized technology in order to make quantitative measures of colour perception. Most fundamentally, these were instruments used to determine the relationships between colours as well as to measure pigment intensity. The precise properties of commercially produced sets of coloured cardboards could be verified, and, if necessary corrected, using the spinning wheel. Complementary colour pairs—hues of blue and yellow, for instance—produce the impression of colourless light (a shade of grey) when placed in the correct proportions as sectors of a spinning disk.<sup>31</sup>

Kirschmann and his students used the Zimmermann variable mixer, discussed earlier, to test the accuracy of the Prang and Milton Bradley colour cardboards (**Figure 8**) by checking whether the complementary colours could produce a colourless grey. They determined, in both cases, that few of the provided colours were perfect complements. To be used as such, the colours required the addition of a certain amount of a third colour—one important use of the colour wheel was to facilitate these sorts of corrections. A second variable mixer, set up with black and white sectors, could be used to determine the brightness of a colourless blend of two complements by matching both greys. The relative brightness of each pigment could be discovered mathematically once the values for several of these blends had been determined.<sup>32</sup>

Whereas historians have noted the impressive nature of the German manufactured instruments as a prominent feature of early experimental psychology, a number of Kirschmann's early material contributions were of simple construction. One experiment, described in an article published in 1892 in the *American Journal of Psychology*, was

essentially a tube offering a restricted view into a darkened closet in which white and dark cardboards, themselves illuminated, were presented to a viewer outside. Lacking visual context, the viewer could not distinguish black from white, but rather perceived shades of grey depending on how the cardboard was illuminated. This demonstration was meant to refute an aspect of the opponent theory of colour vision advanced by German physiologist Ewald Hering (1834-1918). Hering proposed that black and white, like the colour opponent pairs of red-green and yellow-blue which underlay the human colour sense, could be represented as fundamental and opposed sensations: as Kirschmann noted, no two colours could be mistaken for another under the same circumstances in which a black and white surface could be confused.<sup>33</sup>

In 1889, while still at Leipzig, Kirschmann had published a paper describing a similarly modest instrument. This was a photometer—an instrument meant to measure the intensity of light—which he used to calibrate his experiments. The Kirschmann photometer was part of an early generation of disk-based photometers. Like other photometers of similar vintage, and various other scientific instruments from pyrometers to hemometers, Kirschmann's instrument required the involvement of human vision and human judgement in order to determine the point at which an unknown signal appeared to match a known one.<sup>34</sup>

Kirschmann's photometer was like the episcotister described above insofar as it also involved a spinning wheel with a hole of adjustable size. In this case, the disk was made of white cardboard and the void opened onto a darkened cavity consisting of a blackened cardboard tube. By adjusting the angular proportion of the white disk surface to black void, the mix could be made to match a sample grey. The sample could then be assigned a numerical brightness value based on the proportion of black to white.<sup>35</sup> The photometer was immediately useful in demonstrating and quantifying, for instance, the significant differences among several black pigments that had previously been used interchangeably.<sup>36</sup>

That this photometer required only inexpensive materials and a simple colour mixer to operate meant that it was suited to classroom teaching. Simple colour wheels, such as the one shown in **Figure 1**, would have been widely available for student instruction. Titchener included Kirschmann's photometer among the apparatus needed to complete the experiments on contrast phenomena that he presented in the second volume of his seminal *Experimental Psychology: A Manual of Laboratory Practice*.<sup>37</sup>

The instrument's simple construction was also a limitation. It was difficult to set up, challenging to use, and even more difficult to maintain. Edwin G. Boring (1886-1968) a student of Titchener's, who had used his mentor's published teaching experiments in his own instruction, proposed improvements to its design in 1917. He noted that: "In general we have found that every pair of students requires a new set of disks, which take a couple of hours to prepare...The photometers are difficult to make, and soon get dirty. The samples of paper to be tested, even when accurately cut, are difficult to center and may be smudged in pasting."<sup>38</sup>

Kirschmann's position as the head of the psychological laboratory of the University of Toronto permitted him to construct new instruments of his own design. He had at his disposal both the space of the laboratory and the services of university technicians and workshops. His status at the head of the psychological laboratory permitted him to enlist graduate students in developing and operating equipment and in carrying out experiments.

### Local Apparatus, Local Community

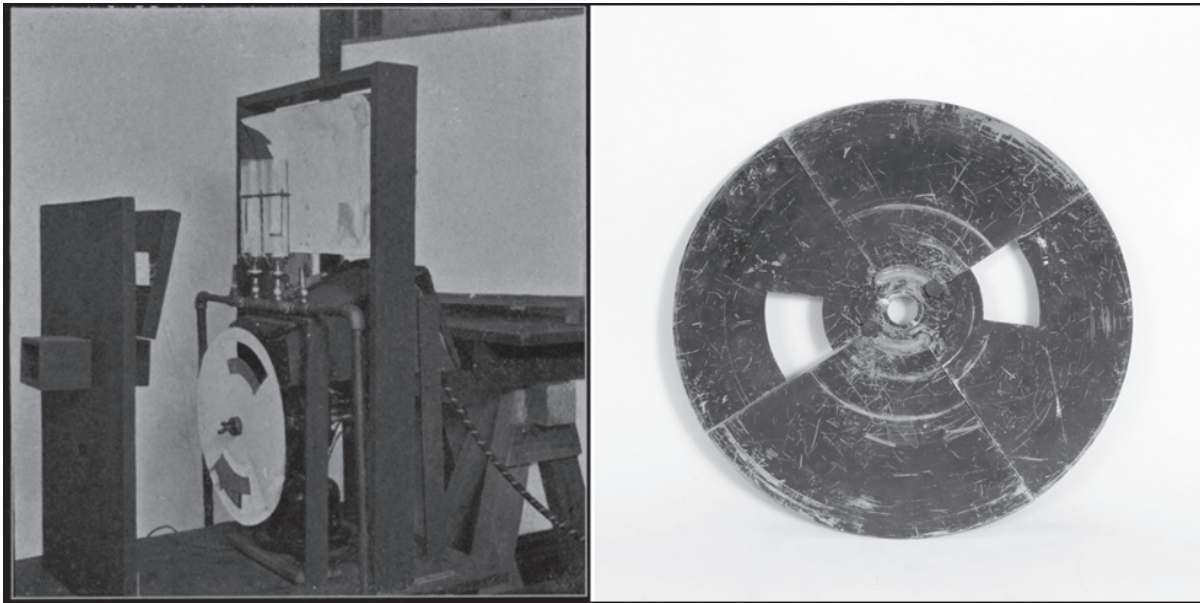
As head of the University of Toronto Psychological Laboratory, Kirschmann enjoyed several advantages. Given his initially poor knowledge of English, the experimental accounts written by his students provided a fluent voice through which to disseminate his ideas to the English-speaking world. To this end, he established a journal to publish and disseminate the experiments that he supervised. *The Psychological Series of the University of Toronto Studies* appeared in two volumes during his tenure. Its purpose was, in his words, “to inaugurate an exponent of psychological research in Canada, which has hitherto been without a representative publication.”<sup>39</sup> These volumes also provided a venue for his views on aesthetics which, among other purposes, served to highlight the broader relevance of this research. These essays, along with his publications in other journals, were likely edited by one or more student collaborators. It is also notable that Kirschmann appears among the co-editors of the *American Journal of Psychology* beginning with Volume 7 in 1895.

The community surrounding the laboratory may be glimpsed through the *Psychological Series*, especially where these papers describe the subjects involved in particular experiments. Experiments tended to fall into two broad categories, either studying several subjects closely to explore their perceptual abilities, or surveying larger groups to find regularities in aesthetic judgement. One of the latter involved around thirty observers, which included “professors, the wives of professors, and men and women students from the different departments of the University. There were also a few ladies not connected with the University.”<sup>40</sup>

Slater notes that “[t]o his lasting credit Kirschmann did not discriminate against women who wanted to do experimental or any other kind of academic work.”<sup>41</sup> A close study of the experiments in this laboratory would certainly shed light on the early situation of women within the experimental culture at an emerging research university. As noted below, Kirschmann’s female students tended to study the problem of aesthetics. It is also notable that, in those experiments which involved the close examination of the perceptual characteristics of a few subjects, only men were studied. Kirschmann himself was invariably a subject in all such investigations.<sup>42</sup>

Kirschmann’s time at the University of Toronto afforded him the workers and material resources necessary to develop and operate sturdier, more dependable apparatus. He, for instance, developed his photometer into a robust instrument with an integrated light source (**Figure 9**). This was a far more reliable calibration instrument than the cardboard version described by Titchener. Just as he had himself mastered the instruments used to calibrate the chronometer in Wundt’s laboratory, Kirschmann assigned a graduate student to carry out “photometrical measurements for various purposes” using this instrument. The improved Kirschmann Photometer, in operation by 1900, is described in a paper written by that student.<sup>43</sup>

A similarly elaborate apparatus, developed by Kirschmann at the University of Toronto, was used to present highly accurate fields of colour—a foreground field of precisely adjustable size against a background field (**Figure 6**). This was used in a number of experimental investigations by Kirschmann’s graduate students. The first of these, an investigation of colour threshold, determined the minimum size at which a given foreground colour became visible against a contrasting background colour. This was an early extension of Kirschmann’s graduate study of contrast. The apparatus was also used to explore the binary combinations of spectrally pure colours as part of an



**Figure 9.** Left: The Kirschmann photometer as used for calibration purposes in the psychological laboratory. The apparatus notably includes an illumination system using reflected light from gas Auer lamps. Right: A sturdy aluminum wheel (2016. psy.163) like the one visible in the image at left.

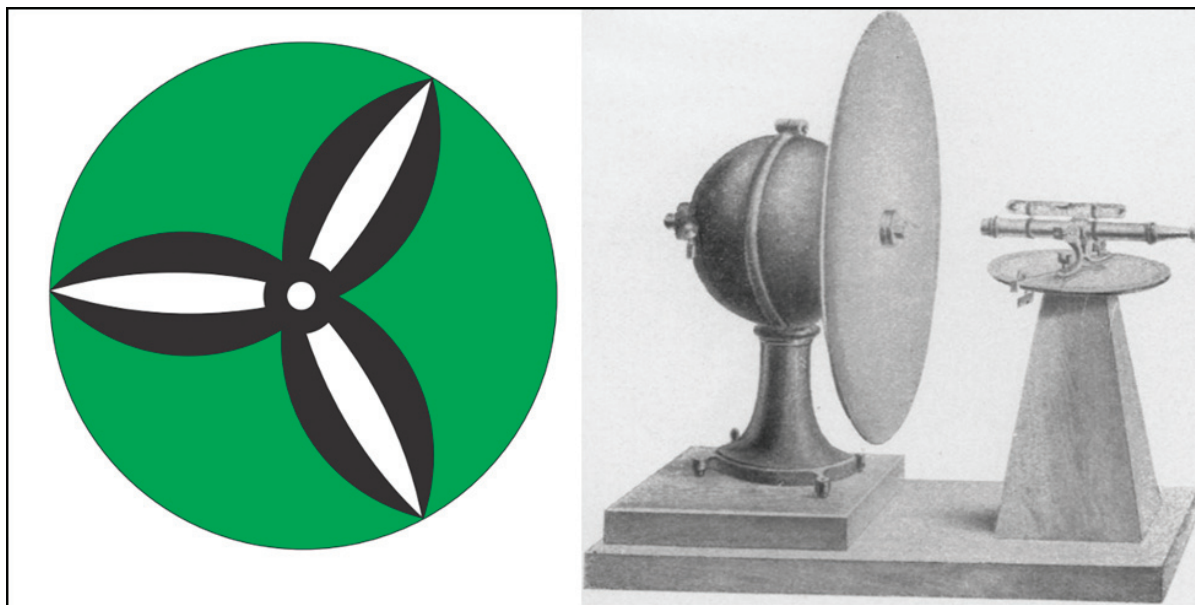
extensive investigation of aesthetic colour combinations.

The apparatus differed slightly in either investigation, though its basic configuration remained the same. A colour wheel was used to generate a colour in the further plane. A viewer, observing the colour through a viewing tube in a darkened room, observed this patch of foreground colour through a brass diaphragm whose opening could be precisely adjusted using a micrometer screw. On the surface of the diaphragm was pasted the background colour such that, when the diaphragm was closed, the observer saw a seamless field of colour, the foreground colour becoming visible as the diaphragm was opened. As the two colours were not necessarily equally reflective, their relative brightness could be adjusted by shifting the distance of two lights relative to foreground and background along enclosed tracks. Near monochromatic colours were produced by illuminating both pigmented surfaces using a series of colour filters placed in front of the respective light sources.<sup>44</sup>

There is a third significant apparatus that deserves mention. In 1896, Kirschmann published an article on colour saturation in the *American Journal of Psychology*. In it, he introduced a patterned colour disk which, when spun, would show a steady change in saturation across its surface, from a fully saturated colour to an uncoloured grey. This produced “a surface which would have in all its parts the same color-tone and the same light intensity and yet show differences in its appearance.” Its purpose was to prove the necessity of the concept of colour saturation, in addition to colour tone and brightness, to an account of colour.<sup>45</sup>

In the article, Kirschmann noted that a greatly enlarged version of this disk had been adapted for experimental purposes in his laboratory. A large colour disk was spun before a subject who observed a very small segment of it through the tube of a telescope which was set up to traverse laterally from the centre to one edge of the disk. Looking through the tube of the telescope, the observer would see a sufficiently small area of the disk to give the impression of a uniform colour. The telescope was then moved





**Figure 10.** The Kirschmann wheel (left) meant to show a constant decrease in saturation from edge to centre. Black and white combine to produce a consistent grey whose proportion increases relative to a colour. Right: An illustration of the wheel apparatus meant to explore the relevance of Weber's law to saturation

horizontally to another point on the disk and the observer was asked to return it to the initial point. Kirschmann hoped thereby to determine whether Weber's law—an important psychological law quantifying regularities in the perception of change—applied to the experience of colour saturation.<sup>46</sup>

Kirschmann's paper included an illustration of the apparatus. It also mentioned that a full experimental account would be published in the same journal. No such account appeared, nor is there any mention of such an instrument in the pages of the *Psychological Series*. No part of it has yet been discovered within the collection of instruments at the University Of Toronto Department of Psychology. The fate and nature of this locally made instrument, its makers, operators and its subjects, represent one of many important material questions whose answer awaits a closer investigation of the early psychological laboratory.

### The Aesthetics of Light and Colour

The aesthetic study of colour occupied the psychological laboratory throughout Kirschmann's tenure. This was closely related, in terms of experimental approach, to Kirschmann's longstanding interest in the problem of contrast. As experiments on simultaneous contrast had shown, the perception of colour depended profoundly on neighbouring colour, a fact that suggested strongly that colour comparison might reveal consistencies in the judgement of colour combinations.

Some of the earliest experiments carried out at the psychological laboratory sought to discover regularities in human preferences for certain colour combinations. Previous researchers had carried out experiments that presented subjects with colour combinations and subjected their choices to statistical analysis.<sup>47</sup> Others had proposed theories that explained human colour preferences. Canadian science writer Grant Allen (1848-1899) proposed, for instance, that the red-orange end of the spectrum was more pleasing than the blue-green because evolution had conditioned the human

species to search for fruit. He likewise maintained that similar colours were displeasing because they exhausted the eye. Neither claim was supported by the investigations of Kirschmann and his Toronto graduate students.<sup>48</sup>

Kirschmann's views on aesthetics formed the basis for several major projects carried out by his students during his tenure in Toronto. Such experiments tended to be carried out by women, who were well represented at the Toronto psychological laboratory, albeit primarily within this field of study. An early and important example is the research carried out between 1898 and 1899 by Emma S. Baker (1856-1943) one of at least three women who studied the problem of aesthetics during Kirschmann's tenure in Toronto.<sup>49</sup>

Published in 1900, Baker's paper was preceded by a long dissertation by Kirschmann on aesthetics. It also cited, and explicitly supported, Kirschmann's ten provisional aesthetic rules governing light and colour which he had presented in his course lectures at the Department of Philosophy.<sup>50</sup> It notably supported his conjecture that pleasant binary combinations are typically close to, but not exactly, complementary colours.<sup>51</sup> Baker's later experiments made use of the apparatus for colour presentation, depicted in **Figure 6**, which permitted her to verify her earlier experiments that had relied on coloured cardboards. Subsequent experiments pushed this research beyond the realm of fully saturated colours by including uncoloured light and combinations of saturated colours with tints and shades.<sup>52</sup>

Such research into aesthetics was particularly important to Kirschmann's role at the University of Toronto. He was, like many other early psychologists, working within a philosophy department. Aesthetics was a philosophical problem of longstanding importance. He not only believed that laws governing the human perception of beauty could be empirically determined, but also that a rational understanding of these laws would lead to a renovation in the way that art was understood and adjudicated. In an essay on aesthetics, published in the *Psychological Series*, he railed against the imprecise language of art criticism:

All expressions used in aesthetic and art-criticism which can not, unambiguously and without contradiction, be defined in terms of really simple elements.... are nothing but pseudo conceptions; and all distinctions and classifications into which such expressions enter are illegitimate or pseudo-distinctions; and all alleged knowledge based on such conceptions and distinctions is sham-knowledge; and if the originators and propagators adhere to such expressions after they have realized the truth of what is said above, it is not only sham-knowledge, it is then imposition, deception, fraud.<sup>53</sup>

His opinions on artistic representation reveal a bracing literalism founded in his scientific understanding of the material nature of pigments and light:

By cleverly making use of [the law of contrast, the painter] may even raise the intensities of very small, white, yellow, or orange surfaces so as to give the appearance of a certain luminosity, as for instance, in the case of glowing coals and sparks of a smith's fire, the illuminated windows in an evening landscape, the Alpine glow, etc. But he should never try to paint the flames of candles, lamps, or torches themselves, or the celestial bodies, for this is, with respect to true reproduction of intensities, absolutely impossible.<sup>54</sup>

A final object—one apparently developed by Kirschmann himself—evokes this aesthetic side of his research and teaching. First produced by the Zimmermann workshop at some point between 1894 and 1903, the "Farbenmisch-Apparat nach Kirschmann" ("Colour mixing apparatus after Kirschmann's design") is a curious

instrument that was first produced during Kirschmann's time in Toronto.<sup>55</sup> Working on the familiar colour-wheel principle, the instrument uses two coaxial wheels, the first presenting a rainbow of coloured segments, the second, one of several "masking wheels," containing patterns of holes through which the colour wheel is partly visible. The two wheels are spun using pulleys of slightly different diameter with the result that the openings of the masking wheel progress across the surface of the colour wheel while both are spinning. This presents a striking pattern of changing colour whose appearance depends on the masking wheel used.

The colour mixing apparatus bears comparison to the Marbe variable-colour wheel. Both were manufactured by Zimmermann and sold internationally. Both were conceived within the context of German laboratories. However, whereas the colour variator is an experimental instrument, the colour-mixing apparatus is intended to demonstrate lovely patterns resulting from the eye's perception of a complicated colour stimulus.<sup>56</sup>

### Conclusion

In 1909, during a return visit to Germany which amounted to a research sabbatical, Kirschmann fell ill. He was never to return to his post in Toronto. In his absence, the psychological laboratory within the Department of Philosophy entered a period of decline during which it was staffed by underpaid former graduate students of Kirschmann. Psychology was finally separated from the Department of Philosophy in 1920.<sup>57</sup>

To historians of science, Kirschmann is largely a forgotten figure. His name does not appear, for instance, in several historical surveys of colour theory, vision, and photometry.<sup>58</sup> On the other hand, an internet search of scholarly material reveals that his research—particularly his early work on colour contrast—has been well cited by researchers in the areas of vision research, neurophysiology, and experimental psychology. This disparity belies his status within the community of early experimental psychologists; his cosmopolitan career and place among the (often imported) scholars who founded the Canadian research tradition; his technological contribution to a vital, emerging field of research; and the insight that his views on science and aesthetics contributed to the then-uncertain place of early experimental psychology. Kirschmann deserves more attention than he has received.

There remains a great deal more to be learned about the experimental work done during the early period of the University of Toronto psychological laboratory under Kirschmann. Such an examination requires a continued survey of the material remaining at the Department of Psychology, especially numerous heretofore unidentified pieces of apparatus. It also demands a deeper investigation of the relevant archival material at the University of Toronto Records and Archives Service, particularly student notebooks and records relating to equipment purchases and commissions from local workshops. This further research promises a deeper understanding of the movement of experimental technology beyond established centres in Germany, as well as between commercial ateliers and university workshops.

Further investigation is also needed to delineate the particular characteristics of this early material culture of colour research. One element, notable in all emerging scientific fields, is the fabrication and development of apparatus, the spread of this technology, and the eventual emergence of standardized manufactured instrumentation. The particular characteristics of the early stages of colour research involve the development and calibration of accurate colour, as described above, but it also centers on a "visual





Figure 11. A lantern slide version of Kirschmann's *Farbenmisch-Apparat* that survives in the Department of Psychology collection (2015.psy.160).

tradition" that depended on the eye and judgement in operating the apparatus used to obtain experimental results about the visual system. This human element distinguishes this early stage of instrumentation and instrumental skill from subsequent periods, which depended increasingly on photoelectric detectors independent of the human senses. This shift involved debates about the reliability and training of the human eye and operator that deserve further study in this context.<sup>59</sup>

The material approach to early colour research permits a longer view of this technological evolution. Research collections, such as the University of Toronto Scientific Instruments Collection, permit us to study the development and dissemination of the photometric practices and technologies that emerged from fin-de-siècle psychological research. At the University of Toronto, for instance, research and demonstration equipment related to psychology, physics, and engineering psychology include later 20th century photometers, monochromators, and CRT screens, which represent the gradual mastery of calibrated colour.

Perhaps most useful would be a closer study of Kirschmann's students and their career trajectories before and after their time in his lab. What drew these young, affluent Canadians to this new and foreign experimental program that had recently taken root in the Department of Philosophy? Where did their studies take them? What accounts



for the notable participation of women and their conspicuous engagement with the study of aesthetics?

What is clear thus far is that the technology and culture of the visual landscape was changing along with the language and ideas used to represent it. Kirschmann's explicit belief that the reasoned use of technology would transform the world of art and colour invites us to the sorts of ahistorical comparisons that we might otherwise avoid. A century later, the human visual system is well understood, and the technology exists to analyse and reproduce colour with extreme accuracy, practically on demand. The artifacts representing Kirschmann's laboratory permit us to look back to a point over a century ago at which that process of transformation was gathering pace at an expanding network of laboratories. At that point, the cultural implications of the approaching scientific mastery of colour were not yet clear.

*This paper is dedicated to Dr. Trevor Levere, a mentor to me and many others.*

*Erich Weidenhammer completed his PhD in 2014 at the Institute for the History and Philosophy of Science and Technology of the University of Toronto on the Scottish physician and natural philosopher John Pringle (1707-1782). He is currently curator of the University of Toronto Scientific Instruments Collection (UTSIC.org).*

## Endnotes

- 1 The most complete account of Kirschmann's career in Toronto remains the chapter entitled "The Emergence of Psychology" in John G. Slater, *Minerva's Aviary: Philosophy at Toronto, 1843-2003* (Toronto: University of Toronto Press, 2005) 172-188.
- 2 Sean F. Johnston, *A History of Light and Colour Measurement: Science in the Shadows* (Bristol: Institute of Physics Publishing, 2002) 126-128; Xian Chen, *Instrumental Traditions and Theories of Light: The Uses of Instruments in the Optical Revolution* (Norwell, MA: Kluwer Academic Publishers, 2000) 121-124.
- 3 Chris Otter, *The Victorian Eye: A Political History of Light and Vision in Britain, 1800-1910* (Chicago: The University Press of Chicago, 2008) 182-187.
- 4 Susie A. Chown, "Combinations of Colours and Uncoloured Light," in *University of Toronto Studies. Psychological Series. Vol 2.*, ed. August Kirschmann (Toronto: University of Toronto, 1907) 87-89.
- 5 For an account of the complicated process through which Baldwin was chosen for the position over a rival Canadian candidate favored by a "nativist" faction within the university and community, see Christopher D. Green, "The Hiring of James Mark Baldwin and James Gibson Hume at the University of Toronto in 1889," *History of Psychology* 7, 2 (2004) 130-153 and Chapter 4 of Slater, *Minerva's Aviary*, 139-167.
- 6 James Mark Baldwin, *Between Two Wars, 1861-1921 being Memories, Opinions, and Letters Received. Vol. 1* (Boston: The Stratford Company, 1926) 32-36.
- 7 Slater, *Minerva's Aviary* 168-169.
- 8 Thank you to Dr. Christopher Green for this anecdote.
- 9 David K. Robinson, "Reaction-time Experiments in Wundt's Institute and Beyond," in *Wilhelm Wundt in History: The Making of a Scientific Psychology*, eds. Robert W. Rieber and David K. Robinson (New York: Kluwer Academic/ Plenum Publishers, 2001) 161-163.
- 10 James McKeen Cattell, "The Psychological Laboratory at Leipsic," *Mind* 13, 49 (1888) 39.
- 11 Oswald Külpe and August Kirschmann, "Ein neuer Apparat zur Controle zeitmessender Instrumente," *Philosophische Studien* 8 (1893) 145-172. The Control Hammer and Gravity Chronometer, both used to calibrate the Chronoscope, survive as testimony to the University of Toronto lab's early history.
- 12 M. A. Shaw and F. S. Wrinch "A Contribution to the Psychology of Time," in *University of Toronto Studies. Psychological Series. Vol 1.*, ed. August Kirschmann (Toronto: University of Toronto, 1900) 105-154; A. S. Hurst and John McKay, "Experiments on Time Relations of Poetical Metres," in *University of Toronto Studies. Psychological Series. Vol 1.*, ed. August Kirschmann (Toronto: University of Toronto, 1900) 155-176.

- 13 Simultaneous contrast is a phenomenon in which the appearance of a particular colour is influenced by the presence of another colour. One of his students defined this field as phenomena of simultaneous contrast as including “all such phenomena as the modification in apparent size, colour, etc., which one visible surface exerts upon our visual impression of another surface at the moment of that impression.” The effect is most evident when the colours are compliments. “Kirschmann’s laws” on the subject appear in the final summary of Kirschmann’s thesis “Ueber die quantitativen Verhältnisse des simultanen Helligkeits- und Farben-Contrastes” (“on the quantitative relations of simultaneous brightness and color contrast”). This was published in 1891 in Wundt’s *Philosophische Studien*. The findings were presented the following year in “Some effects of Contrast” in *The American Journal of Psychology*. Kirschmann’s fourth law, which concerns the degree to which this contrast changes based on the saturation of a surrounding colour, seems to have drawn the most comment. A summary of publications on this topic is given in J. M. Bosten and J. D. Mollon, “Kirschmann’s Fourth Law,” *Vision Research* 53 (2012) 41.
- 14 R. J. Wilson, “On Colour-Photometry and the Phenomenon of Purkinje” in *University of Toronto Studies. Psychological Series. Vol 2.*, ed. August Kirschmann (Toronto: University of Toronto, 1907) 52-53; D. C. MacGregor and D. S. Dix, “The Complementary Relations of some Systems of Coloured Papers” in *University of Toronto Studies. Psychological Series. Vol 2.*, ed. August Kirschmann (Toronto: University of Toronto, 1907) 105-106.
- 15 Miles A. Tinker, “Wundt’s Doctorate Students and Their Theses 1875-1920,” *The American Journal of Psychology* 44, 4 (1932) 630.
- 16 See Slater, *Minerva’s Aviary* 174-175 for a discussion of Kirschmann’s academic rank and salary.
- 17 Baldwin, *Between Two Wars*, 32.
- 18 James Mark Baldwin, “The Psychological Laboratory in the University of Toronto,” *Science* XIX, 471 (1892): 143-144.
- 19 Chown, “Combinations of Colours,” 87-90.
- 20 The phenomenon of “Purkinje” was named for Jan Evangelista Purkyn (1787-1869) who observed that red flowers appear much more luminous in bright sunshine while blues and greens appear brighter in the lower light of morning and evening.
- 21 Wilson, “On Colour-Photometry,” 54.
- 22 *Ibid.*, 55.
- 23 *Ibid.*, 57. Though the episcotister was not described in detail, an instrument apparently matching its description survives in the Department of Psychology collection (see **Figure 6**)
- 24 August Kirschmann, ‘Ueber die quantitativen Verhältnisse des simultanen Helligkeits- und Farben-Contrastes’, *Philosophische Studien* 6 (1891): 466-467.
- 25 Wilson, 25.
- 26 August Kirschmann, “Ueber die Herstellung monochromatischen Lichtes,” *Philosophische Studien* 6 (1891): 543. The production of near monochromatic light using filters was investigated in the early decades of the 19th century by the Scottish polymath Sir David Brewster (1781-1868). See, Sherman, *Colour Vision*, 23. Another means of obtaining colours involved the mixing of refracted light. This method was developed by John Clerk Maxwell. It required complicated equipment, could only produce small patches of colour, and required a powerful light source. See Sherman, *Colour Vision*, 189-193.
- 27 Emma S. Baker “Experiments on the Aesthetic of Light and Colour: On Combinations of Two Colours,” in *University of Toronto Studies. Psychological Series. Vol 1.*, ed. August Kirschmann (Toronto: University of Toronto, 1900) 201-250.
- 28 The Milton Bradley system consisted of 18 colours; the Prang system, considered by Kirschmann to be more accurate, had 24; the coloured papers produced by Hering’s lab had 13. Wilson, 42; Baker, 218, 243; MacGregor and Dix, 105-107.
- 29 Edward B. Titchener, “Class Experiments and Demonstration Apparatus,” *The American Journal of Psychology*, 14, 3/4 (1903): 182.
- 30 *Ibid.*, 181-182.
- 31 Every homogenous colour can be paired with a second compound colour to produce the impression of colourless light, a phenomenon first explained and explored by the German polymath Hermann Günther Grassmann (1809-1877). See Paul D. Sherman, *Colour Vision in the Nineteenth Century: The Young-Helmholtz-Maxwell Theory* (Bristol: Adam Hilger Ltd., 1981) 96-101.

- 32 MacGregor and Dix, "Complementary Relations," 106.
- 33 Kirschmann, "Some effects of Contrast," 543-546.
- 34 The subsequent development of photoelectric cells removed the human visual system from photometric technology. See Johnston, 22-24, 126-128; Chen, 121-124.
- 35 Edward Bradford Titchener, *Experimental Psychology: A Manual of Laboratory Practice*. Volume II (London: Macmillan and co., 1905) 34-37. Photometry of colour could, around the turn of the century, be accomplished several ways, one of which was developed by Kirschmann in 1891 and used in the Psychological laboratory. See Wilson, "On Colour-Photometry," 47; August Kirschmann, "Ein photometrischer Apparat zu psychophysischen Zwecken," *Philosophische Studien* 5 (1893): 300.
- 36 Kirschmann tested black pigments including shades of pencil graphite, "China Ink," and "Paris black." W. B. Lane, "The Space Threshold of Colours and its dependence upon Contrast" in *University of Toronto Studies. Psychological Series. Vol 1.*, ed. August Kirschmann (Toronto: University of Toronto, 1900) 14.
- 37 Titchener, *Experimental Psychology, Vol 2*, 34-37, 66-67, 86, 89-90.
- 38 Edgar G. Boring, "II. Deboeuf Disks and the Kirschmann Photometer," *The American Journal of Psychology* 28, 2 (1917): 279-280.
- 39 August Kirschmann, "Introduction," in *University of Toronto Studies. Psychological Series. Vol 1.*, ed. August Kirschmann (Toronto: University of Toronto, 1900).
- 40 Baker, "Experiments," 221.
- 41 Slater, *Minerva's Aviary*, 180.
- 42 The wealth of experimental data pertaining to Kirschmann, compared to the relative poverty of archival records on him, raises the interesting possibility that we can know more about the characteristics of his visual system than we can about his years as a lecturer and mentor.
- 43 W. G. Smith, "Some Photometrical Measurements," in *University of Toronto Studies. Psychological Series. Vol 2.*, ed. August Kirschmann (Toronto: University of Toronto, 1907) 113-120.
- 44 Lane, 24-25; Emma S. Baker, "Spectrally Pure Colours in Binary Combinations," in *University of Toronto Studies. Psychological Series. Vol 2.*, ed. August Kirschmann (Toronto: University of Toronto, 1907) 28.
- 45 August Kirschmann, "Color-Saturation and Its Quantitative Relations," *The American Journal of Psychology* 7, 3 (1896): 396.
- 46 *Ibid.*, 401.
- 47 Baker, "Experiments," 210-211.
- 48 *Ibid.*, 207-208.
- 49 Baker, who graduated in 1903, went on to a career at the Ladies' College at Mount Allison University in Sackville, New Brunswick and later the Maryland College for Women in Lutherville, Maryland. For a biography and bibliography, see Corinne Smirle, "Profile of Emma Sophia Baker," in A. Rutherford (Ed.) *Psychology's Feminist Voices Multimedia Internet Archive*, 2012, accessed November 2, 2017, <http://www.feministvoices.com/emma-sophia-baker/> and P. K. Goraya, "Emma Sophia Baker: First PhD in psychology from the University of Toronto," (Unpublished Honours Thesis, York University, Toronto, 2008).
- 50 *Ibid.*, 215.
- 51 *Ibid.*, 247.
- 52 See: F. Louis Barber, "Combinations of Colours with Tints and with Shades," in *University of Toronto Studies. Psychological Series. Vol 2.*, ed. August Kirschmann (Toronto: University of Toronto, 1907) 167-186; F. Louis Barber, "Combinations of Colours with Tints and with Shades (Second Article)" in *University of Toronto Studies. Psychological Series. Vol 2.*, ed. August Kirschmann (Toronto: University of Toronto, 1907) 245-290.
- 53 August Kirschmann. "Conceptions and Laws in Aesthetic" in *University of Toronto Studies. Psychological Series. Vol 1.*, ed. August Kirschmann (Toronto: University of Toronto, 1900) 197.
- 54 *Ibid.*, 190.

- 55 Dating this equipment is challenging. The best and most accessible source is the digitized collection of Zimmermann catalogues published by the Max Planck. This collection is incomplete. Kirschmann's instrument is not listed in the 1894 catalogue and appears in the 1903 catalogue. It is therefore reasonable to assume that the instrument could have been conceived during Kirschmann's time in Toronto. See: E. Zimmermann, *Preis-Liste über psychologische und physiologische Apparate* (Leipzig, 1903) 4-5.
- 56 A second version of the instrument in the form of a lantern slide, which replaced the opaque segments of the coloured wheel with shards of transparent coloured gelatine, survives in the collection of the University of Toronto Department of Psychology. Given Kirschmann's departure in 1908, it is likely that this object was used in his lectures on philosophical optics. This object is damaged, its glass colour disk shattered. However the colour and arrangement of the surviving shards of gelatine have permitted the author to build a working model of the original instrument. E. Zimmermann, *Psychologische und Physiologische Apparate. Liste 25* (Leipzig-Berlin, 1912) 18
- 57 Slater, *Minerva's Aviary*, 182, 188-209
- 58 See, for instance, Johnston, *A History of Light*; Chen, *Instrumental Traditions*; Stephen Turner, *In the Eye's Mind: Vision and the Helmholtz-Hering Controversy* (Princeton, NJ: Princeton University Press, 1994); Paul D. Sherman, *Colour Vision in the Nineteenth Century: The Yonge-Helmholtz-Maxwell Theory* (Bristol: Adam Hilger Ltd., 1981).
- 59 Chen, *Instrumental Traditions*, 121-124; Johnston, *A History of Light*, 126-128.