Figure 8. Reputedly, the Argus is and was the most popular camera model ever made, selling more of this model than any single camera model, before or since during its heyday in the 1940's through about 1965. Digital cameras, eat your heart out.

My research has not determined whether Kodak used logarithmic formulae to calibrate these two slide charts/rules, or whether trial and error, and much field work determined the results. Wikipedia says that the *f*- stop identifies the diameter of the lens, and based on that, indicate the relative lens area (pi times radius squared), and when plotted, give the logarithmic scales. Please join me in enjoying a little Kodak nostalgia by admiring the "Kodaguide" and "Outdoor Filter Guide".

Figure 8. The Argus C-3 Camera
Note that the split image range finder/distance meter on the Argus C-3 reads in logarithmic scale distances.

The Aristo System Czerny Slide Rule for Thermal Radiation Calculations

Seán M. Stewart

Introduction

The growing number of technological applications from the early 1930s onwards that made use of the infrared portion of the electromagnetic spectrum slowly drew a steadily increasing number of applied scientists and engineers into the field of thermal radiation – the radiation emitted by a body due to its temperature alone. With obvious military applications, a field once of interest to only a small handful of scientists suddenly became an area of considerable technological importance. The elevation in status caused the field of thermal radiation to rapidly develop, generating an urgent need for simple calculating aids. Due to the cumbersome mathematical form the laws of thermal radiation require, calculations encountered in the field are particularly tedious. As high numerical accuracy for many applications was at the time not essential, a special purpose slide rule capable of providing quick, order-of-magnitude estimates would fulfil just such a need. The first tentative steps made towards converting this need into a reality did not come until late 1944 in war-torn Germany. In that year in one of the country's technical journals a short note appeared on a hand-built slide rule designed to aid its maker, the experimental physicist Marianus Czerny (1896–1985), perform many of the calculations associated with thermal radiation. The potential usefulness of Czerny's invention was immediately recognised and within a few short years a model based on his prototype was commercially available from Aristo, one of Germany's leading slide rule manufacturers of the day. Czerny's invention was a first-of-a-kind "radiation slide rule" and this specialized slide rule produced by Aristo based on his design we consider in this paper.

Blackbody Radiation

All objects emit radiation as a result of their temperature. The amount of radiation emitted increases as the temperature increases. The occurrence of very hot objects changing colour as their temperature increases is familiar to most. For example, a solid metal rod glows a dull red colour at a much lower temperature compared to when it glows a bright, yellowish-white colour. Knowing the body which emits the greatest amount of radiation compared to all other bodies at the same temperature is of considerable importance. Knowledge of such a body allows it to serve as the ideal theoretical standard against which all real radiating bodies can be compared and is known as a *blackbody*.

A blackbody is defined as a body that absorbs all thermal radiation incident upon it. The name given to the body is appropriate. Provided the body is not hot enough to appear self-luminous, because no radiation is reflected by the body, it appears completely black. Nor is any radiation lost by transmission through the body. The complete absorption of radiation by a blackbody holds true for radiation at all wavelengths and for all angles of incidence upon the body. In 1860 the German experimental physicist Gustav Robert Kirchhoff (1824–1887), following a simple yet brilliant line of physical reasoning, postulated that the radiation emitted at a given wavelength is a universal function for all blackbodies depending only on the temperature of the body [1]. For a blackbody in thermal equilibrium that means that all radiation received through absorption must be emitted if its temperature is to remain constant as there is no other mechanism available to the body to lose energy without a corresponding increase in its temperature. A blackbody therefore radiates more energy per unit time in any given wavelength interval and more total energy per unit time over all wavelengths than any other body at the same temperature. In relation to radiation slide rules, the radiation of black bodies, rather than their absorbing property, interests us.

Kirchhoff did not give the mathematical form of the universal function associated with blackbody radiation but suspected the form must be relatively simple. However, the universal character of blackbody radiation did ensure that the problem remained a very important one in need of a solution. Kirchhoff left the job of determining the final form to others. The task they inherited however proved far more difficult than even Kirchhoff himself had anticipated. Its solution, when finally found, shook the very foundations of physics and ultimately led to the development of a completely new branch of physics known as quantum mechanics.

By the close of the nineteenth century the exact mathematical form for the universal function of blackbody radiation continued to elude physicists. They had none-the-less established two important results relating to blackbody radiation. The first relates to the total energy emitted from the surface of a blackbody at temperature T per unit time per unit area in all directions into the half sphere above the surface. Known as the "total emittance" [2] and denoted by M, the equation is:

$$M(T) = \sigma T^4 \qquad (1)$$

Here the constant σ is known as the Stefan–Boltzmann constant and is named after Jožef Štefan (1835–1893) who deduced the law empirically in 1879 based on experimental data available at the time [3], and Ludwig Eduard Boltzmann (1844–1906) who deduced the result theoretically five years later using thermodynamical arguments [4]. In honour of both men's work the equation (1) is known today as the "Stefan–Boltzmann law."

The second important result from the late nineteenth century relates to the particular form Kirchhoff's universal function can take. Experimentally we knew that radiation emitted from a blackbody was spread continuously over a spectrum consisting of all wavelengths. The universal function of Kirchhoff's for a given wavelength λ could be identified with what is now known as the "spectral emittance" $M\lambda,T$. The quantity $M\lambda,T\,d\lambda$ corresponds to the amount of energy within a part of the spectrum given by the spectral range λ to $\lambda+d\lambda$ radiated into a hemispherical envelope in space, per unit time per unit area of the radiating body.

In 1893, using thermodynamic arguments together with a principle related to the change in wavelength a wave experiences as the wave moves relative to a source known as the Doppler Effect, Wilhelm Carl Werner Otto Fritz Franz Wien (1864–1928) deduced theoretically the important result [5]:

$$M(\lambda, T) = \frac{1}{\lambda^5} F(\lambda T) \qquad (2)$$

Wien showed that Kirchhoff's unknown universal function of two variables $M(\lambda,T)$ reduces to the determination of an unknown function F of a single variable λT only. To understand the significance of the result, this means that if $\lambda^5 M(\lambda,T)$ were to be plotted as a function of λT, a single spectral curve for the radiation from a blackbody results regardless of the blackbody's temperature. This universal curve is shown later in Figure 3. Known as "Wien's general displacement law" [6] it is an important property for blackbody radiation and is often used in the design of slide rules for such bodies. The special case of this general law is often cited. If $\lambda_{\max}$ is the wavelength at which $M(\lambda,T)$ has its maximum value, the peak in the curve is determined by a fixed value of λT, that is, by:

$$\lambda_{\max} T = b \qquad (3)$$

Here b is a constant and in this special form the law is known simply as "Wien's displacement law." The law derives its name from the fact that as the temperature increases, the peak in the spectral curve of $M(\lambda,T)$ plotted as a function of wavelength becomes "displaced" towards shorter wavelengths.

Despite what had been achieved by the close of the nineteenth century, the final form for the function $F(\lambda T)$ found in Wien's general displacement law continued to remain unknown. This is not to say that explicit forms for Wien's law had not been proposed. They had been, but under close experimental scrutiny all were found insufficient in one way or another in describing the radiation emitted from a blackbody for all wavelengths. The final solution required a conceptual break in how physics up until that time had conceived energy to be. In late 1900 Max Karl Ernst Ludwig Planck (1858–1947), by considering that the energy emitted from a blackbody is not continuous but rather discrete and only comes in amounts made up of multiples of some fundamental "quanta,", finally gave the correct mathematical form for $M(\lambda,T)$ valid for all wavelengths [7]. Now known as "Planck's law for blackbody radiation" the formula has held up to all subsequent experimental scrutiny. His law takes the form:

$$M(T) = \frac{c_1}{\lambda^5\left[\exp\left(\frac{c_2}{\lambda T}\right)-1\right]} \qquad (4)$$

The two so-called radiation constants c_1 and c_2 are made up of fundamental constants of nature [8]. The cumbersome mathematical form of Planck's law is apparent, and in an age before electronic computing devices, made it tedious and time consuming to work with.

In the application of thermal radiation to the solution of many physical problems, one must often know not only the spectral distribution of energy radiated from a blackbody as described by Planck's law, but also the total energy radiated by a blackbody into a certain wavelength interval. Because the spectral quantity $M\lambda,T\,d\lambda$ corresponds to the amount of energy radiated from a blackbody into a spectral range λ to $\lambda+d\lambda$, summing each of these spectral components over the complete spectrum, namely over all wavelengths from zero to infinity, gives the total emittance $M(T)$. Mathematically, summing infinitesimally small spectral components together amounts to a process known as integration. When this is done one finds:

$$M(T) = c_1 \int_0^{\infty} \frac{d\lambda}{\lambda^5\left[\exp\left(\frac{c_2}{\lambda T}\right)-1\right]} = \frac{\pi^4}{15}\frac{c_1}{c_2}T^4 = \sigma T^4 \qquad (5)$$

and is nothing more than the Stefan–Boltzmann law as already seen. On the other hand, the amount of energy radiated within a spectral band between the wavelengths λ_1 and λ_2 , if required, is found from:

$$M_{\lambda_1 \to \lambda_2} = c_1 \int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda^5\left[\exp\left(\frac{c_2}{\lambda T}\right)-1\right]} \qquad (6)$$

We return to the problem of calculating $M_{\lambda 1 \to \lambda 2}$ later, as this quantity is closely related to the principal scale found on the Aristo "System Czerny" radiation slide rule.

Marianus Czerny and his *Hilfsmittel*

Probably sometime in late 1943 or early 1944 Czerny held for the first time a modestly built slide rule of his own design and making. Initially he thought of his new tool as little more than a convenient aid (*Hilfsmittel* in German) to his work in infrared radiation. Designed to relieve him of the tedium associated with calculations involving blackbody radiation, his rule would not only become the basis for a specialized slide rule produced a few years later by Aristo, it would go on to inspire others to design similar but more advanced special-purpose slide rules for thermal radiation calculations.

By 1944 Czerny was already well known for his experimental work in the infrared [9]. For example, in 1929 he developed what he called "evaporography," a photographic technique for making heat radiation visible. From 1938 until the time of his retirement in 1961 he worked as a Professor of Experimental Physics, and later as Director of the Institute of Physics, at the Johann Wolfgang Goethe–Universität in Frankfurt am Main. As an experimentalist he did not fail to neglect the instrumental side of his work either. The attention and dedication he paid to this aspect of his work led to a number of important instrumental developments in the infrared, his radiation slide rule being one modest example.

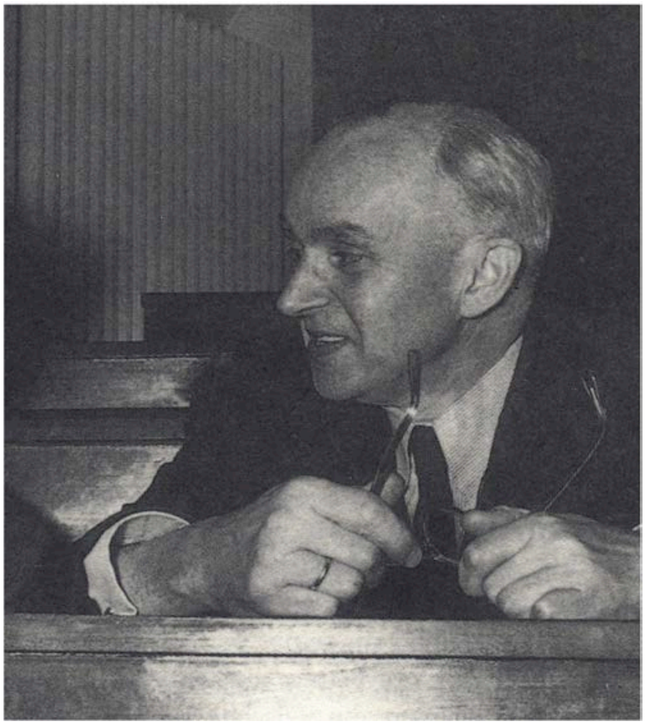


Figure 1. Marianus Czerny circa 1954

In the 1944 December issue of the journal *Physikalische Zeitschrift,* a short two page note appeared in which Czerny describes his rule for the first time [10]. The photograph of his rule, accompanying the note, is reproduced in Figure 2. He writes that due to the difficulty of not being able to integrate Planck's law in closed form over an arbitrary spectral wavelength range prompted him to design a slide rule for the sole purpose of solving this problem. What Czerny meant by not being able to integrate Planck's law in closed form relates

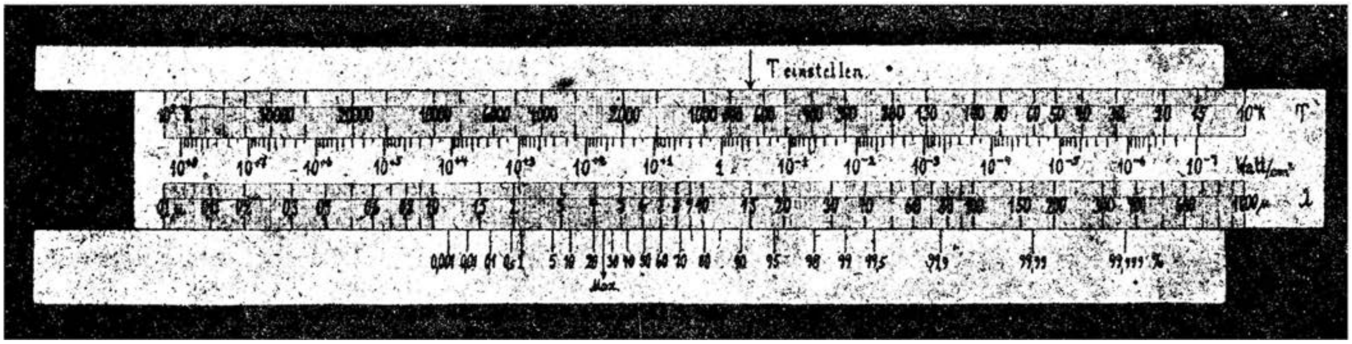


Figure 2. Czerny's hand-built radiation slide rule of 1944

to equation (6). Only when the limits of integration extend from zero to infinity, as in equation (5), can one perform the integration analytically. However, for the important case of finite limits, as in equation (6), integrating the expression and obtaining an answer expressible in terms of any of the known functions of mathematics is not possible. Instead one must use long and laborious numerical methods in order to find the numerical value to the integral.

Because equation (6) is related to the main scale on Czerny's rule, let us consider it in some detail. From properties of definite integrals, equation (6) can be re-written in the more convenient form of:

$$M_{\lambda_1 \to \lambda_2} = M_{0 \to \lambda_2} - M_{0 \to \lambda_1}, \qquad (7)$$

where,

$$M_{0 \to \lambda_\star} = c_1 \int_0^{\lambda_\star} \frac{d\lambda}{\lambda^5 \left[\exp\left(\frac{c_2}{\lambda T}\right) - 1\right]} \qquad (8)$$

The above integral gives the amount of energy radiated into a spectral band from zero up to some wavelength $\lambda_\star$ for a blackbody at temperature T. If the integral appearing in equation (8) is made dimensionless, the computation is more convenient. By doing so the integral becomes a number not dependent on any of the fundamental constants of nature and is achieved by making the substitution $x = c_2/\lambda T$. When this is done one obtains:

$$M_{0 \to \lambda} = \frac{15}{\pi^4} \sigma T^4 \int_z^\infty \frac{x^3}{e^x - 1} dx \qquad (9)$$

where $z = c_2/\lambda_\star T$. Finally, expressed as a fractional amount between zero and one, we arrive at the ratio:

$$\mathfrak{F}_{0 \to \lambda} = \frac{M_{0 \to \lambda}}{M(T)} = \frac{15}{\pi^4} \int_z^\infty \frac{x^3}{e^x - 1} dx \qquad (10)$$

These fractional amounts appear as one of the scales on Czerny's slide rule. They were tabulated by hand by Czerny with the help of a Mr. Kurt Schäfer who was presumably either one of Czerny's students or technical assistants at the time.

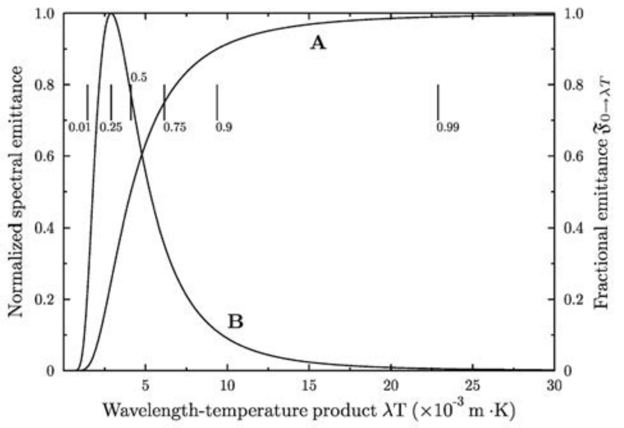


Figure 3.
Fractional Emittance (curve A) and Spectral Emittance (curve B) for a Blackbody as a Function of the Wavelength–Temperature Product

The result of the evaluation of equation (10) carried out numerically is given graphically as a function of the wavelength–temperature product in Figure 3. The result is the curve labelled **A**. The six short vertical lines appearing across the top of the plot indicate, from left to right, the fractional amounts 0.01, 0.25, 0.5, 0.75, 0.9, and 0.99 of the total emittance. The curve labelled **B** is a plot of the spectral emittance for a blackbody as a function of the wavelength–temperature product. Recall that a single universal curve is for blackbody radiation at any temperature. For convenience the curve has been normalized so its peak has a value equal to unity. Interestingly, the peak in the curve occurs for a fractional amount equal to 25%.

Czerny's rule is a relatively simple affair. It contains four scales, two gauge marks, and comes without a cursor. The rule appears to be of the open-frame type, though how the upper and lower stocks were held in place relative to each other as the slide moves is not clear, because, the rule has no end braces. Its dimensions and what it was made of are not given. Apparently all markings found on the rule are hand written. Running along the top of the bottom stock is the scale for the fractional amounts found numerically from equation (10). These are expressed as a percentage and run from 0.001 to 99.999%. The gauge mark "Max" on the bottom stock gives the fractional amount when the interval from zero up to the peak wavelength in the spectral curve as given by Wien's displacement law is considered. As noted earlier, this value is equal to 25%. On the slide a logarithmic temperature scale T, measured in Kelvin (K), from 10 to 10^5 K runs along the top and a reverse logarithmic scale for the wavelength λ, measured in micrometres (μm, though on the rule this unit appears simply as μ), from 0.1 to 1000 μm runs along the bottom.

Running through the middle of the slide is a scale for the total radiance $L(T)$. Radiance is a directional quantity and represents the part of the total emittance falling into a certain section in space. For a perfectly diffuse radiator [11] such as a blackbody, when the total radiance is summed over all possible space the radiation can be emitted into, namely over a hemispherical envelope above the surface of the body, the following formula yields the simple relationship between total emittance and radiance:

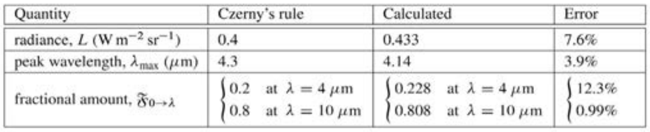
$$L(T) = \frac{1}{\pi} M(T) \qquad (11)$$

In this regard Czerny was unusual. Later radiation slide rules that appeared in England and the US always used the total hemispherical quantity $M(T)$ rather than the total directional quantity $L(T)$. The scale runs from 10^{-7} to 10^8 and is measured in watts per square centimetre (W/cm^2) [12].

Labelled "T *einstellen*" (temperature setting) on the top stock is the second gauge mark. In operation the slide was adjusted to the desired temperature by aligning the value of the temperature with the upper gauge mark. The total radiance could then be read off from the scale appearing in the middle of the slide. In making this reading the rule could have benefitted from being fitted with a cursor. At any selected temperature, the wavelength at which the spectral radiation curve peaks can be read off directly from the bottom gauge mark. The inverse of this calculation is also possible. Lastly, using the wavelength scale on the bottom of the slide in conjunction with the adjacent percentage scale on the bottom stock allows one to determine the fraction of the total radiance within the wavelength range from zero up to some arbitrary value for the wavelength λ.

Taking the setting shown in Figure 1 as an example, the temperature is seen to be set close to 700 K. At this temperature the total radiance emitted by the body is 0.4 W/cm^2 while the corresponding spectral radiation curve peaks at a wavelength of 4.3 μm. Finally we see, for example, that about 20% of the total radiance emitted by the blackbody at this temperature lies in the wavelength interval from zero to 4 μm while about 80% lies between zero to 10 μm.

Checking the accuracy of these values is made difficult by the fact that Czerny does not mention the values he used for the physical constants in calculating his scales. Probably, however, we are safe to assume that he used the latest known values at the time. These were the values of Raymond Thayer Birge (1887–1980). Announced three years earlier, Birge's values were widely adopted at the time [13]. A comparison between the values found above to those calculated using Birge's 1941 values for the fundamental constants, together with the size of the relative error in each (expressed as a percentage), are summarized in Figure 4. The two sets of values agree on order of magnitude. The error is within about 10% of the true value.



Quantity	Czerny's rule	Calculated	Error
radiance, L (W m^{-2} sr^{-1})	0.4	0.433	7.6%
peak wavelength, $\lambda_{\max}$ (μm)	4.3	4.14	3.9%
fractional amount, $\mathfrak{F}_{0\to\lambda}$	$\begin{cases} 0.2 & \text{at } \lambda = 4\ \mu\text{m} \\ 0.8 & \text{at } \lambda = 10\ \mu\text{m} \end{cases}$	$\begin{cases} 0.228 & \text{at } \lambda = 4\ \mu\text{m} \\ 0.808 & \text{at } \lambda = 10\ \mu\text{m} \end{cases}$	$\begin{cases} 12.3\% \\ 0.99\% \end{cases}$

Figure 4. Comparison between the Various Quantities Found Using Czerny's Rule to Those Calculated

Aristo's *System Czerny* slide rule

A small number of radiation slide rules were constructed by Czerny [4]. These were apparently used by his students and staff in his infrared laboratory at Frankfurt. Czerny's design served as a prototype for a rule later produced by Aristo. Due to the unique arrangement of scales on the rule compared to those found on a standard slide rule, the new arrangement was designated "System Czerny" after its inventor, a practice commonly used by Aristo for many of their specialized rules. The first rule of this type produced by Aristo was known as the *Rechenschieber für Temperaturstrahlung* (slide rule for thermal radiation) and appeared under a model number of 10048. Determining a date for the first appearance of the rule is difficult. For the Aristo brand five-figure model numbers beginning with 10 were assigned to special purpose slide rules between the years 1940 until 1958 [15]. As a point of reference the rule does appear in the Aristo catalogue of 1955 [16]. An earlier reference to it is, however, made in the 1951 text *Phyisk und Technik der Ultrarotstrahlung* by Dr. Werner Brügel [17]. Here a photograph of the rule accompanies a short description outlining how the rule was to be used. However, the most definitive source dating the availability of the rule to the late 1940s comes from a paper authored by Alfred H. Canada (1918–2002), an engineer who at the time was working with the General Electric Company. Inspired by Czerny, he was writing about his design for a radiation slide rule made for General Electric in the company's in-house trade journal *General Electric Review* [18]. Canada, as far as he was aware, correctly noted that specialized rules of this nature had been first proposed and produced in Germany and were, at the time of writing, available in the US from George Haas of Engineering Research and Development Laboratories at Fort Belvoir, Virginia. The publication date for Canada's article is December, 1948.

A photograph of the only specimen of the Nr. 10048 I have managed to locate is shown in Figure 5 [19]. The rule is from the private collection of Emeritus Professor William L. Wolfe and is of the closed-frame construction and is made of plastic, as all Aristo slide rules were from 1936 onwards. The four scales and two gauge marks are identical to those found on Czerny's original rule. An obvious improvement made by Aristo to Czerny's original design is the addition of a fixed plastic cursor placed over the gauge mark labelled "*Einstellen T*". For a given temperature setting this allowed the total radiance running centrally along the scale of the slide to be read with far greater accuracy. A centimetre scale from 0 to 28 is marked along the top of the rule. The addition of this scale had nothing to do with the operation of the slide rule and merely allowed the rule to double as a simple ruler.

On the specimen examined the word Aristo is nowhere to be found and this seems unusual for an Aristo produced rule. At the left end of the lower stock is a small oval trench. Interestingly, in this place the word Aristo does appear on the rule shown in Brügel's 1951 text so why it would be missing from Prof. Wolfe's rule is somewhat of a mystery. The rule came with a very brief two-page instruction manual [20]. Neither a name for the author nor the publisher of the instruction manual is given. Understanding how to use the rule was gained by following a simple worked example. The text in the manual appears to be hand typed while all formulae and Greek letters are hand written. An interesting feature of Brügel's text is the addition of a number of advertisements at the end of his book. Presumably these were targeted at those working in the infrared field. Surprisingly, one of these advertisements was for Aristo's *Rechenschieber für*

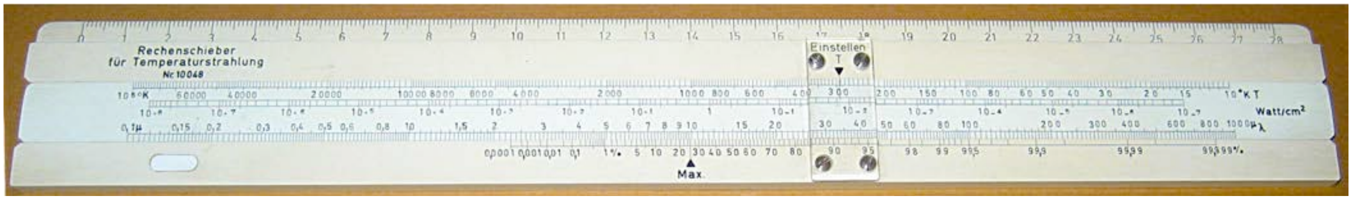


Figure 5. Front Face of the Aristo Nr. 10048 – Rechenschieber für Temperaturstrahlung from the Early 1950s

Temperaturstrahlung, shown in Figure 6, and suggests the rule was widely available by 1951.

ARISTO

verleiht
Überlegenheit

SONDER-RECHENSCHIEBER

FÜR TEMPERATURSTRAHLUNG

nach Prof. Dr. Czerny

DENNERT & PAPE • HAMBURG-ALTONA

Figure 6.
A 1951 Advertisement for the Nr. 10048.
The text reads: "Aristo confers superiority. A special purpose slide rule for thermal radiation by Prof. Dr. Czerny."

An updated version of the 10048 appeared in the late 1950s under the new model number of 922. Probably it became available either in late 1957 or sometime in 1958. The year 1957 represents a somewhat interesting transitional period for the rule. In the Aristo catalogue of that year the rule appears under the label "Aristo Nr. 922 – *Rechenstab für Temperaturstrahlung*" and is described as being 25 cm. long. Yet the catalogue photograph accompanying the rule is that of the 10048 except for two minor changes. At the left hand end of the top stock the former name of *Rechenschieber für Temperaturstrahlung* still appears, but the old model number of "Nr. 10048" has been removed, although the word "Aristo" now appears at the right hand end of the top stock. Also, the centimetre scale running along the top of the rule clearly indicates the rule is well over 25 cm. in length, contrary to the description given in the catalogue. Whether this transitional form was ever actually produced is doubtful. I suspect the 922, which in construction is a very different rule to the 10048, at the time the catalogue was prepared had not yet gone into production. Three years later we find the 922 being correctly depicted in the Aristo catalogue of 1960.

The Aristo Nr. 922 – *Rechenstab für Temperaturstrahlung* is a single sided open-frame rule. Made of plastic, it was 25 cm. long; a feature reflected in its new model number of 9*xx* as these numbers were usually assigned by Aristo to its full length linear slide rules from the late 1950s onwards. As previously mentioned, the assignment of model numbers 10*xxx* to special purpose rules ceased in 1958. More than likely the 922 first appeared in this year. The second edition of Brügel's text [21], published in 1961, contains an updated description of the rule and the accompanying photograph is for that of the more recent 922, again placing a helpful upper limit on when the 922 model became widely available.

Unlike the 10048, the 922 came with an adjustable cursor made of plastic which contained a single hairline. Printed in black on the cursor at the bottom and to the right of the hairline is the word Aristo. The number of scales and gauge marks remained unchanged, although the former use of longitudinal lines in the scales on the slide rule were removed. The positioning of an adjustable cursor running along the outer edges of the rule meant the rule no longer had an uninterrupted straight edge. Therefore, the former centimetre scale found on the 10048 is removed. In operation the 922 functioned in exactly the same manner as its predecessor. The adjustable cursor now allowed for more accurate fractional parts to be read for any arbitrary wavelength of interest.

As a further minor improvement to the rule, clear labels for each of the scales were added to the far left hand end of the rule. Vertically aligned, reading from top to bottom these were T, Q, λ, and W(z) for temperature, total radiance, wavelength, and fractional amount, respectively. Note the 922's symbols Q and W(z) correspond to the modern day symbols of L and $\mathfrak{F}_0 \rightarrow \lambda$ respectively. At the far end of the slide just in front of the right end brace, on three lines running vertically appears: Aristo, Nr. 922, MADE IN GERMANY. The Aristo logo was not used on either the 922 or the 10048. On the stock at the top left appears "*Rechenstab für Temperaturstrahlung*". Why the change in terminology used for slide rule from "*Rechenschieber*" (calculating slide) to "*Rechenstab*" (calculating stick) is not clear but possibly reflects a more general shift in term used by Aristo for all of their slide rules starting from the late 1950s onwards. Finally, the 922 came with a slightly longer four page instruction manual [22]. Once more, no name for the author or the publisher of the instruction manual is given. The directions for use, in the form of the same worked example as previously used in the instruction manual for the 10048, is now preceded by two brief sections discussing the laws of blackbody radiation and the scales used on the rule.

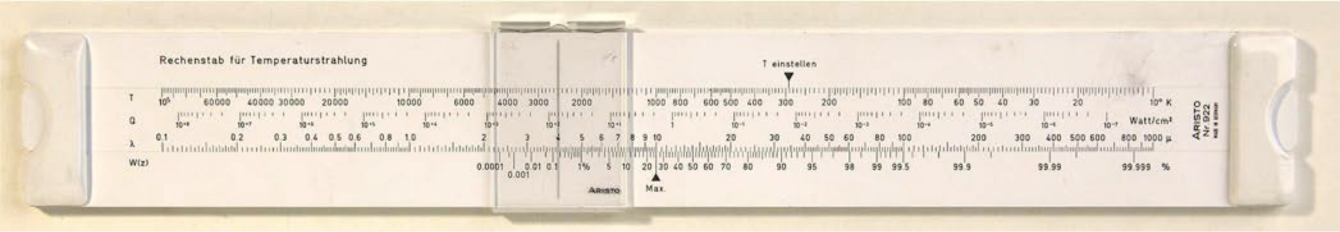


Figure 7. Front Face of the Aristo Nr. 922 – Rechenstab für Temperaturstrahlung from the early 1960s

Again the text appears to have been hand typed while all formulae and Greek letters are hand written.

A variety of end brace styles were used by Aristo on their open-frame rules [23]. The two specimens examined here had two different types of end braces. The first was a white, plastic, rounded end brace (Type 3 in Mosand's scheme). This type dates from approximately 1952 to 1964. The second type was a white, plastic, wedge-shaped end brace with "Aristo" embossed vertically across it (Type 6 in Mosand's scheme). This type of end brace was used on Aristo's rules from approximately 1971 right up until the end of the slide rule era in 1977. The two different types of end braces for each are shown in Figure 8.

Two specimens of the 922 are known to exist in public collections in Germany. The first is part of the Schuitema Collection [24] and is currently housed by Arithmeum in Bonn. The second is with the Deutsches Museum in Munich. A short description of the 922 has also been given by Giovanni Pastore in his *Antikythera e i regoli calcolatori* [25].

Adoption, Impact, and Conclusion

How widely the System Czerny slide rules produced by Aristo were used is difficult to assess. References to the rule in the technical literature are minimal compared to similar rules available later in England and the US. As noted earlier, Brügel gave short descriptions of both the Aristo 10048 and 922 in each edition of his text. Apparently, at least in Germany, the Aristo rule was the radiation slide rule of choice, because the rule likely remained in production right up to the end of the slide rule era. Writing in 1954, in a paper in which he reconsiders the integration of Planck's law of radiation over a finite wavelength band, Czerny points out the evaluation of such an integral had been given a mechanical form by means of his special purpose slide rule. Czerny's observation suggests that many still may not have been familiar with his rule [26]. The rule is also mentioned in *Ullmanns Encyklopädie der technischen Chemie* of 1960 [27], a widely read reference work that dealt with all aspects of the science and technology of industrial chemistry.

References to the rule in the English literature are somewhat more limited. In a 1955 review on the radiation emitted from the roof and walls of glass furnaces or other related industrial kilns, Wilhelm Eitel suggested instead of using tabulated data for the fractional function of Planck's radiation law, one could instead accomplish the same task using Czerny's slide rule [28]. In a book review for a recent collection of tables for the fractional function of Planck's radiation law from 1962 we find the reviewer, John N. Howard, writing the radiation slide rule produced by Prof.

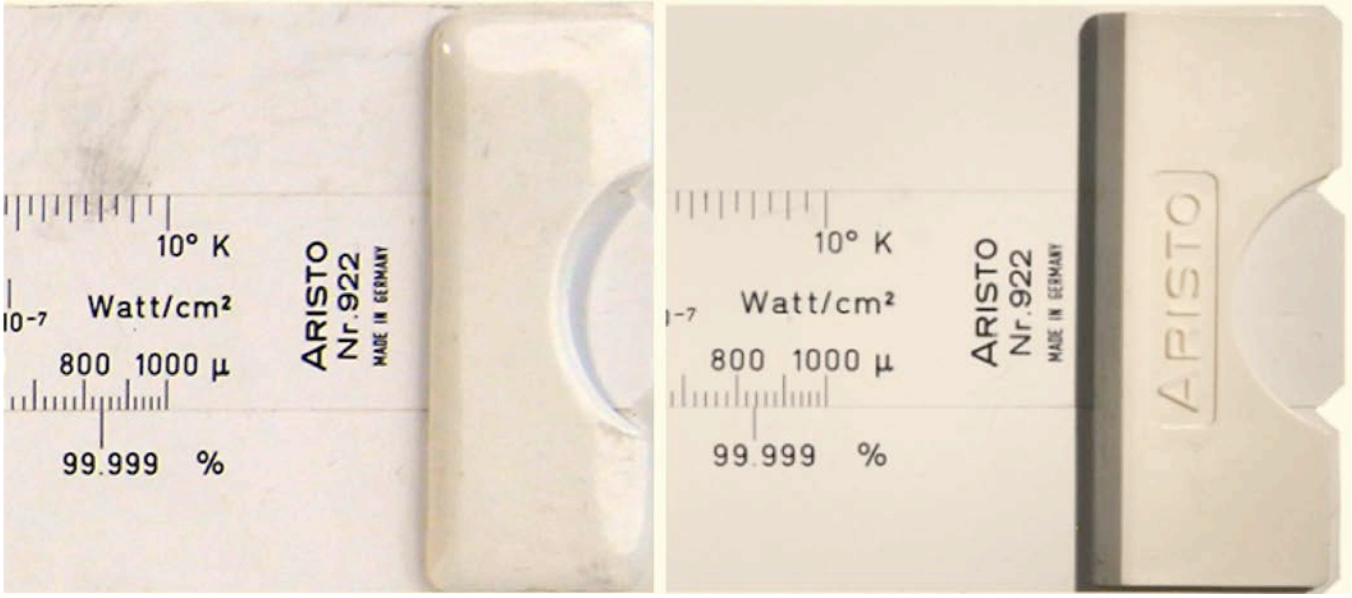


Figure 8. Example of Two Different End Braces for the Aristo Nr. 922

Czerny "… was useful for quick calculations." [29]. Richard D. Hudson in his 1969 text *Infrared System Engineering* [14] briefly mentions the Aristo 922 in a section devoted to a general discussion of the various slide rules available at the time for thermal radiation calculations. He manages to do this in two very short sentences and a footnote. Czerny's rule was also known to infrared workers in Russia, having been mentioned in the 1965 English translation of the 1961 Russian text *Tables for the Energy and Photon Distribution in Equilibrium Radiation Spectra* by P. A. Apanasevich and V. S. Aizenshtadt [30].

While the System Czerny rule seemed to remain a specialized slide rule used by relatively few outside of Germany, by far its most lasting impact is to be seen in the similar special purpose slide rules it inspired others to design. Two of these later rules in particular, one from England [31, 32] the other from the US [18], were widely adopted. Each became the definitive "workhorse" for a generation of engineers involved in infrared systems design and development. These two rules, together with several others, are to be the subject of future work.

Acknowledgements

I would like to thank Emeritus Professor William Wolfe who not only provided to me the photograph of the Aristo Nr. 10048 used here, but also patiently answered the many questions I had about the rule. I thank Nina Senger-Mertens from Arithmeum in Bonn who provided the photograph of the Aristo Nr. 922 from the Schuitema Collection. I thank Bruno Ferrighi for providing photographs of the 922 from his private collection and for sending me copies of the relevant pages relating to the Aristo 922 from Professor Pastore's Italian text. Finally, I thank Peter Holland for providing valuable background material and important leads on both the 10048 and 922 rules at the very beginning of my journey.

Notes and References

1. Kirchhoff, G., *Ueber das Verhältniss zwischen dem Emissionsvermögen und dem Absorptionsvermögen der Körper für Wärme and Licht*, Annalen der Physik und Chemie 109(2), 275–301 (1860). English translation: Kirchhoff, G., *On the Relation Between the Radiating and Absorbing Powers of Different Bodies for Light and Heat*, The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science (Fourth Series), 20(130), 1–21 (1860).

2. Radiometric terminology, that is the terms and symbols used to describe radiant energy, has a long and venerable history. A range of different terms and symbols have been proposed and used for many of the various quantities encountered in this field. All this makes for a very confused state of affairs, particularly for the uninitiated. In this paper we use presently accepted nomenclature for all radiometric terms. As an example of such confusion, in the past "emittance" has been referred to as either "exitance" or "emissive power" and the symbol W used.

3. Stefan, J., *Über die Beziehung zwischen der Wärmestrahlung und der Temperatur*, Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der kaiserlichen Akademie der Wissenschaften (Wien), **79**, 391–428 (1879).

4. Boltzmann, L., *Ableitung des Stefan'schen Gesetzes, betreffend die Abhängigkeit der Wärmestrahlung von der Temperatur aus der electromagnetischen Lichttheorie*, Annalen der Physik und Chemie, 22(6), 291–294 (1884).

5. Wien, W., *Eine neue Beziehung der Strahlung schwarzer Körper zum zweiten Hauptsatz der Wärmetheorie*, Sitzungsbericht der Königlich Preussischen Akademie der Wissenschaften zu Berlin, 55–62 (1893).

6. Because blackbody radiation for any temperature can be served by a single curve when $\lambda 5 M(\lambda,T)$ is plotted as a function of λT, this homologous relationship suggests a more appropriate name would be *Wien's law of homology*. First proposed by J. Lamor in *Theory of radiation*, The Encyclopædia Britannica (11th ed.), Vol. 22, Cambridge University Press, Cambridge, 1911, pp. 785–793. The term, unfortunately, has not gained wide acceptance.

7. Planck, M., *Ueber das Gesetz der Energieverteilung im Normalspectrum*, Annalen der Physik, 4(3), 553–563 (1901).

8. In terms of fundamental constants, the two radiation constants are given by $c_1=2\pi hc^2$ and $c_2=hc/k_B$ respectively. Here c is the speed of light in a vacuum, h is Planck's constant, and k_B Boltzmann's constant. Presently accepted values for the two radiation constants are $c_1=3.741\,771\,53\times10^{-16}$ W·m^2 and $c_2=1.438\,7770\times10^{-2}$ m·K respectively.

9. Professor Dr. phil. Dr. rer. nat. h. c. Marianus Czerny was born on the 17 February 1896 in Breslau and died on 10 September 1985 in Munich. He received his *Doctor philosophiae* (Dr. phil.) from the Universität Berlin in 1923 for a thesis on the so-called "reststrahlen" (residual ray) method. Five years after his retirement, in 1966, he was awarded a *Doctor rerum naturalium honoris causa* (Dr. rer. nat. h. c., literally "Doctor of the things of nature"), an honorary doctorate by his former institution the Johann Wolfgang Goethe-Universität. A short summary of his most important life work in English can be found in: Genzel, L., Martienssen, W., and Mueser, H. A., *Marianus Czerny*, Physics Today, 39(7), 83 (1986). A more extensive biography of his life and work in German can be found in: Wiesbaden, H. M., *Marianus Czerny: 1896–1985*, in Physiker und Astronomen an der Johann Wolfgang Goethe-Universität am Main, Bethge,

K. and Klein, H. (Eds), Hermann Luchterhand Verlag, Frankfurt, 1989, pp. 144–169.

10. Czerny, M., *Ein Hilfsmittel zur Integration des Planckschen Strahlungsgesetzes*, Physikalische Zeitschrift, 45(9/12), 205–206 (1944).

11. A perfectly diffuse radiator is a body that emits radiation such that its radiance in any direction from a unit area of the body varies as the cosine of the angle between the normal to the surface and the direction of the radiation. This means that, when viewed from a distance, a self-luminous, perfectly diffuse radiator will appear as a uniformly illuminated flat surface regardless of its actual shape or orientation. A blackbody is an example of a perfectly diffuse radiator.

12. Units for the total radiance are customarily given as watts per square metre per steradian ($W \cdot m^{-2} \cdot sr^{-1}$). The steradian (sr) is the SI unit used for solid angle. A solid angle is used to describe a two-dimensional angular span in three-dimensional space. Use of the solid angle allows one to account for the part of the total emittance falling into a certain section in space. Writing the unit for total radiance in this way makes clear that $L(T)$ is a directional quantity. Compare this to the SI unit used for the total emittance of watt per square metre (W/m^2).

13. Birge, R. T., *A New Table of Values of the General Physical Constants*, Reviews of Modern Physics, 13(4), 233–239 (1941).

14. Hudson, R. D., Jr., *Infrared System Engineering*. John Wiley & Sons, Hoboken, New Jersey, 1969, pp. 53–54.

15. Dennert, H., *DENNERT & PAPE and Aristo slide rules 1872–1978*, Journal of the Oughtred Society 6:1, 4–14 (1997).

16. ARISTO-WERKE [catalogue], *Slide Rules and Drafting Instruments* (Hamburg, 1955), p. 31.

17. Brügel, W., *Physik und Technik der Ultrarotstrahlung*, Curt R. Vincentz Verlag, Hannover, 1951, pp. 26 and 254.

18. Canada, A. H., *Simplified Calculations of Black-Body Radiation*, General Electric Review, 51(12), 50–54 (1948).

19. Since I initially submitted submitting this paper Peter Holland has sent me photographs he took of an Aristo Nr. 10048 currently on display at Altonaer Museum in Hamburg as part of the Dennert & Pape/Aristo exhibition entitled "Vermessenes Altona".

20. DENNERT & PAPE, *Anleitung zum Gebrauch des ARISTO-Rechenschiebers für Temperaturstrahlung Nr. 10048*, Dennert & Pape, Hamburg, 2 pp.

21. Brügel, W., *Physik und Technik der Ultrarotstrahlung* (2nd ed.). Curt R. Vincentz Verlag, Hannover, 1961, p. 37.

22. ARISTO-WERKE, *ARISTO-Rechenstab für Temperaturstrahlung Nr. 922 Gebrauchsanleitung*, Aristo-Werke, Dennert & Pape KG, Hamburg, 4 pp.

23. Mosand, J., *Aristo End Braces*, Journal of the Oughtred Society, 15:2, 35–36 (2006).

24. Schuitema, IJ., and van Poelje, O. E., *The Schuitema Collection: A Gallery of Panels with Slide Rules and Discs*, Kring Historische Rekeninstrumenten, 2009, pp. 182–183.

25. Pastore, G., *Antikythera e i regoli calcolatori*, Private Publication, Roma, 2006, pp. 681–690.

26. Czerny, M., *Zur Integration des Planckschen Strahlungsgesetzes*, Zeitschrift für Physik, 139(3), 302–308 (1954).

27. Foerst, W. (Ed.), *Ullmanns Encyklopädie der technischen Chemie*, Vol. 11, Urban & Schwarzenberg, München, 1960, p. 715.

28. Eitel, W., *Thermal Transmissivity by Radiation in Glass Furnaces*, Glass Industry, 36(11), 575–581, 592–593 (1955).

29. Howard, J. N., *Review of 'Tables of the Fractional Function for the Planck Radiation Law by M. Czerny and A. Walther, Springer-Verlag, Berlin, 1961*, Applied Optics, 1(3), 342, 358 (1962).

30. Apanasevich, P. A. and Aizenshtadt, V. S., *Tables for the Energy and Photon Distribution in Equilibrium Radiation Spectra*, Pergamon Press, New York, 1965, p. vii.

31. Andrews, H. W., *A Slide Rule for Radiation Calculations*, Journal of the Oughtred Society, 11:1, 32–35 (2002).

32. Smith Hughes, R., *The F5100 Black Body Radiation Slide Rule*, Slide Rule Gazette, 10(Autumn), 75–80 (2009).