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Gloss of hair surfaces: Problems of visual evaluation and possibilities for goniophotometric measurements of treated strands

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Synopsis

A great number of products are offered on the hair cosmetics market that, in addition to their basic benefit, aim to improve hair gloss.

Gloss can be regarded as a special optical property for the description of apparent decorative qualities and for the analysis of surface properties of hair. As it is very complex, no simple relationship exists between the appearance of gloss and the light reflected from the hair. But up to now, investigations made on various materials suggest the spatial distribution of reflected light, the indicatrix, as being very important.

Therefore, hair indicatrices were measured using a precise goniophotometer. The resulting data had to be compressed, both for easier handling and for the description of significant aspects of the visual gloss impression.

Two indicatrix parameters are regarded as "gloss criteria": the improvement of gloss is related to an increasing amount of maximal reflected light and a decreasing half-value angle, which means the spread of reflected light in different angular directions.

The reproducibility and the precision of these measurements required an air-conditioned test room, an optimized preparation technique including the construction of a special sample holder for the hair strands, and the minimizing of the variance between the strands by always comparing the indicatrices of the untreated and the treated samples.

The strands were treated with various hair cosmetics, e.g., hair sprays, lacquers, rinses, care sprays, as well as glazes and hair gels.

To check the correlations between the results of the objective measurements and the visual gloss inspection, several gloss evaluations were made in a "gloss matching booth."

INTRODUCTION

Research on gloss has been published for more than 100 years (see list in reference 1), but very little relates to the gloss of hair (2–4). Therefore, it might be of use to consider this problem in a more general way.

The International Commission on Illumination (CIE) defines the current state-of-the-art for gloss as "the mode of appearance by which reflected highlights of objects are perceived as superimposed on the surface, due to the directionally selective properties of that surface" (5). This definition is not quite satisfactory, but it is the minimum consensus, and it shows at least a clear connection between gloss and preferred reflection of light by the tested sample into the specular direction. Additionally, it indicates that the term "gloss" is reserved exclusively for the visual sensation and that measured related data have to be indicated differently, for example by word combinations like "specular gloss" in ISO 2813 (6).

Stamm *et al.* (2) mentioned in their study that "goniophotometric curves of hair strands do not provide results as precise as those obtained from monolayers of parallel oriented fibers." They decided to design and make a rack on which a number of fibers could be strung. Normally they worked with an arrangement of 21 single fibers.

On styled hair, however, the hair fibers are not arranged next to one another in parallel and exact distances but one on top of the other in several layers and also touching one another. Especially with tests of sprays and hair lacquers, the appearance of a polymer film is influenced by its distribution on the hair. The distribution itself depends, to a large extent, on the position of the hair fibers, i.e., how closely single hair fibers lie next to each other or one behind the other in a tress of hair and what capillary and interfacial forces are activated.

Moreover, the strands had to be prepared so that, on the one hand, they could be well compared with each other, i.e., that they were provided with a very good homogeneity, and, on the other hand, that they allowed successive shampooing and drying without being disarranged. A loss of the initial arrangement or a displacement of the sample in the measuring device would mean a falsification of the measurement compared with the original measurements (see CHARACTERIZATION OF THE PHOTOMETRIC DATA below). We therefore constructed strandholders to fix the prepared strands in the goniophotometer (see SAMPLES AND THE PREPARATION OF SAMPLES below).

Statistics were also one reason to test on a large hair collective. From a larger surface we expected to obtain a practical averaging and a more even basic measuring curve for our before/after comparisons.

Actually, it was the aim of our studies to test hair cosmetics and raw materials under conditions of use. But we did not want only to obtain qualitative results but also criteria for a quantitative assessment of the hair gloss. During our work we always compared measured results and subjective evaluations.

First results of our measurements showed that the gloss of undamaged black hair could not be improved by products such as gloss sprays obtainable in the free market. We verified this result on a suitable model in a half-side test and finally we came to the same conclusion. We therefore decided to damage test strands in order to achieve a gloss improvement by the use of products.

VISUAL GLOSS EVALUATION

Wundt, one of the earliest researchers, published his results in 1861 (7). At that time, problems in binocular vision were assumed as a source for the appearance of gloss, meaning problems in combining the slightly different images of our environment seen by the left and the right eye. But this influence on gloss is difficult to measure and therefore was neglected for a long time (8).

The research on gloss was mostly concentrated on the description of such photometric properties, which were easy to measure. A very comprehensive summary was formulated by Harrison (1). Although nearly 50 years old, it is still a useful source by information.

Today's considerations of gloss are summarized in a CIE-research note (9). They are more or less related to the so-called reflection indicatrix in Figure 1.

When a light source illuminates an element of the hair surface under an incidence angle, $\epsilon 1$, light is reflected in different receptor or viewing angles, $\epsilon 2$ (both angles count from the normal of the specimen surface). The amount of reflected light is indicated by the length of the arrows pointing into the designated directions. Connecting the peaks of all possible arrows by a curve generates the so-called indicatrix, as a kind of abbreviation for describing the arrows.

Figure 2 shows some examples of indicatrix shapes. The horizontal axis represents the receptor angle, $\epsilon 2$, and the vertical axis the amount of reflected light in units of luminance, L, for reasons explained later on.

A very smooth surface often appears to be highly glossy, and a more or less sharp, bright image of the light source is seen on the surface. It generates an indicatrix similar to curve a, because it reflects nearly all the light into a certain angular region, which is identical with, or in the neighborhood of, the specular direction. With increasing roughness, the surface becomes more mat and less glossy. The peak intensity becomes lower, and the angular region in which the light is reflected increases. An example is given by indicatrix c. An ideal mat surface has no preferred direction for reflection and generates the indicatrix b.

The relation between these measured photometric data and the perceived brightness is still a topic for research. According to CIE, for uniform bright areas the perceived

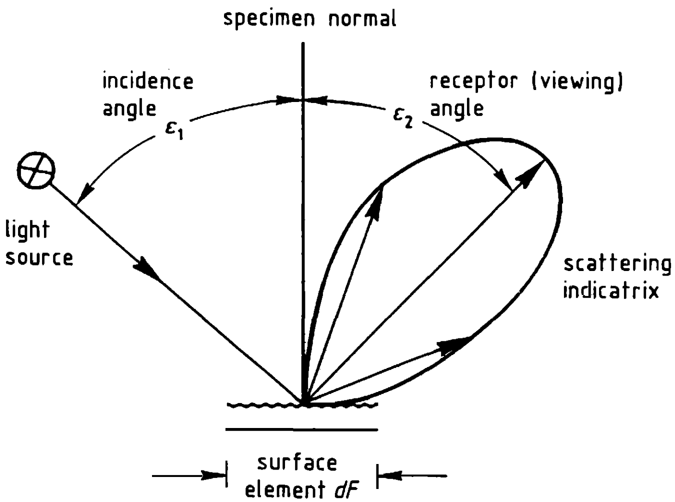

Figure 1. Spatial distribution of reflected light.

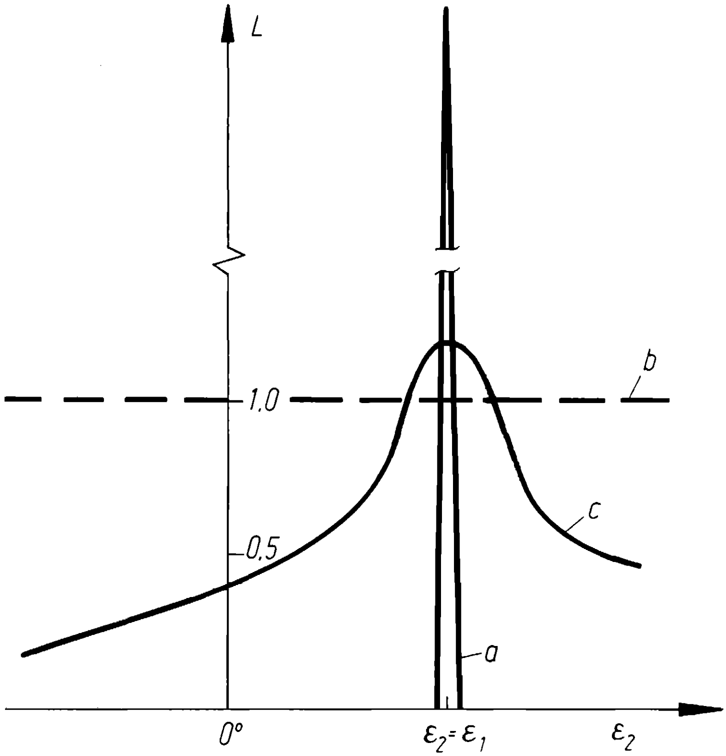

Figure 2. Schematic scattering indicatrices for a specular (a), a uniform diffusing (b), and a mixed reflecting (c) surface.

brightness is a function of the third root of luminance (10). Gloss incorporates a brightness variation on the surface, and this variation may be important for the brightness scaling itself. For example, borderlines between bright and dark areas are enhanced in their contrast (11).

This difficulty—besides others—is responsible for the lack of an unequivocal recommendation in respect to gloss scaling, but CIE considers maximal brightness and sharpness or clarity of the light source image on the sample as very important (9). If these parameters are described by maximal height and width of the luminance indicatrix (see CHARACTERIZATION OF THE PHOTOMETRIC DATA below), a nonlinear scaling of luminance such as the third root would not change the rank order. For reasons of simplification in this publication, the luminance itself is used as a suitable approximation for the brightness. The dimension of gloss is still unknown, but according to investigations by O'Donnel (12), only one parameter is important for one subject at a certain moment. This parameter depends on the photometric properties of the sample and the personal condition of the subject.

PHOTOMETRIC MEASUREMENTS

Although many proposals for the photometric measurement of gloss exist (9), only a few have been accepted worldwide and standardized on a national or international level.

Major reasons are the lack of correlation with visual experiments, the restriction in respect to certain samples, and complicated instruments. Now and then new attempts were made: for example, in the standard ISO 10 216, where gloss is characterized by the clarity of an image seen on the sample (13).

The so-called "glossmeters" or "reflectometers" are widespread, such as in ISO 2813 (6) and ISO 7668 (14). They are shown with respect to their optical layout in Figure 3.

A light source, G, in the focal distance to lens L_1 illuminates the tested sample, P, under a certain incident angle, ϵ_1, between 20° and 85°, depending on the purpose. It is assumed that the indicatrix maximum is located in the specular direction symmetrically to the incidence beam. Here the receptor angle ϵ_2 equals ϵ_1. The reflected light, scaled as luminance or luminous intensity, is integrated by the photometer head consisting of a photoreceiver, E, situated in the focal point of lens L_2. The angular region near the specular direction $2\delta_2$, which is integrated, is adjusted by a diaphragm, B. Two examples are given in Figure 4, where the borders of the adjacent regions are located at $\epsilon_1 \pm \delta$ and $\epsilon_2 \pm \beta$, respectively.

The result is normalized by referring to a highly polished black glass and then expressing a "reflectometer value" or "specular gloss value," $R'(\epsilon_1)$ and $\hat{R}'(\epsilon_1)$, respectively. These types of instruments are restricted to samples with an even surface and only little reflection from the bulk. But hair behaves differently from paint and the metal surfaces for which the gloss meters are mainly standardized.

Figure 5 represents a simplified optical model for the reflection of light by a hair fiber, showing several possible directions for an indicatrix maximum. It only indicates the refraction and neglects scattering effects.

A hair fiber can reflect light symmetrically to the incident direction when a cover of spray or liquid on the cuticle smooths the hair surface (ray A) or when reflecting facets in the cortex center are oriented parallel to the macroscopic hair fiber (ray B).

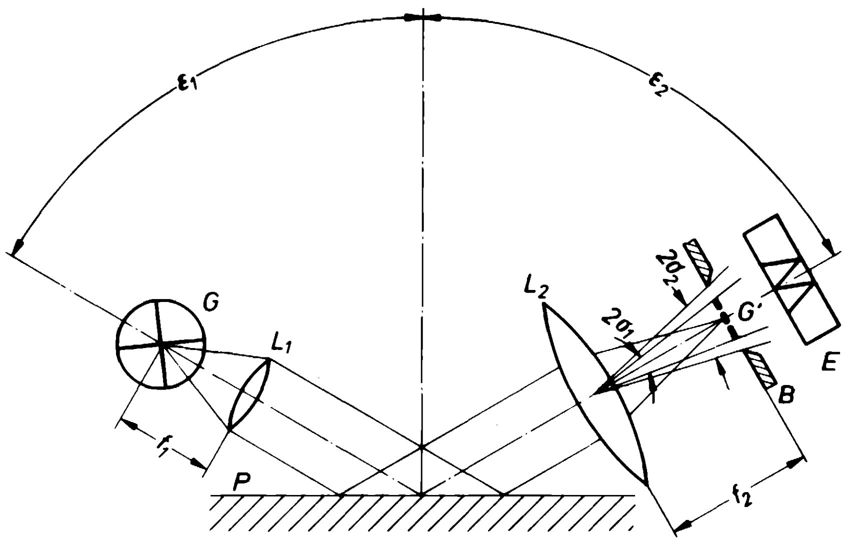

Figure 3. Scheme of a standardized reflectometer for estimating specular gloss acc. ISO 2813 or ISO 7668.

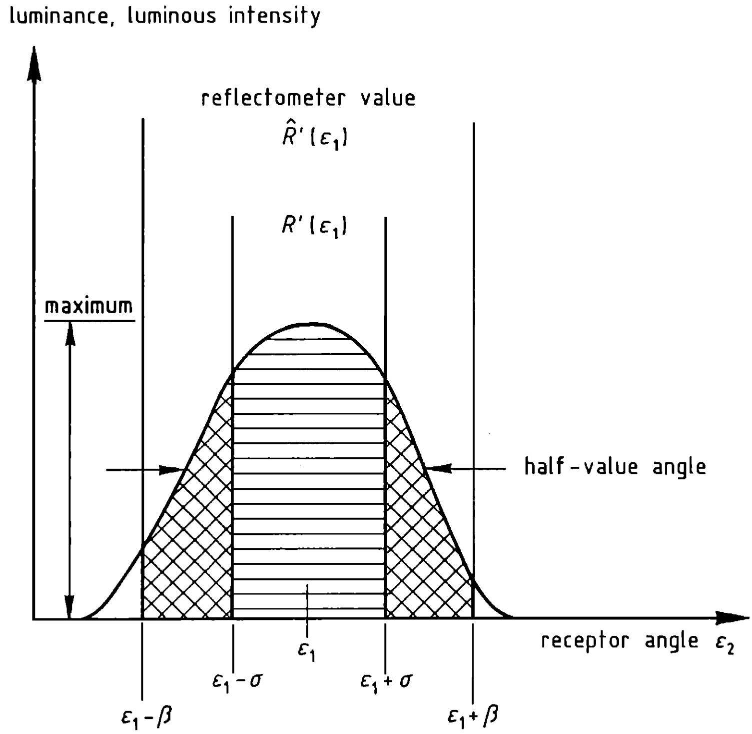

Figure 4. Parametric characterization of a scattering indicatrix.

But there are other possibilities. Light may be reflected by the cuticles before entering the hair, and because these cuticles are tilted against the fiber axis, the orientation of the main reflection direction is also tilted (ray C). If the light has the chance to pass the whole hair, a reflection at the opposite lying cuticles may occur (ray D). They are tilted in the opposite direction and therefore cause an opposite tilt of the reflected light.

To measure the reflection maximum in all these cases, it is useful to move at least the photometer head in different receptor angles ϵ_2.

GONIOPHOTOMETER—PROPERTIES

For this purpose, a more universal instrument is necessary, a so-called goniophotometer. In a basic version it is standardized as "abridged goniophotometer" in ISO 7759 (15).

A precise computer-controlled instrument is shown in Figure 6 and explained more in detail in reference 16. The mechanical parts were designed and supplied by the Halle Company, Berlin; the optical and electronic ones were purchased from several sources and assembled in BAM (Federal Institute for Materials Research and Testing, Berlin). This instrument was used for our research on hair gloss. The fixed horizontal arm carries the equipment for illuminating the hair sample on the central turntable. The illuminated part of the hair is nearly circular, with an area of about 1 cm^2, and the incident angle ϵ_1 is variable ($-75° \leq \epsilon_1 \leq +75°$), but for better comparison with published data (2) for all measurements, $\epsilon_1 = +30°$ was chosen.

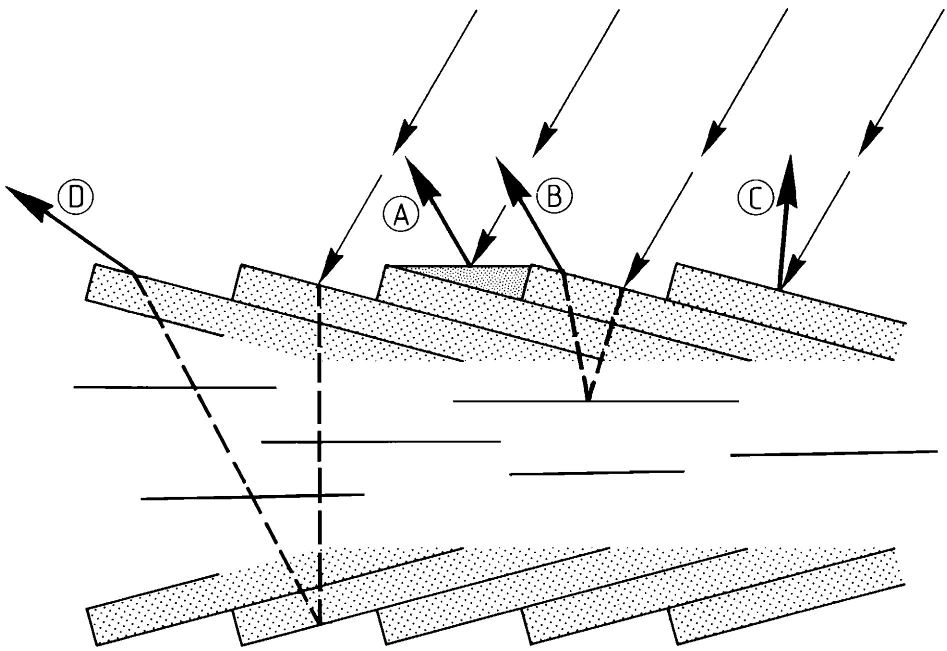

Figure 5. Possible directions for maximal reflection of light by hair. Ray A: reflection by a smoothing substance, covering the hair; ray B: reflection by a cortex cell; ray C: reflection by a cuticle before light enters the fiber; ray D: reflection by a cuticle before light leaves the fiber.

The other arm, seen behind the turntable, has a horizontal working region (horizontal receptor angle) of about 180° and a vertical one (vertical receptor angle) of about 90°, but most hair indicatrices are measured in the horizontal plane only, the optical incidence plane (see CHARACTERIZATION OF THE PHOTOMETRIC DATA below). Therefore, if not otherwise indicated, the vertical receptor angle is fixed at 0°, and the receptor angle given in the figures is identical with the horizontal receptor angle. The movable arm carries the photometer head, the main equipment for detecting the reflected light. It simulates a person who moves around the hair sample and evaluates the gloss from different points of view.

When measuring corresponding hair indicatrices, conformity with natural conditions for gloss evaluation is important—for example, with respect to the illumination. Because the angular diameter of the sun as a natural light source is about 0.5° (17), a similar size for the chosen light source was chosen. Then an exclusively specular reflecting sample generates an indicatrix according to "a" in Figure 2, with a half-value angle of 0.5° (see CHARACTERIZATION OF THE PHOTOMETRIC DATA below). Therefore, no indicatrix details smaller than 0.5° can be resolved. When measuring hair strands, the chosen angular resolution of about 1° results in neglectable errors. The angular resolution is limited by the mechanical parts of the goniophotometer and reaches 0.01° at its best.

According to the section VISUAL GLOSS EVALUATION, the luminance, L, is used as a substitute for the visual brightness stimulus. To measure luminance the goniophotometer has to be calibrated with $BaSO_4$ as a good approximation of an ideal diffuse-reflecting surface. It is also illuminated under $\epsilon_1 = 30°$.

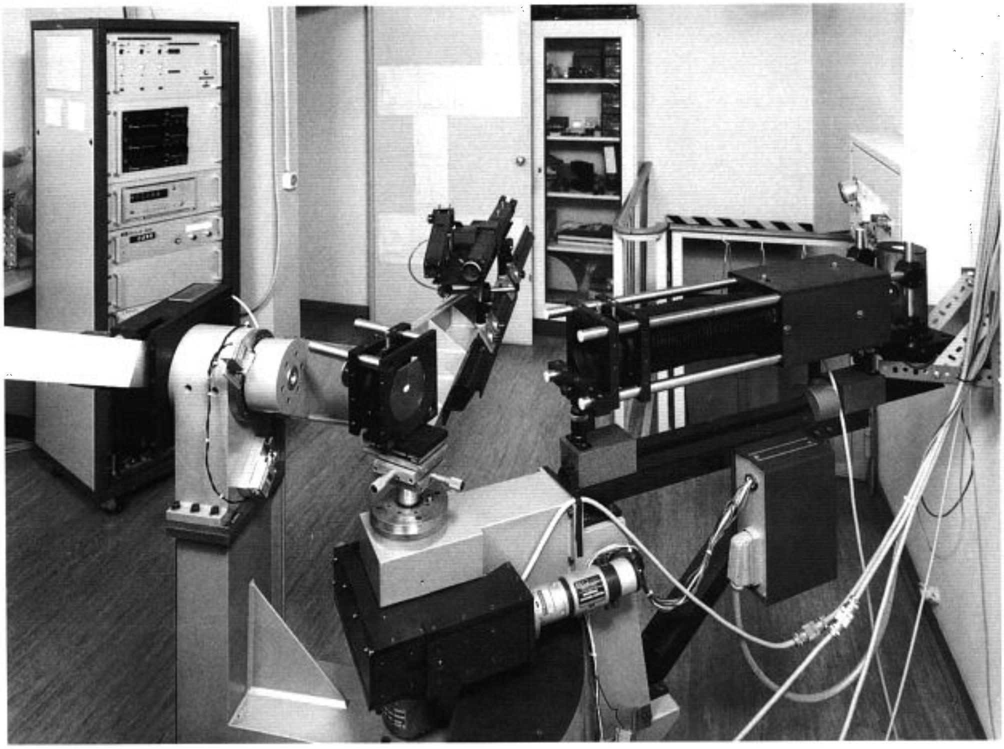

Figure 6. Precision goniophotometer fully equipped and computer controlled. Right side: optomechanical parts for illumination; center (front): turntable for holding the hair sample; center (background): optomechanical parts for light detection; left (background): shelf with electronic equipment.

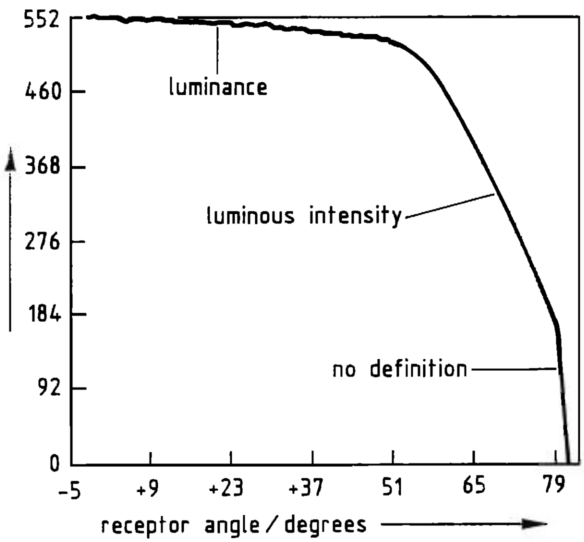

Figure 7. Measured scattering indicatrix of a nearly perfect reflecting diffusor.

The resulting indicatrix in Figure 7 shows that for receptor angles $\epsilon_2 < 50°$, only a small (and for other angles a large) deviation from the ideal horizontal line occurs (indicatrix b in Figure 2). These deviations were checked several times a day and were used as correction functions. Therefore, all indicatrices of hair strands represent luminance distributions, scaled in respect to an ideal diffuse-reflecting surface.

CHARACTERIZATION OF THE PHOTOMETRIC DATA

To achieve a compromise between the demand for collecting as much data as possible and an acceptable time for the measurements, the influence of the horizontal and the vertical receptor angles was checked and plotted as a pseudo-three-dimensional luminance distribution function in Figure 8.

It is composed of ten indicatrices relating to the horizontal receptor angle as an independent variable and a fixed vertical receptor angle between $-15°$ and $+60°$ as a parameter. Additionally, contour lines are drawn, representing iso-luminances, pointing to combinations of horizontal and vertical receptor angles with constant luminance. They are more or less parallel to the axis of the vertical receptor angle and prove that the ten indicatrices do not contain much different information. Investigations were therefore restricted to one cut in the two-dimensional scan at a vertical receptor angle of 0°.

The representation of important photometric properties by this one indicatrix depends very much on its reproducibility, which is mainly influenced by the sample itself. Using one of the hair samples described in RESULTS AND DISCUSSION below and illuminating it under $\epsilon_1 = 30°$ results in the initial luminance indicatrix A in Figure 9.

Without removing the sample from the goniophotometer, a second measurement was made 1 hour later. The corresponding indicatrix B is identical within the line width of the drawing, which means a very good reproducibility.

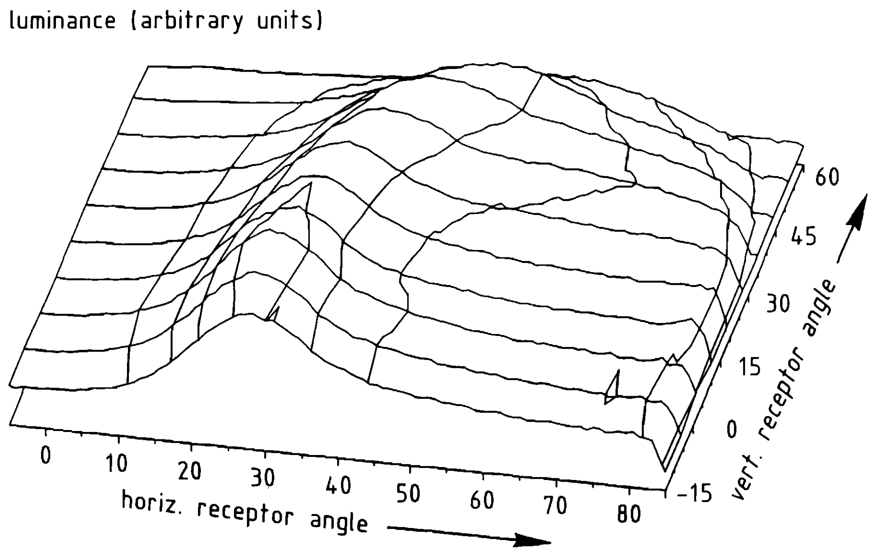

Figure 8. Two-dimensional distribution of light reflected by hair.

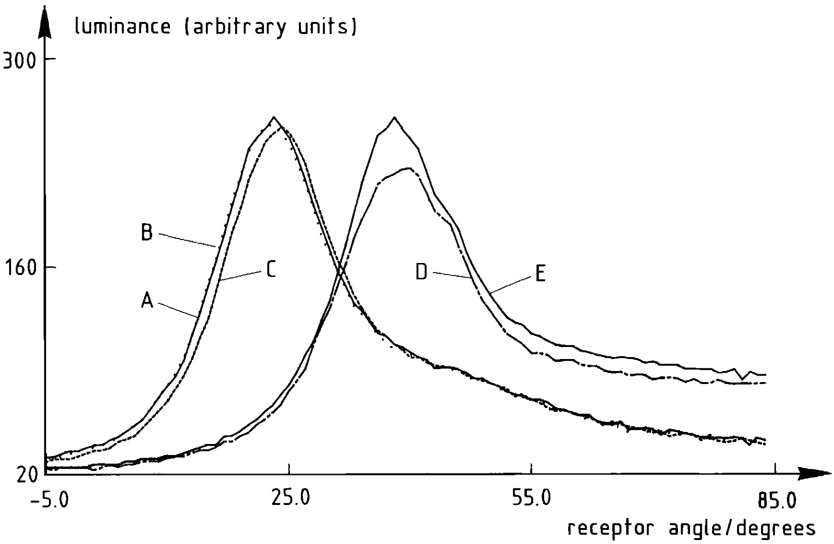

Figure 9. Reproducibility test for measured hair indicatrices.

Sometimes the sample has to be removed from the turntable, e.g., for an additional treatment. If it is possible to remove the hair strands, fixed in the sample holder mentioned in SAMPLES AND THE PREPARATION OF SAMPLES below, a rather good reproducibility can be achieved after reinserting the sample holder in its former place. This is shown in indicatrix C.

The importance of always referring to the same sample area is demonstrated by indicatrix D. It belongs to the adjacent area at a distance of about 10 mm. The indicatrix shape has changed remarkably, and the reproducibility is bad. A similar problem may occur if the hair has to be removed from its sample holder for a treatment. Due to the flexibility of the hair fibers, they are then arranged in a new order representing a slightly different surface. Fixing the hair again in the sample holder results in indicatrix E, which now has to be compared with indicatrix D. The difference is remarkable, and fixing the sample requires some precaution.

Because each hair indicatrix has several data points standing for different viewing directions, a gloss-related data compression is advisable, taking into account the gloss parameters mentioned in VISUAL GLOSS EXAMINATION above. Most indicatrix shapes are similar to Gaussian or normal distribution (Figure 4) and can be described by two parameters: the peak height or maximum and the indicatrix width. The latter stands for the angular spread of the reflected light representing the reduction of the brightness when changing the viewing direction. It is often associated with the sharpness of the reflected light source image. One possibility for characterizing this range is to measure the angular distance between indicatrix parts halfway between the minimum and the maximum of the indicatrix. Then the angular range is called the half-value angle.

SAMPLES AND THE PREPARATION OF SAMPLES

The companies Gustav Kerling (Backnang) and Heinrich G. Herzig (Schwetzingen) were the suppliers of the hair material. As a basic material we used Central European hair without chemical pretreatment. In preinvestigations we had to realize that gloss could not be improved by products such as gloss sprays on undamaged dark brown hair. So for a great number of tests, these strands were damaged by both perm treatment and hair bleaching. The treatments were done with commercial products, as for example:

- Stylewave X (Clynol) and
- Igora Brillantblond R/Oxigenta Lotion 6% (1:2) (Schwarzkopf GmbH)

The perm, however, should not make the hair frizzy. For this reason, the strands were moistened with the perm lotion for 15 minutes with the hair lying flat. After rinsing at 35°C under running water, the hair was neutralized for 10 minutes with a 2% hydrogen peroxide solution. The hair strand was then bleached by applying the bleaching pulp evenly onto the dry tress. After a processing time of 45 minutes, it was again rinsed out under running water at a temperature of 35°C, and finally the strands were left in a bath of 1% citric acid for 30 minutes. After rinsing out again, the strands were dried in the air overnight.

In spite of all the efforts to prepare strands of uniform patterns and to fix them, the measurements display individual characteristics of various hair preparations again and again. Exact comparisons with marginal changes of the scattering indicatrix can therefore only be obtained from the same strand. As indicated in the last chapter, the evaluation of the same tress part always has to be ensured. This refers to the testing of sprays particularly if the hair strands are measured several times after each spray application. A tress sample that will maintain its arrangement of single hair fibers in a strand before and after a treatment (for example, a hair wash) has to be fixed on both ends—the distal and the proximal side. The embedding material must not only allow fast processing but also an acceptable elasticity of the single hair fibers apart from sufficient stability. Of all tested materials, Xantopren L (Bayer Dental) used primarily in dentistry, proved to be most suitable. It is a silicone-based condensation curing elastomeric precision impression material of low viscosity. As an activator we used Optosil-Xantopren liquid, also a product of Bayer Dental.

The embedding of the single strands in a silicone rubber was performed in several steps. First the hair fibers of the strand were straightened out, placed exactly in a parallel direction, and clamped between two Teflon blocks over a length of 2 cm in the measuring area. Both ends were glued on either side with silicone rubber. These gluings were made in a chronological order and required 3–5 minutes for drying each one. Strands prepared in this way showed a high degree of stability even if treated with aqueous or alcoholic solutions, which normally cause considerable changes in both length and diameter. The air-conditioned room was set at 23° ± 2°C and 45% ± 5% R.H.

For measuring the scattering indicatrix, the prepared strand samples are fixed in sample holders in order to achieve a quick changing on the goniophotometer and a good reproducibility. The sample holders, constructed by us, are mainly made of two metal sheets (100 mm × 100 mm × 1 mm), one of them containing a hole to illuminate the samples.

VISUAL EXPERIMENTS AND COMPARISONS

To confirm the relationship between photometric measurements and visual gloss sensation (see VISUAL GLOSS EVALUATION above), some visual experiments were performed. For this purpose a gloss-matching booth was constructed, which allowed a "paired comparison" of two samples under identical conditions. The choice for using "paired comparisons" was governed by the fact that estimating absolute magnitudes in gloss is too difficult at present.

The visual comparisons corresponding to the objective measurements were performed either on identical strands or on strands prepared from the same hair quality with identical treatment conditions. Thus more stable and reproducible test conditions were achieved than by evaluating directly on a model.

To be in accordance with the goniophotometric measurements with respect to the sample illumination, an incident angle of $\epsilon_1 \approx 30°$ was chosen. Three types of light sources were available, fluorescent lamps in warm light (nearest color temperature 2700 K) or in cold light (5000 K), producing convergent beams, as well as a 35-mm slide projector (3200 K) illuminating the samples with nearly parallel light via a mirror through a hole in the ceiling of the booth. To avoid unwanted light scattered from the walls, the whole interior of the booth was painted mat black.

The "paired comparisons" were performed by presenting two hair strands lying side by side as shown in Figure 10. Five persons judged these strands in a blind test as a double operation with the question: better, worse, or the same? An agreement of at least four judgments characterized the sample as "visually identifiable." It turned out that the gloss evaluation of all test persons correlated with the earlier mentioned indicatrix parameters.

RESULTS AND DISCUSSION

Hair strands show a different reflection behavior depending on the orientation of the strands in relation to the direction in which they are illuminated.

An example of the change of the respective indicatrix of the same strand of dark brown hair shape is given in Figure 11. The ordinate shows the indicatrix I in arbitrary units—a measure for the reflected light—and the abscissa the corresponding receptor angle. The dashed lined indicatrix represents the strand that has been placed parallel to

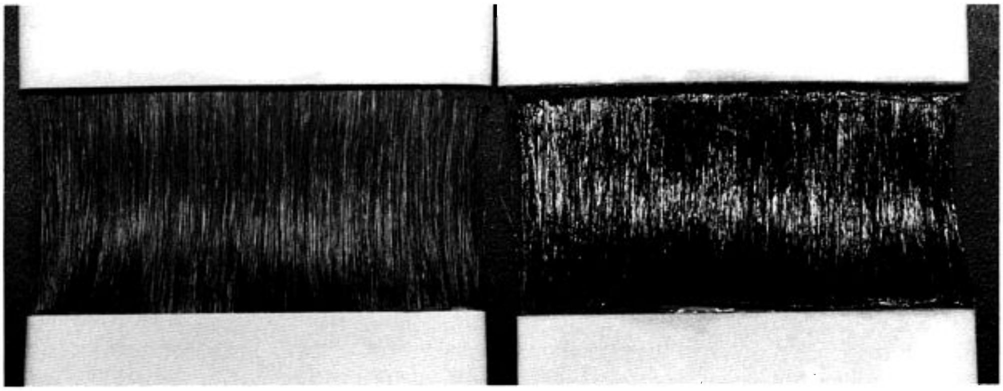

Figure 10. Two hair strands prepared for pair comparison in the gloss-matching booth. Gloss is remarkably increased in the right strand.

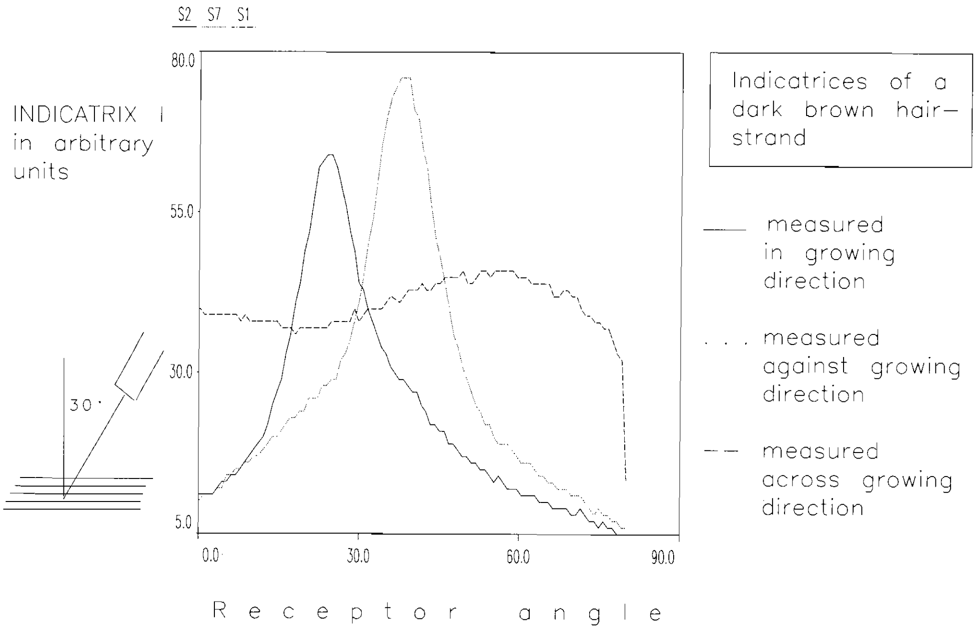

Figure 11. Indicatrix shape variation with changing hair orientation.

the optical incident plane and is illuminated in the direction of the hair growth. Compared to a completely plane surface, which would have its reflection maximum in the specular direction at a receptor angle of $\epsilon_2 = \epsilon_1 = 30°$ (see indicatrix a in Figure 2), in this arrangement the maximum is shifted by 6°–7° to smaller angles. Case C in Figure 5 explains this shift by the inclined position of the undamaged cuticle cells of the hair. The solid line confirms this assumption. By turning the strand 180° and illuminating it against the direction of growth, an equally sized maximum shift to larger angles is obtained. Because the solid indicatrix contains no principal different information besides the shift, we restricted our measurements to the illumination in the growth direction. Illumination across the growth direction (dotted line) mainly generates scattered light without a significant maximum. It is less suitable for gloss evaluation.

EVALUATION OF TREATMENTS WITH CONDITIONING GLOSS TONICS AND A CONDITIONING HAIR RINSE

The indicatrices given in Figures 12 and 13 represent two hair strands damaged by a perm and a hair bleach and sprayed with different conditioning gloss tonics (type I and type II). The initial indicatrices were taken before spraying (solid curves). Ten minutes after spraying, when the solvent was evaporated, a remarkable increase of the luminance maxima can be recognized as an indication for a gloss improvement. Even 24 hours after spraying an improvement against the non-sprayed strands is visible, although less remarkable.

In addition to the increasing maximum, in Figure 13 a decrease of the half-value angle can be seen. Treatment with a tonic type II improves both gloss parameters and is

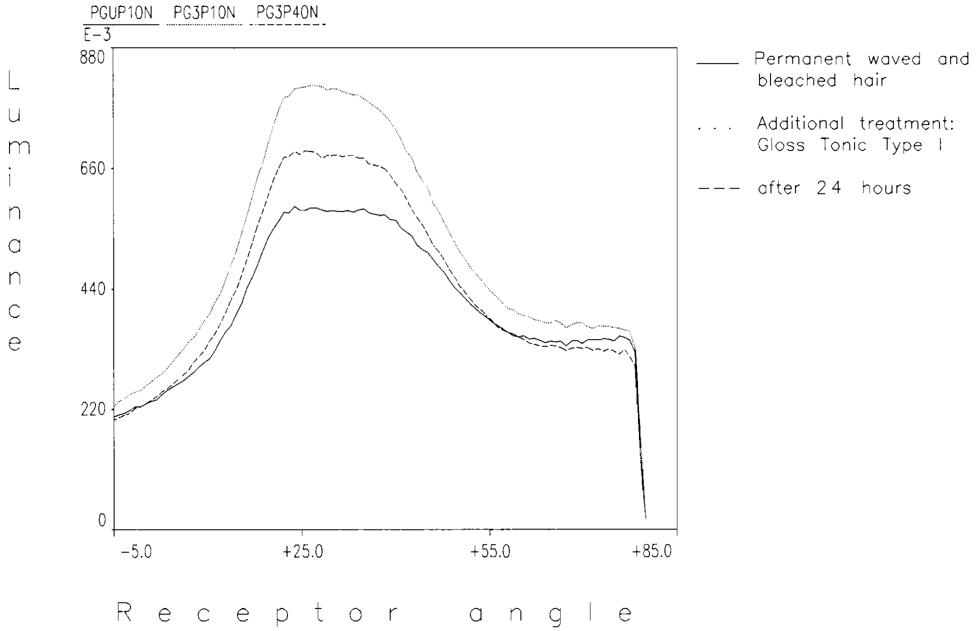

Figure 12. Indicatrix change caused by treatment with "gloss tonic type I."

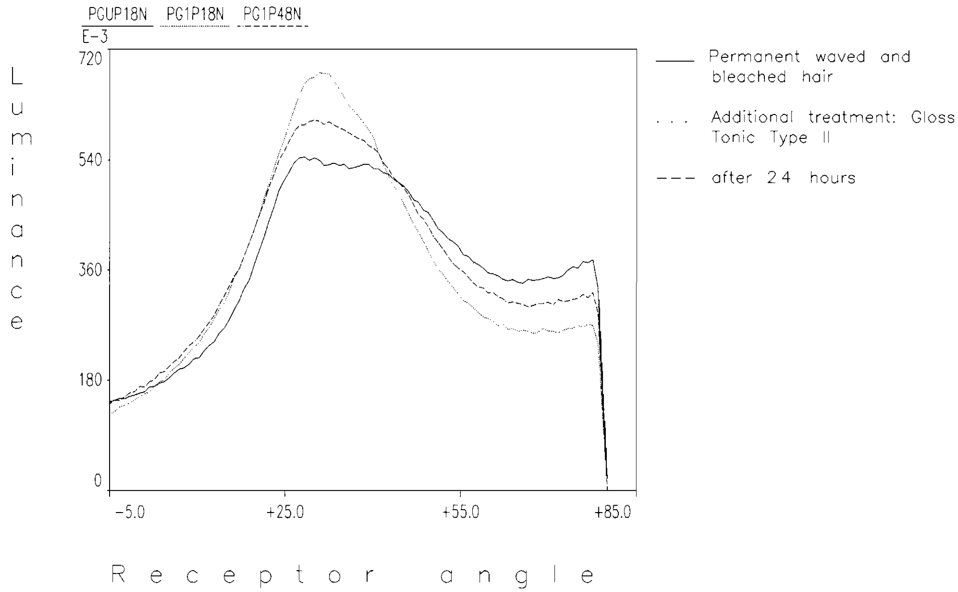

Figure 13. Indicatrix change caused by treatment with "gloss tonic type II."

therefore expected to be accepted to an even higher degree than the treatment with type I.

The use of a "conditioning hair rinse" on a strand damaged by a perm and a hair bleach is shown in Figure 14. The solid line again corresponds to the original strand, the dotted

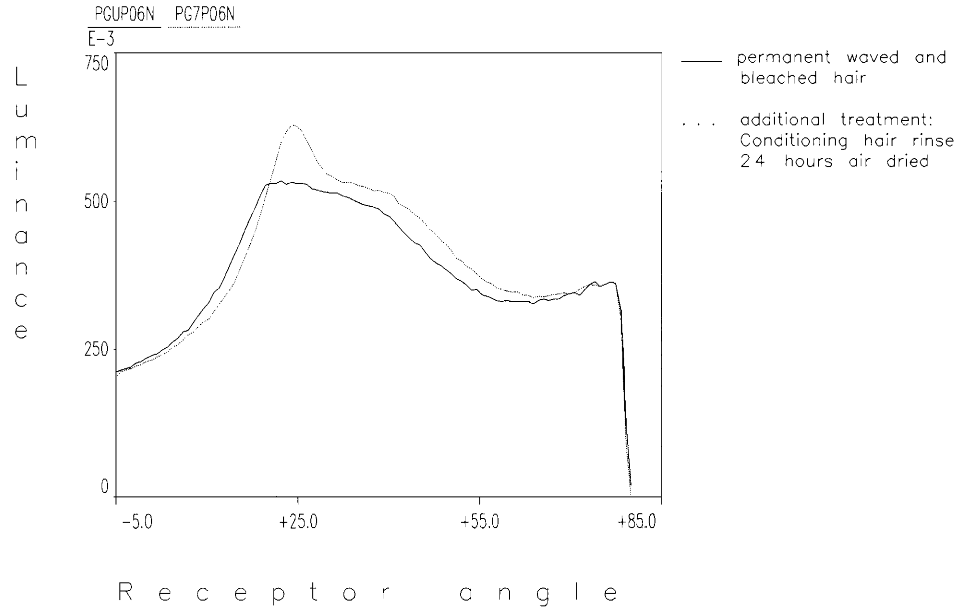

Figure 14. Indicatrix change caused by treatment with conditioning hair rinse.

line to a measurement made after 24 hours by allowing the strand to dry naturally. Both curves resemble Figure 13, but the influence of the hair rinse is more effective. The rinse treatment creates a better surface reflection, which is indicated by an increase of the reflection maximum at $\epsilon_2 = 24°$. Probably the hair surface was polished by the rinse and so the light reflection was better aligned.

DEVELOPMENT OF A GLOSS HAIR LACQUER

For the development of a gloss hair lacquer, the goniophotometric measurements were also of very great importance. In Figure 15 a qualitative comparison made on the same hair base is shown. By spraying the strand with a gloss lacquer, the gloss can be remarkably increased. The dotted curve does not only reveal an increase of the luminance, but also a reduction of the half-value angle. Additionally, it can be recognized that the reflection maximum is almost precisely located at a receptor angle of 30°. That means that the gloss hair lacquer equalizes the scaled layer and that the reflection occurs primarily on the surface of the lacquer. For the optimization of a formula it is of course also necessary to know the applied amount of spray. Due to the extremely small amount, weighing was not possible. The easiest solution for this problem was to determine the applied hair lacquer by the time of spraying.

Figure 16 shows the change of an indicatrix of a similar strand due to repeated short spraying actions. The shortest time that can be set on our automated Aerosol-Sprayer H & R* is 0.2 seconds, which remarkably increases the gloss parameters, the maximum, and the half-value angle. An additional spraying action of 0.2 seconds generates a

* Aerosol-Service AG, Dep. Comes, CH-4313 Möhlin, Switzerland.

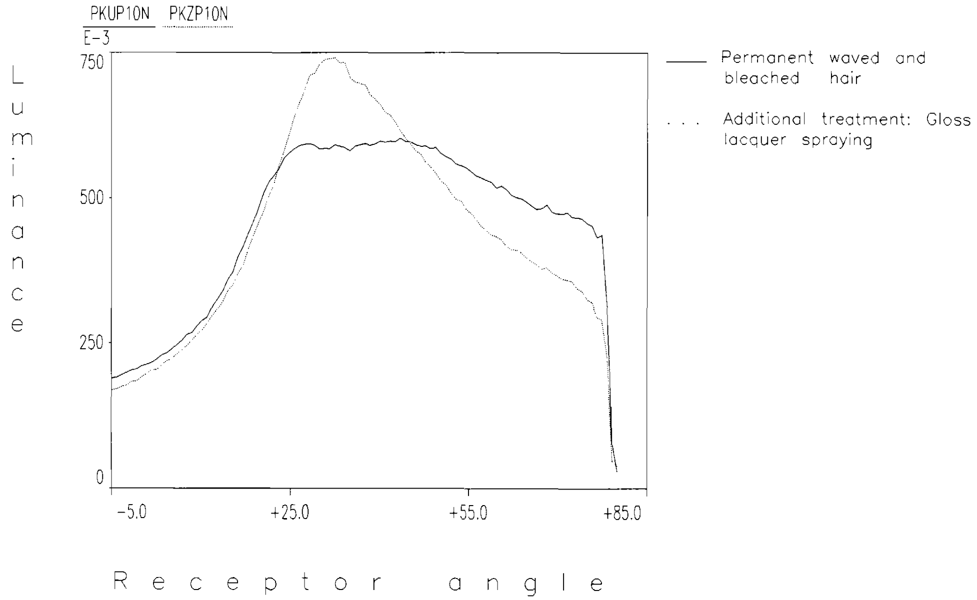

Figure 15. Indicatrix change caused by treatment with "gloss lacquer" spraying (arbitrary spraying).

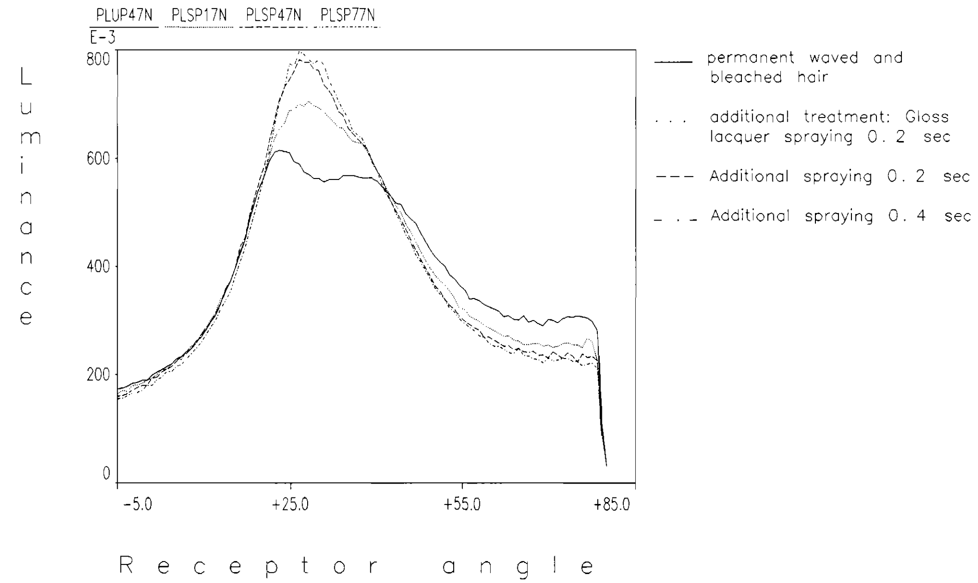

Figure 16. Indicatrix change caused by treatment with "gloss lacquer" spraying (fixed spraying times).

further increase, but gloss can only be slightly reinforced by another spraying of 0.4 seconds.

Figure 17 compares the half-value angles of the sample shown in Figure 16 with two further spray samples in a 3-D column chart. The first spraying action of 0.2 seconds generates the strongest decrease in all cases.

Sample 2 achieves the smallest half-value angle after the last spraying and is therefore

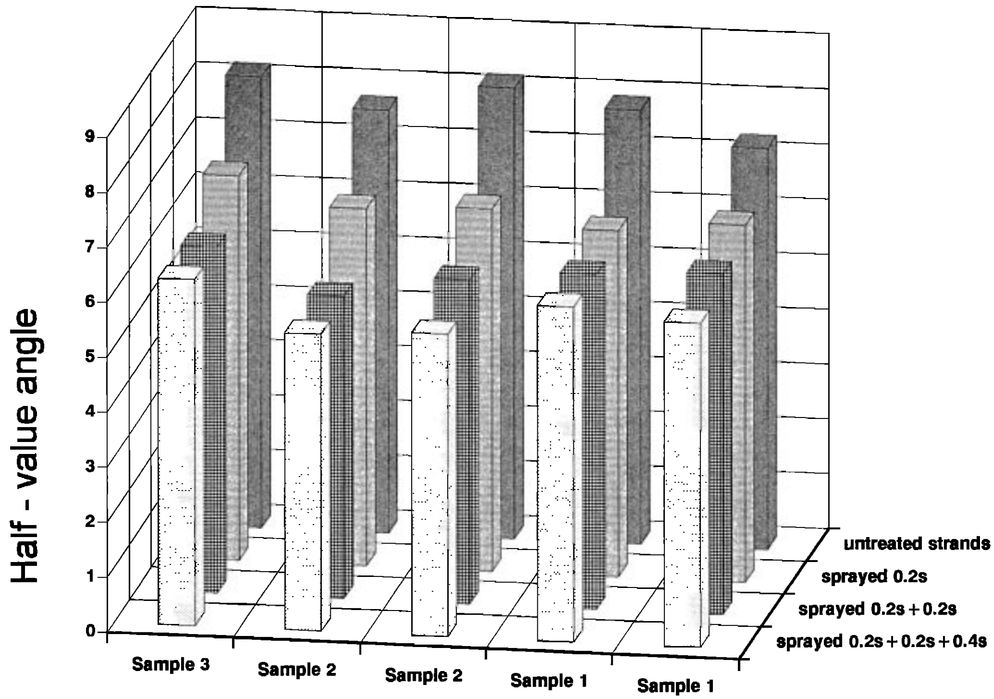

Figure 17. Comparison of half-value angles in arbitrary units as a function of different spraying times and three different samples of gloss hair lacquers (sample 1 and sample 2 each applied on two different strands—sample 2 is identical with the sample in Figure 16).

judged as the best. Comparison of the solid indicatrices of the untreated strands in Figures 15 and 16 again shows the difference between equally prepared strands and the necessity of measuring the same sample before and after treatment. Contrary to Figure 15, the solid line in Figure 16 shows a distinct maximum for a receptor angle of $\epsilon_2 < 30°$, which can be interpreted as surface reflection on the cuticle (ray C in Figure 5), and a second weak maximum at $\epsilon_2 > 30°$. According to reference 2 and ray D in Figure 5, it may originate from a reflection at the opposite lying cuticle. The minor reflection is probably caused by the absorption loss in the fiber. Spraying the hair smoothes the fiber surface again. Most light seems now to be reflected from the lacquer surface (ray A in Figure 5), as in Figure 15.

GLOSS AND STYLING GELS TREATMENTS

The two last examples show the effect of so-called "gloss and styling gels." In Figure 18 the product was first used on a light base—a hair strand treated with both perm and hair bleaching—and in Figure 19 it's applied on undamaged hair. Although the initial indicatrices (solid curves) of both hair types differ in their shapes, a considerable and comparable improvement of the gloss parameters, indicatrix maximum, and half-value angle can be recognized immediately after application of the product.

Moreover, it can be well recognized how the angle of the reflection maximum, originally displaced by 7°, moves to the specular direction at 30°. Here we get the same effect as

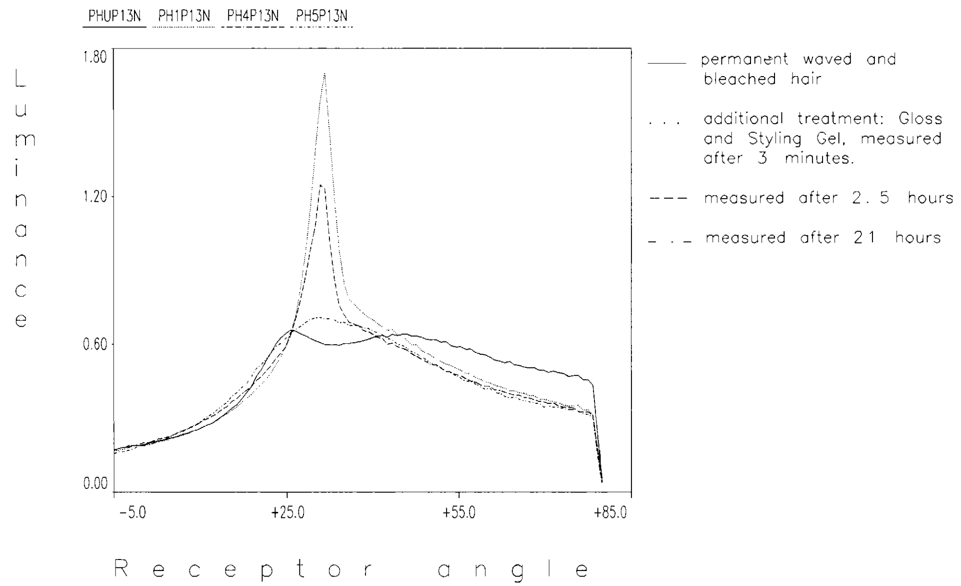

Figure 18. Indicatrix change caused by treatment with "gloss and styling gel" on a permanent-waved and bleached hair.

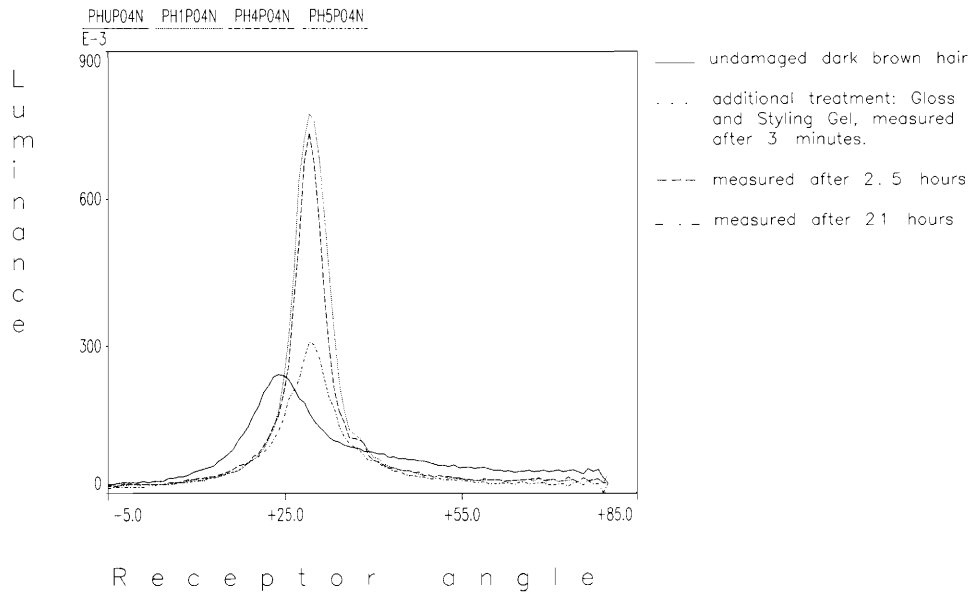

Figure 19. The same treatment as in Figure 18 on undamaged dark brown hair.

by spraying with gloss hair lacquer. The reflection of the incident light occurs mainly on the gel surface, which smoothes the cuticles. Also, on undamaged dark brown hair, we achieve a remarkable gloss improvement compared to previous observations. After several hours, the improvement fades and disappears after one day. But the smoothing effect of the gel persists, and the indicatrix maximum is still at a receptor angle of $\epsilon_2 = 30°$.

CONCLUSIONS

- The estimation of gloss on hair surfaces by goniophotometric measurements requires a restriction to few parameters that correspond with the visible hair properties. An increase in the reflected amount of light in the reflection maximum and a decrease in the half-value angle of the indicatrix result in an improvement of gloss.
- An often underestimated problem, the preparation of testing strands, has been solved. The development of an acceptable technique to fix hair strands in a reproducible manner allows comparisons of the same samples before and after treatments by goniophotometric measurements.
- Although the human eye is indeed able to perceive small differences in gloss, it has problems in realizing the order of magnitude. The objective goniophotometric method was of great significance in detecting these small differences in gloss in absolute values.
- In some samples one can see which way the cuticle surface is influenced by hair rinses and hair gels. Commercial products like care sprays and glazes are only suitable to improve gloss on damaged hair strands. An increase of gloss on undamaged brown hair results from products that are able to smooth the surface of the cuticle and where the light reflection occurs at the treatment area.
- Consisting of various detailed information, gloss is actually a perception of light reflection recognized by the naked eye. Through goniophotometric measurements we can receive a lot of this detailed information, such as surface behavior, cuticle reflection, hair damage, mode of action by different product treatments, smoothing of the cuticle layer, light absorption, and also the coloring of the hair.

In spite of the great number of very interesting results, further refinements of the measuring device will be helpful. The study of hair surfaces by goniophotometric measurements represents an efficient method to solve these problems.

REFERENCES

(1) V. W. G. Harrison, *Definition and Measurement of Gloss* (Hefer & Sons Ltd., Cambridge, 1945).

(2) R. F. Stamm, M. L. Garcia, and J. J. Fuchs, The optical properties of human hair, Parts I and II, *J. Soc. Cosmet. Chem.*, **28**, 571–599, 601–699 (1977).

(3) H. K. Bustard and R. W. Smith, Investigation into the scattering of light by human hair, *Appl. Optics,* **30**, 3485–3491, (1991).

(4) M. Tetsuo, O. Masaaki, and H. Tadashi, *Cosmet. Toiletr.*, **107**, 53–59 (1992).

(5) International Commission on Illumination, *International Lighting Vocabulary,* CIE Publ. No. 17.4 (Bureau Central de la Commission Electrotechnique Internationale, Geneva, 1987), p. 125.

(6) *International Standard ISO 2813:* Paints and varnishes—Measurement of specular gloss of non-metallic paint films at 20°, 60° and 85°. 2nd ed. (1978).

(7) W. Wundt, Über das Binocularsehen und subjektive Farben, *Poggendorfs Annalen der Physik,* **114**, 163–168 (1861).

(8) W. Czepluch, Glanz beim binokularen Sehen, *Fortschr.-Ber. VDI-Z Reihe 17, Nr. 24* (VDI-Verlag, Dusseldorf, 1984).

(9) International Commission on Illumination, CIE research note: Evaluation of the attribute of appearance called gloss, *CIE Journal,* **5**, 41–56 (1986).

(10) International Commission on Illumination: *Colorimetry* (*E-1.3.1*), CIE Publ. No. 15, 1971; *Supplement No. 2* (TC-1.3), 1978 (Bureau de la Commission Electrotechnique Internationale, Geneva).

(11) T. N. Cornsweet, *Visual Perception* (Academic Press, New York and London, 1970), p. 345.

(12) Francis X. D. O'Donnel, *Psychometric Scaling of Gloss,* Thesis, Rensselaer Polytechnic Institute, 1984.