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Reflection Standard

Make and Characteristics

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Abstract

Reflectance surfaces of light and dark materials have been designed to make contrast measurements in normal lighting facilities possible. The surfaces consist of numerous facets, the contribution of which yields the reflection to incident light. The process for manufacturing the surface is reviewed. Principles for deciding the facet distribution are developed through a mathematical model, and investigated for several angles of incident and reflected light.

Zusammenfassung

Reflektierende Oberflächen in einem hellen und dunklen Material wurden entworfen, um Kontrast-Messungen in normalen Licht-Einrichtungen zu ermöglichen. Die Oberfläche besteht aus vielen Facetten, deren Verteilung die Reflexion des einfallenden Lichts bestimmt. Der Herstellungsprozeß der Oberfläche wird erwähnt. Entscheidungsprinzipien für die Wahl der Facettenverteilung sind durch ein mathematisches Model gegeben und für mehrere Ein- und Ausfallswinkel untersucht.

Résumé

Des surfaces réfléchissantes composées de matériaux clair et sombre ont été développées pour rendre possible les mesures de contraste dans des locaux à éclairage ordinaire. Les surfaces consistent en une multitude de facettes dont la distribution détermine la réflexion de la lumière incidente. Le procédé de fabrication de ces surfaces est exposé ici. Le principe de la détermination de la distribution des facettes sur les surfaces a été développé à l'aide d'un modèle mathématique et il a été étudié pour différents angles d'incidence et de réflexion de la lumière.

Introduction

For years, lighting engineers and those engaged in vision research have recognized that substantial losses in contrast, and hence in visibility and visual performance, can occur when light sources are reflected in specular or semi-specular visual tasks.

The term veiling reflection describes the situation very well, where a large luminous area in the surfaces of, for example, a magazine or handwritten notes is difficult to read owing to a reduced contrast between the paper surface and the printed or pencilled parts. There are a great many factors contributing to veiling reflections, and each of them have individually been known for a long time. The specularity of paper covers a wide range of degrees and modes. The specularity of the graphic medium, pencil, ink or carbon, again covers a very wide range, which in many cases reduces the contrast to zero or even changes its sign. The orientation and size of the lighting system with respect to the task greatly influences the magnitude of the effect of veiling reflections. The problem is to integrate the effects of all these interrelated factors.

Investigations carried out at the Danish Illumination laboratory (1) and by Uitterhoeve/Kebschull (2) lead to the conclusion that visual comfort for most office work is related to the reduction in contrast from the maximum obtainable. This is independent of whether the visual task has a high maximum contrast, as in book printing, or a lower one, as in the case of pencil-writing on paper.

Measuring Method

When the visual task is given, the contrast can be calculated in any environment or illumination facility. A given visual task means that luminance factors for the detail and background are defined for every possible direction of light incidence and reflection. The contrast is then calculated by a thorough integration over the whole sphere, both from direct and reflected light sources.

Another method is to produce a defined reflectance surface in a dark and light material corresponding to a typical visual task in office and school work. The contrast of this specific task can be measured in a given environment by placing these surfaces in turn in the normal visual task position and measuring their reflected luminance. The dark surface corresponds to the target and the light surface to the background. Integration is automatically performed as the surfaces are exposed to light from the whole sphere. The contrast is defined as

$$C = \frac{L_2 - L_1}{L_1}$$

where L_1 = background luminance and L_2 = target luminance.

As mentioned earlier, and in the paper given by H. H. Bjørset: "A Proposal for Recommendations for the Limitation of the Contrast Reduction in Office Lighting", visual comfort is related to the contrast reduction R, which means the amount by which the contrast is reduced from a reference called C max, equal to the maximum task contrast obtainable.

$$R = 1 - \frac{C}{C_{max}} \text{ or}$$

$$R = 100 \cdot \left(1 - \frac{C}{C_{max}}\right)\%$$

In collaboration with the Danish illuminating engineering laboratory, a luminance contrast standard has been developed. It incorporates a pair of circular reflectance surfaces, one dark and one light, see fig. 1, which are specially manufactured to have durable and consistent reflectance characteristics. The contrast is defined in terms of the ratio of the reflected luminance values measured at each surface in turn, under identical illumination conditions.

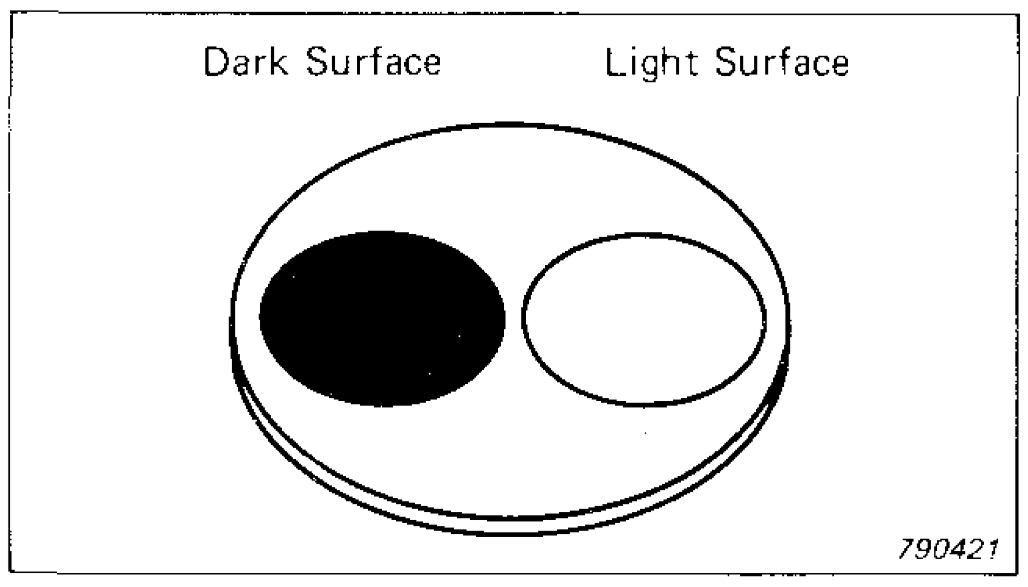


Fig.1. Dark and light reflectance surface.
Dunkle und helle Reflexionsoberfläche.
Surface réfléchissante claire et sombre.

Characteristics

The reflectance surface is designed to be similar to a typical visual task encountered in everyday office activity. The dark surface corresponds to a black type face, and the light surface to the surrounding paper.

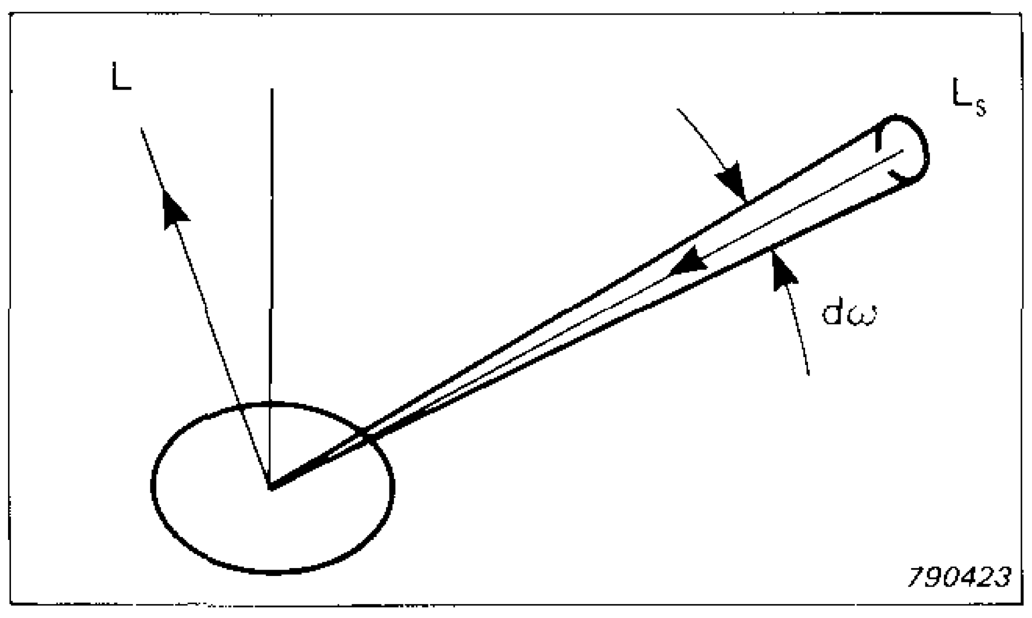


Fig.2. Reflection from a surface.
Reflexion einer Oberfläche.
Réflexion d'une surface.

To describe the light and the dark surface in the whole sphere a set of reflectance characteristics are given in table 1 and table 2. The tables are given on the assumption that a point light source illuminates the surface. By interpolation in the tables and integration in the sphere the luminance for any arbitrary illumination can be calculated. A source, see fig. 2, with the luminance L_s will produce a luminance

$$L = \frac{1}{\pi} \cdot L_s \cdot \beta \cdot d\omega \quad [cd/m^2]$$

When the surface is illuminated by several sources, or sources with some area, the luminance L is calculated from the integral

$$L = \frac{1}{\pi} \int_{\omega=0}^{2\pi} L_s \cdot \beta \cdot d\omega$$

The luminance factor β is defined as the ratio of the actual reflected luminance for each set of angles to the reflected luminance of a perfectly reflecting, perfectly diffusing surface under the same conditions. The luminance factor β is not constant for the given surface, but rather a function depending on V_A, V_B, V_C. β is given in tables 1 and 2. Fig. 3 shows the geometry, where P is the position of the appropriate surface of the luminance contrast standard.

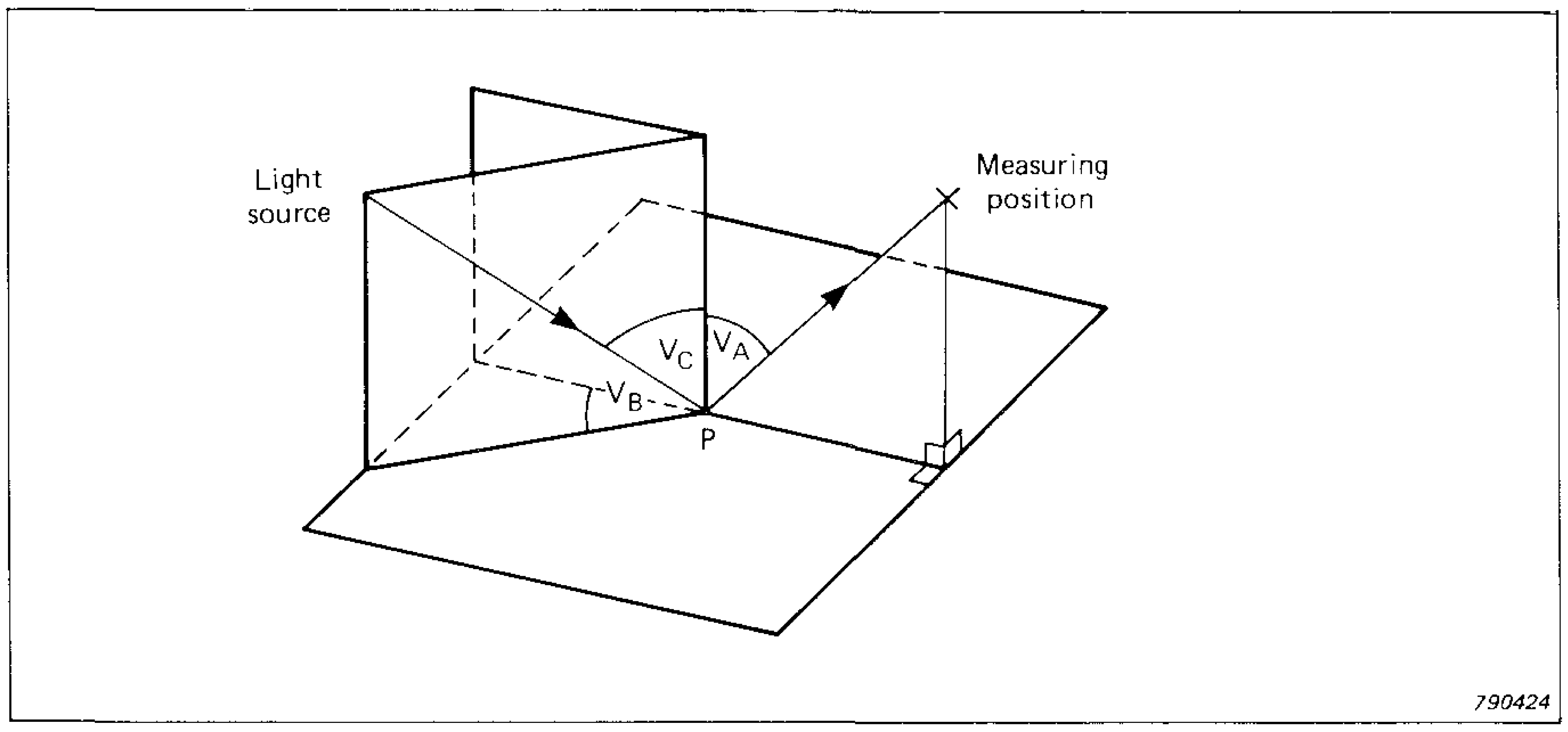


Fig.3. Geometry for incident and reflected light.
Geometrie für Einfallsstrahl und zurückgeworfenes Licht.
Géometrie pour une lumiere incidente et réfléchie.

	V_B \ V_C	0	3	5	7	10	15	20	25	30	35	40	45	50	60	70	80
$V_A = 5°$	0	1,480	1,669	1,718	1,696	1,537	1,190	0,959	0,852	0,801	0,775	0,760	0,748	0,737	0,708	0,655	0,534
	5	1.480	1,667	1,712	1,690	1,501	1,180	0,959	0,851	0,801	0,774	0,759	0,747	0,736	0,707	0,655	0,530
	10	1,480	1,663	1,706	1,681	1,515	1,170	0,953	0,849	0,798	0,772	0,757	0,746	0,735	0,706	0,653	0,530
	20	1,480	1,649	1,656	1,651	1,485	1,148	0,944	0,843	0,789	0,771	0,756	0,744	0,734	0,706	0,653	0,530
	50	1,480	1,567	1,552	1,489	1,322	1,045	0,894	0,820	0,781	0,763	0,750	0,740	0,730	0,702	0,650	0,529
	90	1,480	1,430	1,350	1,259	1,105	0,915	0,832	0,790	0,767	0,753	0,743	0,734	0,726	0,698	0,647	0,529
	120	1,480	1,310	1,230	1,140	1,010	0,855	0,809	0,779	0,760	0,750	0,742	0,734	0,726	0,698	0,647	0,529
	180	1,480	1,300	1,210	1,120	0,995	0,850	0,789	0,771	0,758	0,749	0,742	0,734	0,726	0,698	0,647	0,529

790153

	V_B \ V_C	0	5	10	15	20	23	25	27	30	35	40	45	50	60	70	80
$V_A = 25°$	0	0,804	0,859	0,977	1,234	1,663	1,881	1,954	1,921	1,757	1,347	1,050	0,909	0,839	0,764	0,700	0,573
	5	0,804	0,856	0,971	1,218	1,625	1,823	1,880	1,847	1,691	1,308	1,035	0,900	0,834	0,763	0,698	0,571
	10	0,804	0,855	0,965	1,194	1,520	1,686	1,707	1,686	1,531	1,218	1,000	0,885	0,824	0,760	0,696	0,570
	20	0,804	0,852	0,943	1,101	1,270	1,319	1,319	1,275	1,190	1,021	0,906	0,841	0,802	0,749	0,689	0,564
	50	0,804	0,828	0,851	0,864	0,855	0,843	0,835	0,825	0,811	0,792	0,776	0,763	0,752	0,722	0,670	0,549
	90	0,804	0,798	0,788	0,778	0,769	0,765	0,762	0,759	0,755	0,750	0,745	0,737	0,730	0,704	0,655	0,545
	120	0,804	0,785	0,771	0,764	0,754	0,752	0,750	0,748	0,745	0,741	0,737	0,731	0,725	0,701	0,649	0,529
	180	0,804	0,776	0,756	0,755	0,752	0,750	0,748	0,745	0,741	0,737	0,737	0,725	0,725	0,700	0,648	0,528

790154

	V_B \ V_C	0	10	15	20	25	30	35	40	43	45	47	50	55	60	70	80
$V_A = 45°$	0	0,744	0,762	0,783	0,823	0,908	1,106	1,552	2,400	2,885	3,087	3,142	2,857	2,068	1,501	1,025	0,786
	5	0,744	0,762	0,783	0,821	0,901	1,081	1,470	2,117	2.432	2,580	2,546	2,355	1.784	1,358	0,983	0,760
	10	0,744	0,761	0,781	0,815	0,884	1,019	1.266	1,577	1,687	1,726	1,696	1,590	1.322	1,114	0,893	0,710
	20	0,744	0,760	0,775	0,799	0,737	0,891	0,950	0,989	0,988	0,982	0,969	0,941	0,891	0,846	0,758	0,622
	50	0,744	0,751	0,755	0,757	0,759	0,758	0,756	0,753	0,749	0,747	0,745	0,740	0,730	0,716	0,667	0,548
	90	0,744	0,741	0,739	0,736	0,735	0,733	0,729	0,727	0,724	0,722	0,720	0,717	0,705	0,695	0,645	0,532
	120	0,744	0,736	0,733	0,731	0,728	0,726	0,723	0,721	0,717	0,715	0,713	0,711	0,693	0,686	0,638	0,521
	180	0,744	0,733	0,730	0,728	0,725	0,723	0,721	0,717	0,715	0,713	0,711	0,693	0,686	0,684	0,636	0,519

790155

Table 1. Luminance factor for the light reflectance surface.
Leuchtdichtefaktor für die helle reflektierende Oberfläche.
Facteur de luminance de la surface réfléchissante claire.

	V_B \ V_C	0	3	5	7	10	15	20	25	30	35	40	45	50	60	70	80
$V_A = 5°$	0	1,150	1,767	1,924	1,822	1,265	0,485	0,191	0,090	0,052	0,034	0,026	0,021	0,019	0,016	0,016	0,014
	5	1,150	1,760	1,911	1,805	1,236	0,480	0,190	0,090	0,052	0,034	0,026	0,021	0,019	0,016	0,016	0,014
	10	1,150	1,743	1,882	1,768	1,198	0,468	0,184	0,087	0,051	0,034	0,026	0,021	0,019	0,016	0,016	0,014
	20	1,150	1,691	1,799	1,660	1,130	0,446	0,179	0,085	0,051	0,034	0,026	0,021	0,019	0,016	0,016	0,014
	50	1,150	1,395	1,353	1,144	0,733	0,290	0,127	0,068	0,041	0,028	0,023	0,019	0,017	0,016	0,015	0,014
	90	1,150	1,000	0,803	0,588	0,365	0,153	0,078	0,046	0,031	0,023	0,019	0,017	0,016	0,015	0,014	0,013
	120	1,150	0,750	0,540	0,395	0,240	0,106	0,058	0,036	0,026	0,021	0,017	0,016	0,015	0,014	0,014	0,013
	180	1,150	0,640	0,435	0,300	0,175	0,083	0,047	0,031	0,024	0,020	0,017	0,015	0,014	0,014	0,014	0,013

790150

	V_B \ V_C	0	5	10	15	20	23	25	27	30	35	40	45	50	60	70	80
$V_A = 25°$	0	0,050	0,092	0,203	0,545	1,471	2,160	2.350	2,226	1,579	0,631	0,257	0,129	0,078	0,043	0,032	0,025
	5	0,050	0,092	0,202	0,527	1,369	1,975	2,105	1,975	1,394	0,572	0,242	0,124	0,076	0,042	0,032	0,025
	10	0,050	0,091	0,194	0,482	1,120	1,507	1,566	1,441	1,030	0,454	0,208	0,111	0,070	0,040	0,030	0,025
	20	0,050	0,087	0,170	0,348	0,600	0,672	0,659	0,583	0,447	0,230	0,129	0,079	0,054	0,035	0,028	0,024
	50	0,050	0,068	0,087	0,097	0,090	0,080	0,073	0,066	0,055	0,042	0,033	0,027	0,023	0,020	0,019	0,016
	90	0,050	0,046	0,040	0,033	0,027	0,024	0,022	0,021	0,019	0,017	0,016	0,015	0,014	0,014	0,014	0,013
	120	0,050	0,037	0,028	0,022	0,019	0,017	0,016	0,015	0,015	0,014	0,013	0,013	0,013	0,013	0,013	0,011
	180	0,050	0,031	0,022	0,019	0,017	0,016	0,015	0,015	0,014	0,013	0,012	0,012	0,012	0,012	0,012	0,011

790151

	V_B \ V_C	0	10	15	20	25	30	35	40	43	45	47	50	55	60	70	80
$V_A = 45°$	0	0,017	0,028	0,042	0,069	0,134	0,312	0,893	2,656	4,207	4,815	4,650	3,328	1,429	0,648	0,255	0,156
	5	0,017	0,028	0,041	0,067	0,127	0,281	0,734	1,868	2,662	2,879	2,721	2,069	1,007	0,513	0,222	0,141
	10	0,017	0,028	0,040	0,064	0,114	0,227	0,473	0,874	1,050	1,067	0,985	0,816	0,495	0,307	0,162	0,111
	20	0,017	0,027	0,036	0,053	0,080	0,121	0,169	0,198	0,199	0,192	0,181	0,162	0,128	0,102	0,073	0,058
	50	0,017	0,022	0,024	0,026	0,027	0,027	0,026	0,025	0,024	0,024	0,024	0,023	0,023	0,023	0,022	0,021
	90	0,017	0,016	0,016	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,014
	120	0,017	0,015	0,014	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,012
	180	0,017	0,013	0,013	0,013	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,011

790152

Table 2. Luminance factor for the dark reflectance surface.
Leuchtdichtefaktor für die dunkle reflektierende Oberfläche.
Facteur de luminance de la surface réfléchissante sombre.

Process

It is a requirement of a standard that it should have a stable luminance factor, insensitive to environmental influence. This calls for an inorganic material to be used. Several materials have been tested, and the final choice is ceramics and glass. The light surface has a glass layer printed directly on the ceramic base material. The mask used for the printing has a pattern, which leaves a relief in the surface. This relief changes in the subsequent thermal process, the time and temperature of which is under control. The final reflectance then consists of surface reflection from the facets in the relief and reflection from the ceramic base below.

The dark surface is designed to inhibit reflection from the base material below. For this reason a non-reflective material is put in between the base and the upper glass. This non-reflective material is a combination of glass and metal particles with very little reflection. As no reflection is wanted from the junction layer, the index of refraction for the upper layer and that containing metal-particles must be equal. Therefore the reflection from the dark surface is only a surface phenomena. Here again the surface relief is controlled through a thermal process. Careful investigations, however, show a small portion of diffuse reflection from the glass.

Considerations of surface reflection

In the case of pure surface reflection from non-metallic materials, the luminance factor is a function of the distribution of the different facets spread over the gross area. When this distribution is found, the luminance factor may be calculated for any angle of light incidence and reflection. Some limiting requirements must be considered. Firstly, the shadowing effect between facets has to be negligible. Secondly, the wavelength of light must be small compared to the size of facets.

In a given situation, see fig. 4, with light incidence and reflection in the same plane, parallel light rays are falling upon the surface at an angle V_C with the surface normal. The reflected light is investigated at the angle V_A to the normal.

The total area of the surface is called So, and in this hypothetical case it is found for a large quantity of small facets or mirrors. The angle between surface normal and facet normal is V_N. Some incremental part dS of the total area So has its normal inside a certain small solid angle called $d\Omega$. The distribution of the facets is a function f_Ω (V_N) and relates in the following manner.

$$dS = S_o \cdot f_\Omega (V_N)\, d\Omega \qquad (1)$$

The distribution function f_Ω depends only on V_N and therefore the luminance factor remains constant, when rotating the surface. The term f_Ω expresses the distribution of normals to the microstructure. The area dS yielding specular reflection inside a solid angle $d\omega$ has its normal inside a solid angle

$$d\Omega = \frac{d\omega}{4 \cos (V_C + V_N)} \qquad (2)$$

The flux falling upon dS is

$$\phi = \psi \cdot dS \cdot \cos (V_C + V_N) \;\; [\text{lumen}] \qquad (3)$$

Consequently the intensity in the direction V_A is

$$I_A = \frac{\phi \cdot F (V_i, n)}{d\omega} \;\; [\text{candela}] \qquad (4)$$

where $F(V_i,n)$ is the surface reflection according to Fresnel's law

$$F (V_i, n) = \frac{1}{2} \cdot \frac{\sin^2 (V_i - V_i')}{\sin^2 (V_i + V_i')} + \frac{1}{2} \cdot \frac{tg^2 (V_i - V_i')}{tg^2 (V_i + V_i')}$$

$$V_i = \sin^{-1} \frac{\sin V_i}{n} \qquad (5)$$

V_i is the angle of reflection for the facet and n is the refractive index for the surface material.

$$V_i = \frac{V_A + V_C}{2} \qquad V_N = \frac{V_A - V_C}{2}$$

The luminance in the direction V_A is calculated by combining the equations (2), (3), (4) and (5)

$$L_A = \frac{\phi \cdot F (V_i, n)}{d\omega \cdot S_o \cdot \cos V_A}$$

$$L_A = \frac{\psi \cdot S_o \cdot f_\Omega (V_N) \cdot d\Omega \cdot \cos (V_C + V_N) \cdot F (V_i, n)}{d\Omega \cdot 4 \cdot \cos (V_C + V_N) \cdot S_o \cdot \cos V_A}$$

$$L_A = \frac{\psi \cdot f_\Omega (V_N) \cdot F (V_i, n)}{4 \cos V_A} \qquad (6)$$

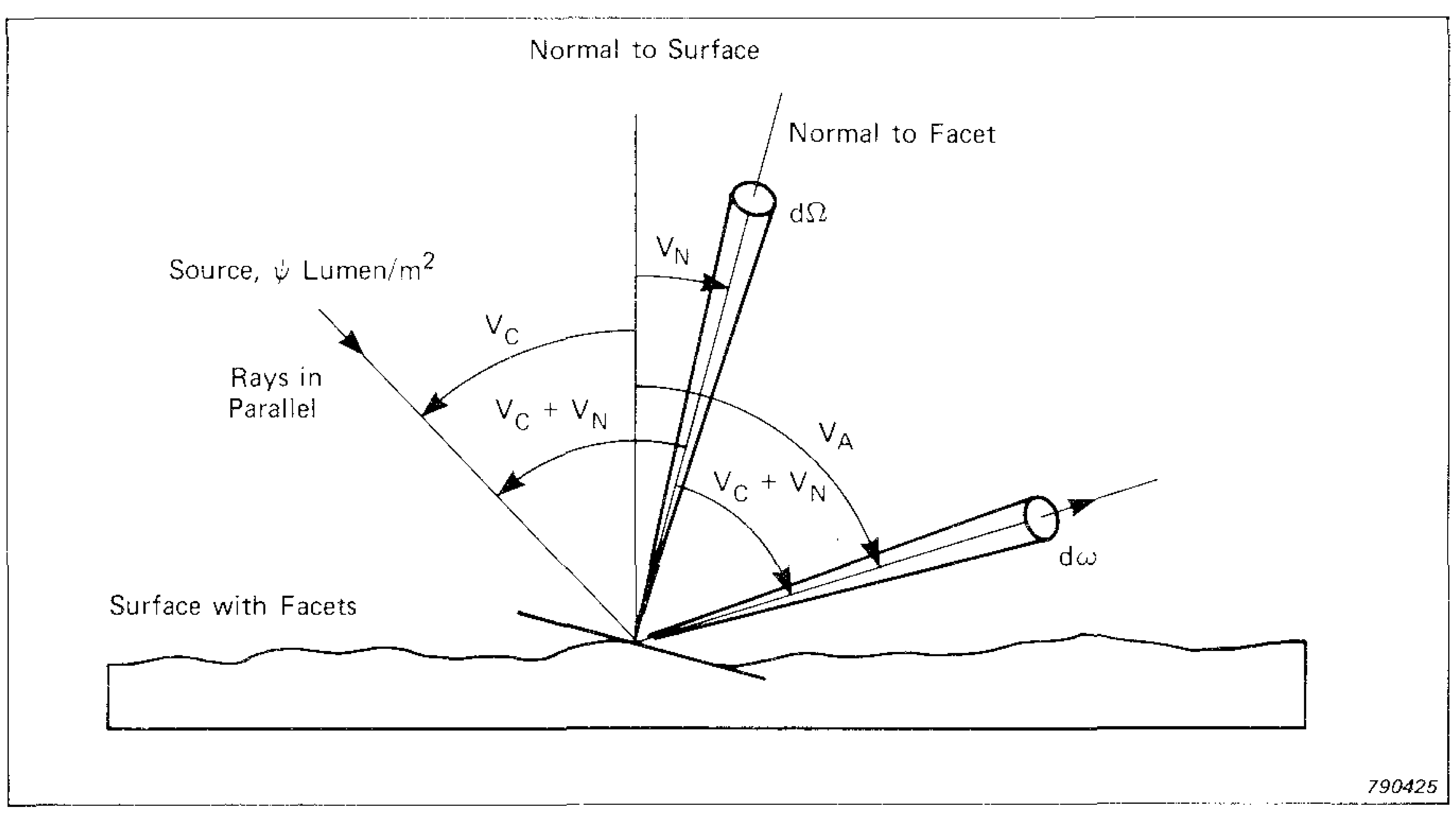


Fig.4. Angles describing the facet model.
Winkel, die das Facettenmodell beschreiben.
Modèle mathématique décrivant la réflexion.

A perfectly diffuse, perfectly reflecting surface will under the same relations as shown in fig. 4 have a luminance

$$L_D = \frac{\psi}{\pi} \cdot \cos V_C$$

This makes it possible to calculate the luminance factor for the facet surface

$$\beta(V_A, V_C) = \frac{4 \cdot F(V_i, n) \cdot f_\Omega(V_N)}{\pi \cdot \cos V_C \cdot \cos V_A} \qquad (7)$$

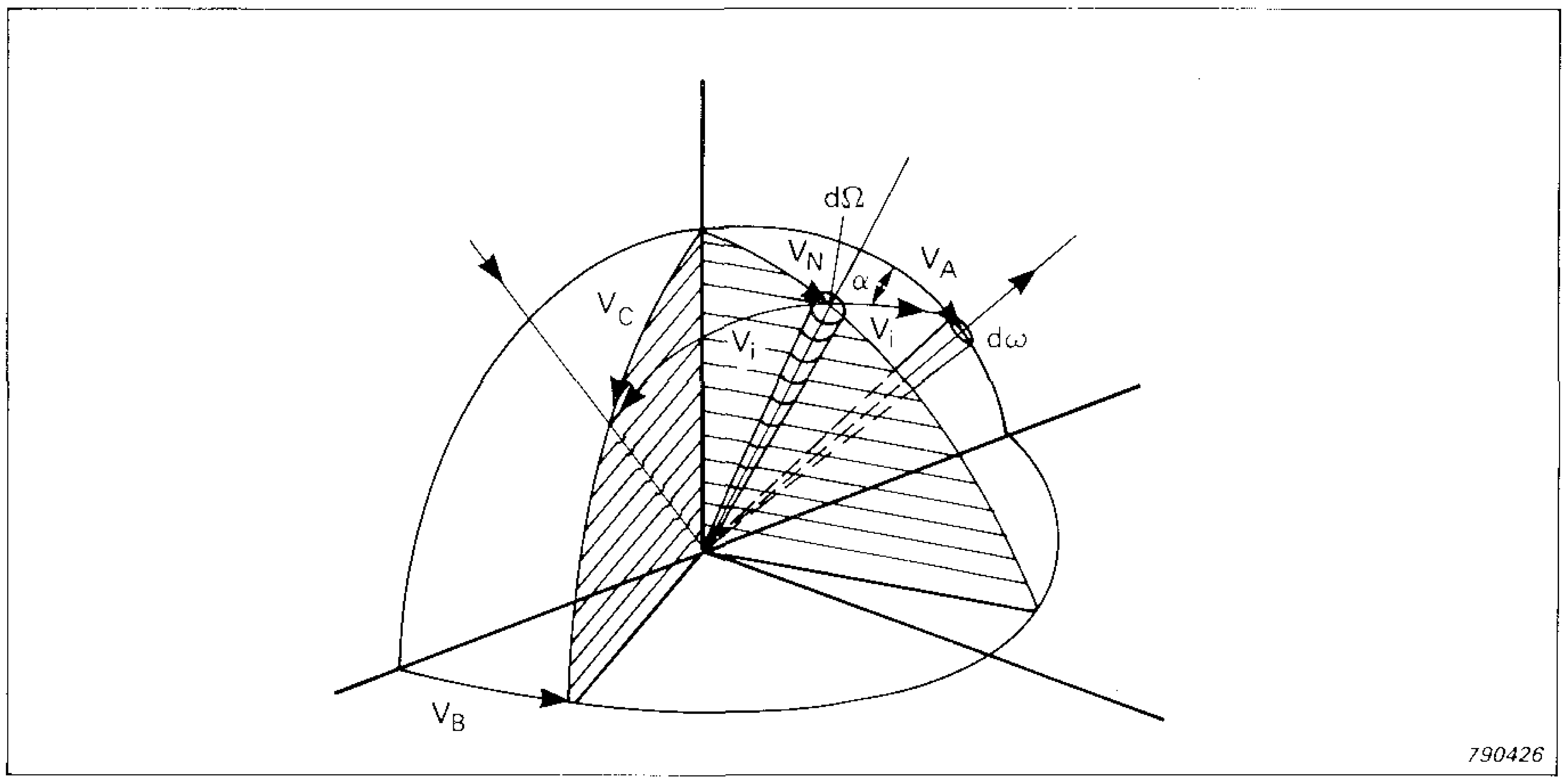


Fig.5. Geometry for spherical angles.
Geometrie für sphärische Winkel.
Géometrie pour des angles sphériques.

When V_C and V_A approach 90°, the luminance factor β tends towards infinity. This is not realistic but, allowing for the fact that facets are shadowing each other for high values of V_A and V_C, it improves the model.

K. E. Torrance and E. M. Sparrow (3) have shown a good agreement between theory and practical measurements. As long as V_A and V_C are below 60°, the shadowing effect is negligible.

When the plane at light incidence and reflection is not the same, the angles V_N and V_i (see fig.5) are found mathematically by the following formula:

$$V_i = \frac{1}{2}\cos^{-1}(\cos V_A \cdot \cos V_C - \sin V_A \sin V_C \cos V_B)$$

$$V_N = \cos^{-1}(\cos V_C \cos V_i + \sin V_C \cdot \sin V_i \cdot \cos \alpha)$$

$$\alpha = \sin^{-1}(\sin V_B \cdot \sin V_A / \sin 2 V_i)$$

Analysis of the dark surface

The luminance factor is described by

$$\beta(V_A, V_B, V_C) = \frac{4 \cdot F(V_i, n) \cdot f_\Omega(V_N)}{\pi \cdot \cos V_C \cos V_A} + K \qquad (8)$$

The number K is added according to the residual diffuse reflection in the glass as mentioned earlier. The value $K \approx 0.01$ and is significant for large values of facet angles V_N. By re-arranging the equation (8) the distribution $f\Omega(V_N)$ of facets as a function of V_N is found by measuring β and calculating the Fresnel term:

$$f_\Omega(V_N) = \frac{4 \cdot (\beta - K) \cdot \cos V_C \cdot \cos V_A}{\pi \cdot F(V_i, n)}$$

In fig. 6 the result is shown for the $f\Omega$ values taken from rows in table 1.

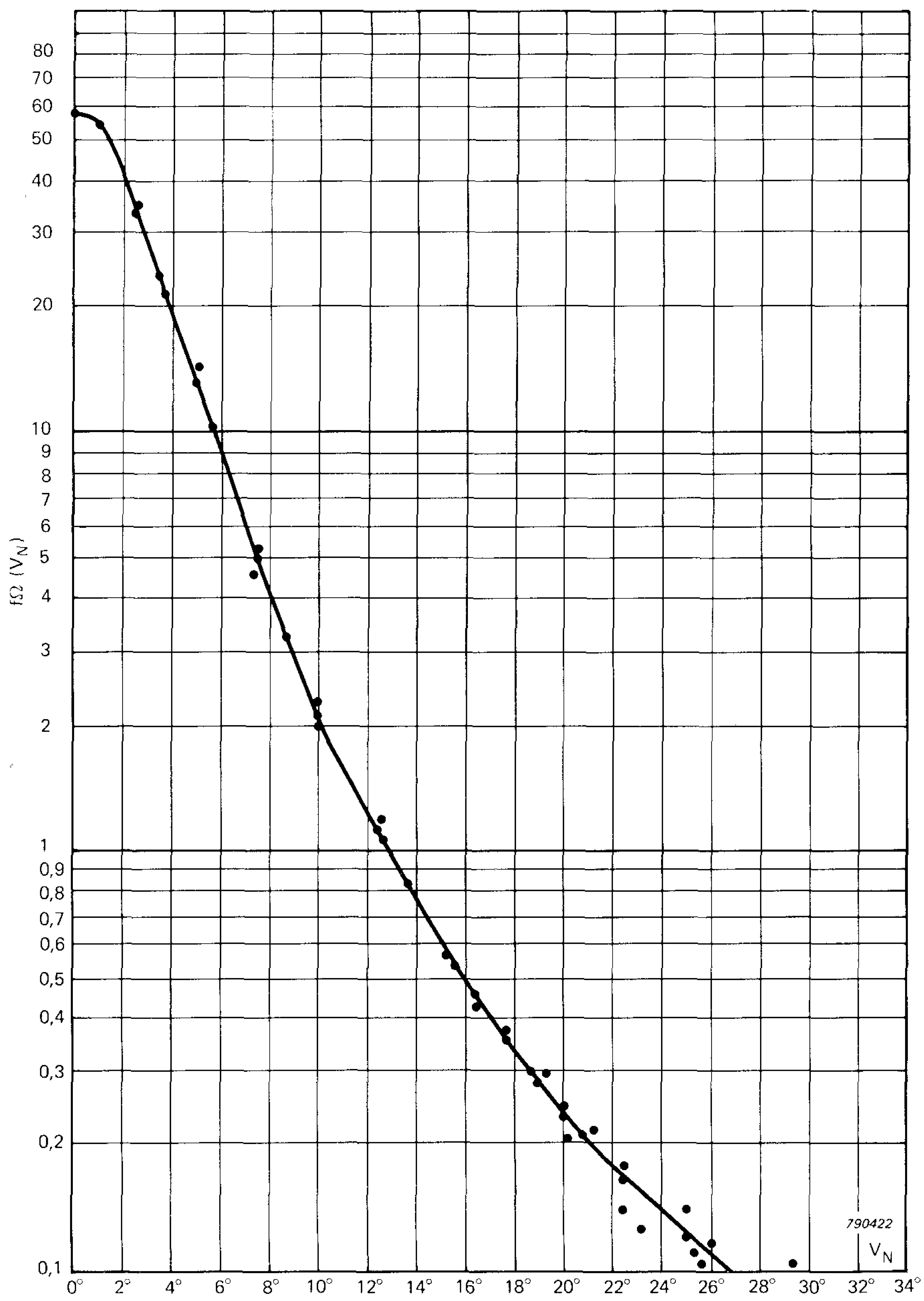
$V_A = 5°$ $\quad V_B = 0, 50, 90, 180°$

$V_A = 25°$ $\quad V_B = 0, 50, 90, 180°$

$V_A = 45°$ $\quad V_B = 0, 50, 90, 180°$

V_C = variable

The values follow the drawn curve very well, showing that the hypothesis is reasonable. If the term K is neglected, a spread in values for higher angles of facets is recognized.



The conclusion

The conclusion is that the model is useful to describe reflection from rugged non-metallic surfaces, and knowing β as a function of V_C for fixed values of V_A and V_B is enough to describe the reflection ability for any other direction, presuming moderate sizes of V_A, V_B and V_C.

References

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Fig.6. Distribution of facets f_Ω versus V_N. Verteilung von Facetten f_Ω gegen V_N. Distribution des facettes, f_Ω en fonction de V_N.

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