Performance of retroreflective road equipment

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Foreword

This textbook on the performance of retroreflective road equipment has been prepared by the NMF with the scope to collect the knowledge that has been obtained in a number of projects carried out by the NMF or with the assistance of members of the NMF, to put this knowledge into an international and practical perspective, and make it available for future use, in particular for the education of persons working in the field of road signing.

It is the intention that the textbook itself is translated to Nordic language, when this is relevant, while the annexes A to C with more detailed information remain in the English language only. It may also be useful to translate the annex X on light and units.

A similar textbook on road markings and road surfaces has already been prepared. It is a further intention to prepare additional textbooks on other types of road equipment on which the NMF has worked; including variable message signs, road lighting, signal heads and yellow flashing lights at road works.

NMF (Nordisk Møde for Forbedret vejudstyr – translates to Nordic Meeting for improved road equipment) was founded in 1973 and is a well established forum in the Nordic countries for co-operation between the national road administrations and researchers in the field of development and improvement of road equipment. It is the scope of the NMF to provide – through FoU activities – the knowledge basis for improvement of the visibility and/or legibility of the road and its various components (road markings, road signs, road lighting, retroreflectors, delineators, signal and warning lights etc.).

The road road users orientation and understanding of the road and current traffic situations is to be supported through improvement of the transfer of information between the road and the road user.

An important activity of the NMF is to take part in the European standards work within the CEN. Through the conduction of research, whose results should have directs consequences for the drafting of standards for road equipment, the Nordic countries together have the possibility of playing a positive and decisive role in this work.

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Introduction

Chapter 1 provides a brief account of the different types of retroreflective road equipment.

The chapters 2, 3 and 4 may be considered as shorter versions of annexes A, B and C which give more extensive accounts of:
Annex A: Retroreflectors and retroreflective sheeting materials
Annex B: The performance of retroreflective road signs
Annex C: Measurement of retroreflection

It is the intention that the chapters 2, 3 and 4 should be easier to read than the annexes and that the interested reader can find more detailed information in the annexes.

An additional annex X explains light and units and it intended for reference regarding characteristics and units for illumination and reflection.

1. Retroreflection and retroreflective road equipment

1.1 Introduction

Retroreflection in general is introduced in 1.2, characteristics and units for retroreflection in 1.3, colour and daylight reflection in 1.4, general properties of retroreflection in 1.5 and technologies for retroreflection in 1.6.

A distinction is made between the two technologies of lens and prism based retroreflection and also between retroreflectors and retroreflective sheeting materials. Accordingly, 1.7, 1.8, 1.9 and 1.10 describe respectively lens based retroreflectors, prism based retroreflectors, glass beaded sheeting materials and microprismatic sheeting materials.

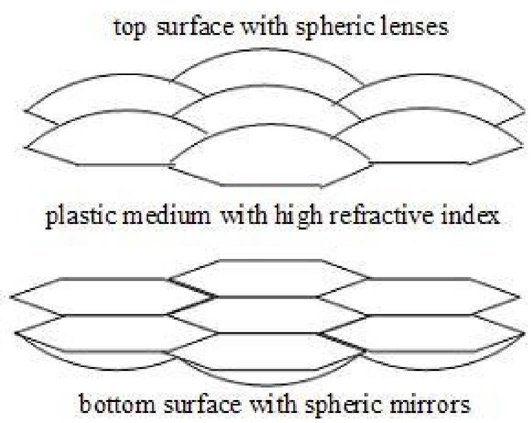
The last-mentioned clauses seem to indicate a conflict between the concerns of a high retroreflectance on one hand and a good entrance angularity and simplicity on the other hand.

There is no theoretical proof that there should be such a conflict, so the question arises if it is practically or theoretically possible to achieve everything – high retroreflectance, good entrance angularity, simplicity and good daylight reflection in a single product.

The author is not able to answer that question.

A glass bead with a particular volume variation of the refractive index could be used to make a perfect glass beaded material – but such a glass bead is perhaps only an idea of the mind. A microprismatic material made of a high refractive index material would show better entrance angularity – but not without disadvantages.

A perhaps good candidate is shown below. It is a hexagonal packing of spherical lenses in a top surface and the same packing of spherical mirrors in a bottom surface. In between the two surfaces there is a plastic medium with a high refractive index. It is like a HI material, but avoids the aberrations from the peripheral parts of glass beads and uses all of the incoming light up to an entrance angle of perhaps 40°.



1.2 General about retroreflection

Retroreflection of an object is the ability of the object to reflect incoming light in a narrow beam about the direction opposite to the direction of the incoming light. Retroreflection serves to make retroreflective objects much brighter in headlamp illumination at night than they would be with ordinary reflection, typically by a factor of 10 to 1000. Ordinary reflection and retroreflection is illustrated in figure 1.

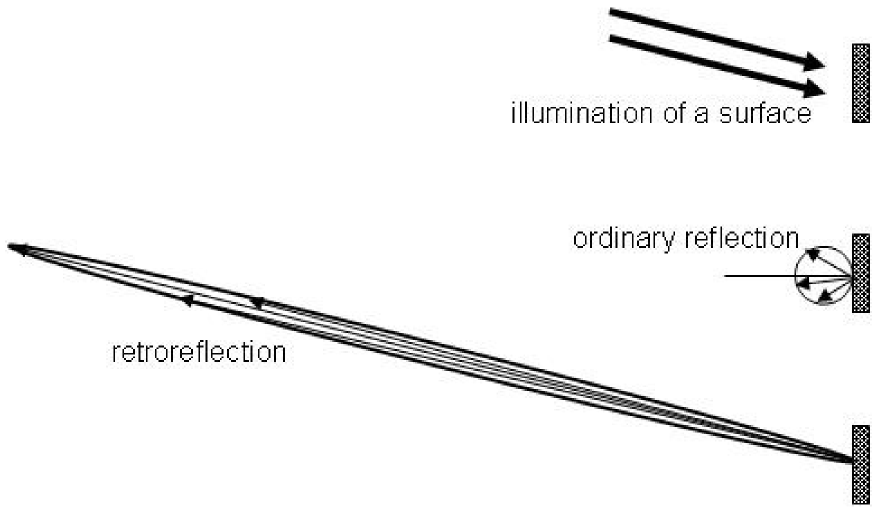


Figure 1: Illustration of ordinary reflection and retroreflection.

The power of retroreflection compared to ordinary reflection can be explained by the width of the reflected beam, which is typically ±2°-3° as compared to ±90° for ordinary reflection.

NOTE: The intensity of reflected light within a cone is in inverse proportion to the solid angle of the cone. The solid angle of a cone of a width of ±2°-3° is of the order of 1000 times smaller than a cone of a width of ±90°.

The above-mentioned factor between retroreflection and ordinary reflection is impressive. Additionally, retroreflection is a cheap means to improve visibility conditions at night compared to the use of signal lights and illumination. This explains why retroreflection has an extensive use for night traffic. However, as it will become clear gradually, retroreflection does not provide ample light at night – in many conditions it is actually barely sufficient.

1.3 Characteristics and units for retroreflection

Small retroreflective objects used on vehicles, in road studs and on delineators etc. are called retroreflectors. The ability of a retroreflector to retroreflect in a particular geometrical situation is measured by the ratio between the luminous intensity I produced by retroreflection and the illuminance E produced by the headlamps at the location of the retroreflector. The ratio is called the coefficient of luminous intensity CIL.

The natural unit for CIL is candelas per lux ($cd \cdot lx^{-1}$) as the luminous intensity is measured in candela and the illuminance is measured in lux. However, the one thousand times smaller unit of millicandelas per lux ($mcd \cdot lx^{-1}$) is used in practice in order to obtain convenient numerical values.

Large retroreflective surfaces, such as retroreflective sign faces, obtain their retroreflection by means of retroreflective sheeting materials applied to substrates. Large retroreflective surfaces can therefore be discussed in terms of retroreflective sheeting materials.

The ability of a large retroreflective surface to retroreflect in a particular geometrical situation is measured by the ratio between the luminance L produced by retroreflection and the illuminance E produced by the headlamps at the location of the retroreflective surface. This ratio is called the coefficient of retroreflected luminance R_L. The unit is candelas per square metres per lux ($cd \cdot m^{-2} \cdot lx^{-1}$).

However, for some traditional reason, another measure is used in practice, which is the CIL per square metres of the surface. This ratio is called the coefficient of retroreflection R_A in the unit of candela per lux per square metres ($cd \cdot lx^{-1} \cdot m^{-2}$).

The two measures are related by $R_A = R_L \times \cos(\beta)$ or $R_L = R_A / \cos(\beta)$ where β is the angle of incidence measured between the direction of illumination and the normal to the surface. This angle is normally called the entrance angle in connection with retroreflective surfaces.

1.4 Colour and daylight reflection

The colour of retroreflected light is an essential characteristic for retroreflectors as these are generally used with specified colours. The colour is measured in a particular geometry assuming standard illuminant A, which represents an incandescent lamp, and expressed by the CIE chromaticity coordinates x and y. Refer to CIE 15.

In some cases the colour of retroreflected light is also used as a characteristic for large retroreflective surfaces such as retroreflective sign faces, but it is mostly assumed that an acceptable daylight colour ensures that the colour of retroreflected light is also acceptable.

Daylight reflection and colour is unimportant for the retroreflective surface of retroreflectors, but may be a meaningful characteristic for the body holding the retroreflector. Daylight reflection and colour is an essential characteristic for retroreflective sheeting materials.

Daylight reflection and colour is measured the 0°/45° or 45°/0° geometry assuming standard illuminant D65, which represents daylight, and is expressed by the luminance factor and the CIE chromaticity coordinates x and y. Refer again to CIE 15.

The levels of retroreflection that are mentioned in the following are intended for white retroreflectors and retroreflective surfaces. Other colours are associated with lower levels of retroreflection as the colours are created by selective absorption.

Colours of retroreflectors are normally obtained by inherent colours of the materials of which the retroreflectors are made.

Colours of large retroreflective surfaces are created either by inherent colours of the sheeting materials, use of coloured overlay films or screen printing.

1.5 General properties of retroreflection

The intention of using retroreflectors is that the retroreflection in combination with headlamp illumination provide enough luminous intensity to make them visible at sufficient distances at night. Similarly, the intention of using retroreflective signs is that the retroreflection in combination with headlamp illumination provide enough luminance to make the legends of the signs legible at night.

The width of the beam of retroreflected light is important as the retroreflected beams created by the two headlamps must be wide enough to include the eyes of the drivers in relevant traffic situations. The beams should, on the other hand, not be much wider than necessary as the brightness of the object would otherwise become unnecessarily low.

NOTE: With a given luminous flux within a cone, the luminous intensity or luminance is in inverse proportion to the square of the angular width of the cone.

There is no single optimum beam width as some retroreflective objects are intended to be visible at long distances, while others are intended to be visible at shorter distances. However, the beam should not be much wider than ±2°-3° in general.

A good retroreflective object should retroreflect a sizeable proportion of the luminous flux that falls on the retroreflective surface. This proportion is called the retroreflectance and is expressed as a fraction or a percentage. The concept of retroreflectance is used in the following in the sense that only light reflected within a useful width of the beam is included.

Another important feature is the ability of a retroreflective object to maintain retroreflection in a range of illumination directions that is sufficient in view of the relevant traffic situations. The range should not be just barely sufficient, but have a reserve for variations in the mounting and alignment of the retroreflective object.

This concept is in general called "entrance angularity. In some cases a range of ±10° would be sufficient, but in other cases a much bigger range is needed, up to perhaps ±40°.

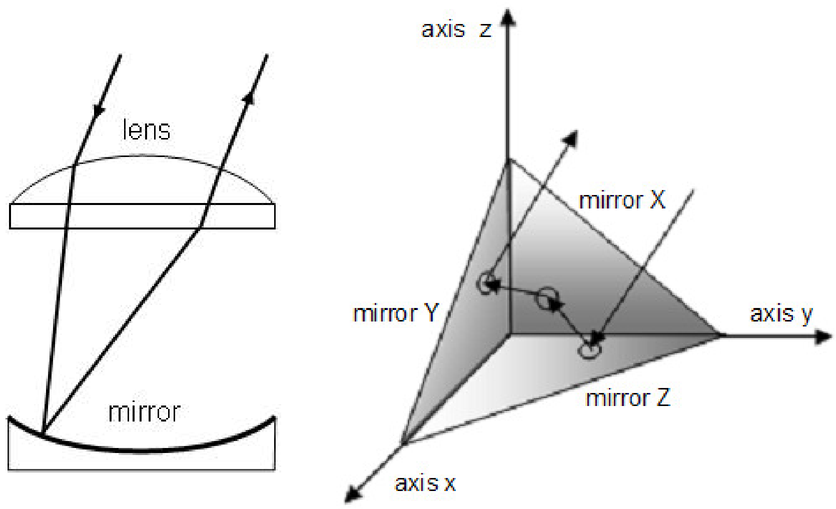
Simplicity of the retroreflective features is also a consideration. For instance that the retroreflected beam has a gradual variation like a bell shape, and that the beam intensity and shape and does not vary strongly with the details of the geometry of the traffic situation.

It is with the above-mentioned loosely described quality measures in mind that different technologies for retroreflection can be discussed.

1.6 Technologies for retroreflection

Surprisingly, there are two and only two methods to produce retroreflection in use – perhaps at all – and they are almost equally important in practice. The first method is to use a lens in combination with a mirror at the focal width of the lens, and the second is to use three mutually orthogonal mirrors that in general are three faces of a prism. The two methods are illustrated in figure 2.

Figure 2: Two methods to produce retroreflection: a lens and a mirror (left) three orthogonal mirrors (right)



Both of these methods are used for both retroreflectors and retroreflective sheeting materials.

It is useful to distinguish between the two methods as they lead to different qualities. Further, it is useful to distinguish between retroreflectors and retroreflective sheeting materials for a couple of reasons:

- the measures of brightness are different
- the two methods of retroreflection are applied in different ways
- daylight reflection is unimportant for retroreflectors, but essential for retroreflective sheeting materials.

Accordingly, the discussion is divided into lens based retroreflectors, prism based retroreflectors, retroreflective sheeting materials using glass beads and microprismatic sheeting materials.

Retroreflectors are also produced by mounting sheeting materials on small substrates. Such retroreflectors possess the properties of the sheeting materials in proportion to the areas and are not mentioned further.

1.7 Lens based retroreflectors

A lens based retroreflector incorporates one or more "cats eyes" that are traditionally made in glass. This technology is old, from the childhood of car driving, but is still in use and competitive. Examples of use are road studs (raised pavement markers) and delineators.

A cats eye retroreflector has the lens and the mirror integrated in a single body. This is shown in figure 3, while figure 4 shows the working principle of the retroreflector. Figure 5 shows a particular cats eye with a diameter of approximately 10 mm and figure 6 two such cats eyes mounted in a road stud (raised pavement marker).

Figure 3: Cats eye retroreflector.

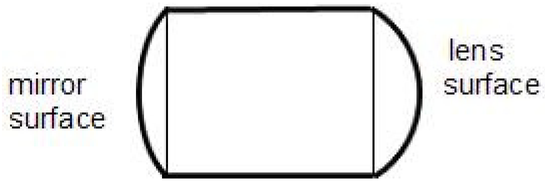


Figure 4: The principle of the cats eye retroreflector.

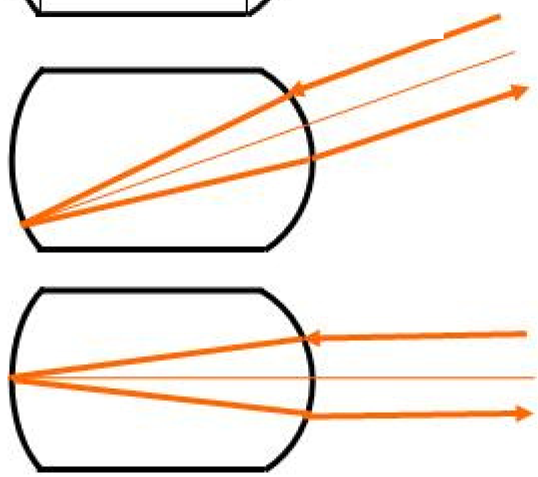


Figure 5: A particular cats eye.

Figure 6: Two cats eyes mounted in a road stud.

A cats eye retroreflector can have a high retroreflectance, a good entrance angularity and simple symmetrical properties of retroreflection. The road stud shown in figure 6 has the peculiar feature that the body is in rubber, so that the eyes blink when the road stud is run over by the wheels of vehicles.

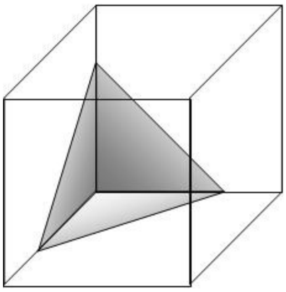
The disadvantage of cats eyes is that the active area is rather small, which puts a limit to the CIL values.

1.8 Prism based retroreflectors

Prism based retroreflectors are discussed in some detail in the following – partly because the principles are interesting and partly because the same principles apply for microprismatic sheeting materials.

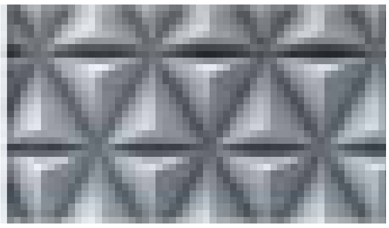
Prism based retroreflectors are also called cube corner retroreflectors because the prism faces relate to each other as the adjourning sides at a corner of a cube as shown in figure 7.

Figure 7: Three surfaces in a cube corner prism.



The prisms need to be packed to form the total retroreflector. The classic layout is obtained by placing triangular prisms (as illustrated in figure 7) side by side in a hexagonal pattern. This packing, as seen from the back of the retroreflector, is shown in figure 8.

Figure 8: The classic packing of prisms seen from the back.



Cube corner retroreflectors were originally made in glass and has a history almost as long as cats eyes. Nowadays, these retroreflectors are in moulded plastic and have a wide range of use on vehicles, cycles, pedestrian clothes and in road equipment including road studs and delineators.

There are two conditions for retroreflection in a cube corner prism; both are discussed in the following.

The first condition is that each of the three backsides of the prism actually provide mirror reflection.

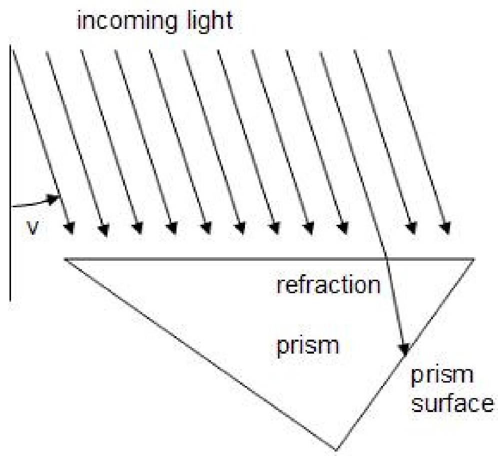
In some rare cases, the backsides of the prisms are metallised in order to ensure mirror reflection with, however, some loss. In the general case, however, the mirror reflection is provided by total reflection in the interfaces from plastic to air of the backsides.

Total reflection is ensured whenever the angle of incidence on a surface exceeds the minimum angle for total reflection. This angle is given by $\sin^{-1}(1/n)$, where n is the refractive index of the plastic material. When assuming a refractive index of approximately 1,55 for the plastics normally used, the angle is approximately 40°.

A ray of light in a direction perpendicular to the aperture meets any of the three prism faces at an angle of incidence of 54,7°, which ensures total reflection with some reserve.

However, when the light is directed an angle v towards one of the prism surfaces as shown in figure 9, the angle of incidence on that surface decreases. The angle within the plastic medium changes by less than v because of refraction in the air-plastic interface, actually by $\sin^{-1}(\sin v/n)$ and v needs to be approximately 22° before total reflection fails.

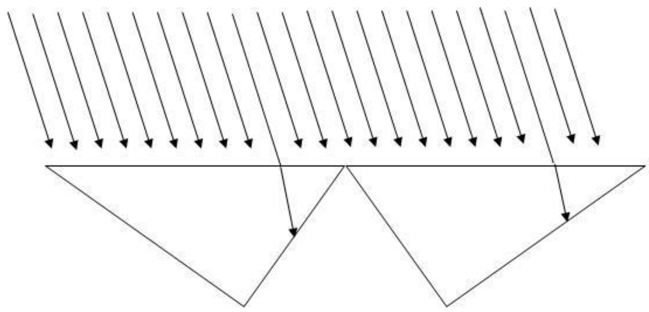
Figure 9: Incoming light directed an angle v towards one of the prism surfaces.



In the classic lay-out, two prisms form a pair, and the whole packing is made up of such pairs. A pair is shown in figure 10.

When the light is directed towards a prism face in one prism, it is directed away from the opposing face in the other prism. Therefore, when total reflection fails in one prism, it remains for the other prism even at large entrance angles.

Figure 10: A pair of prisms.

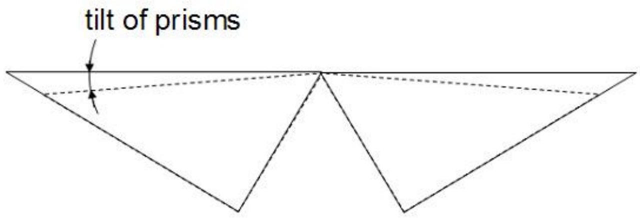


For this reason, the retroreflection does not fail for all of the prisms at an entrance angle of approximately 22°, only for half of them. This feature applies for every 60° rotation of the prismatic retroreflector relative to the light (or vice versa). At rotations in between, total reflection is maintained up to somewhat higher entrance angles.

However, an abrupt loss of half of the retroreflection at moderate entrance angles is bad enough and, therefore, various means are in use to counteract that.

One of these means is to tilt the prisms in the way indicated in figure 11, so that total reflection is maintained in a somewhat wider range of entrance angles. This helps only when the light arrives from the sides, not if the light enters from up or down. However, many retroreflectors sit at about the same height as the vehicle headlamps, so that the light can be expected to arrive from the sides.

Figure 11: A pair of prisms with a tilt.



Another of these means is to provide fields of cube corner prisms that are tilted to the sides. See the cycle retroreflector in figure 12.

Figure 12: A cycle retroreflector with tilted fields of prisms.

Both of those means destroy the above-mentioned repetition for every 60° rotation and replaces it with symmetry up/down and right/left.

The second condition for retroreflection is that the ray of light meets all three prism faces on its path. This condition is complied with, when the ray in its original direction points towards the triple mirror image of the aperture of the prism.

By triple mirror image is meant the mirror image of the aperture after mirror reflection in one of the prism faces, then one more and finally the third of the prism faces. Figure 13 shows the three faces and their triple images, while figure 14 shows the active and non-active areas of the aperture for the particular direction of view used in figure 13.

Figure 13: Prism faces and their triple images.

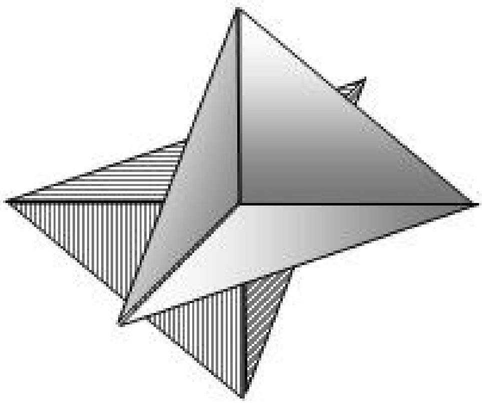
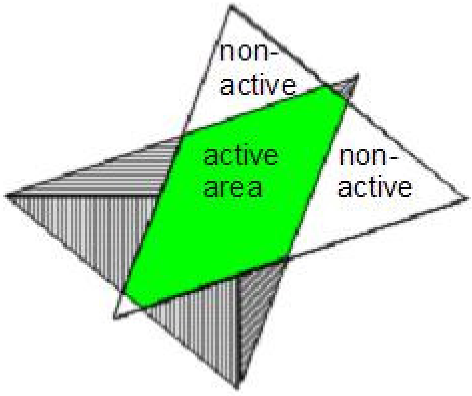


Figure 14: Active and non-active areas for a particular direction.



A ray of light that does not enter at an active area (for the particular direction) is only reflected in one or two of the prism faces – and is not retroreflected. Therefore, light entering at non-active areas is lost in terms of retroreflection.

The active area depends on the packing of the prisms and on the direction. For the classic packing of prisms, the maximum active area is 2/3 of the aperture area and is obtained for the direction perpendicular to the front. For other directions the active area is smaller and decreases with the entrance angle.

Another lay-out of the prisms has square instead of triangular prism faces as shown in figure 15. Such prisms do not have a plane aperture, but this does not prevent that they are packed tightly like an incomplete stack of boxes as illustrated in figure 16. A cube corner retroreflector with this lay-out is shown in figure 17.

Figure 15: Prism faces with the shape of squares.

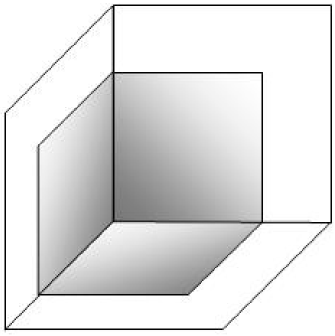


Figure 16: Packing of square prism faces.

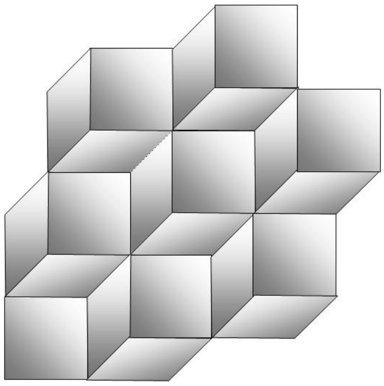


Figure 17: A retroreflector with square prism faces.

Cube corner retroreflectors with square prism faces have the special feature that the whole area is active for the direction perpendicular to the front. A retroreflector of this type looks almost black when observed face on – at least when it is of good quality. The reason is that the retroreflector reflects the black pupils of the observers own eyes.

Accordingly, the packing of squares is 50 % more efficient for the central direction than the classic packing of triangles. However, the active area decreases more quickly with the entrance angle, so that the gain is not big in practice when considering a range of entrance angles. The above-mentioned repetition for every 60° rotation is replaced with a repetition for every 120° rotation.

In order to improve on the entrance angularity, retroreflectors with square prism faces are also sometimes divided into fields with different orientations. See the cycle retroreflector in figure 18.

Figure 18: A cycle retroreflector with square prism faces and three field of different orientations.

1.9 Glass beaded sheeting materials

Glass beaded sheeting materials rely on the lens/mirror method of retroreflection. High index glass beads serve as lenses and an aluminium layer shaped to each glass bead serve as mirrors. The glass beads are small in order that the sheeting materials can be thin and flexible.

This construction has a number of consequences for the retroreflection:

- The smallness of the beads causes diffraction in a ring shaped pattern that tends to broaden the retroreflected beam and add colour fringes.
- Dispersion (variation of the refractive index with the wavelength) causes poor collimation that tends to broaden the retroreflected beam and add colour fringes.
- A glass bead is a poor lens in the sense that the focal width varies from the centre out towards the periphery of the bead. This tends to broaden the retroreflected beam and also adds a corona in a cone out to ±20° or more.
- There are aberrations in the sense that the beads are not perfect spheres, they vary in size and the mirrors are not always precisely located. This tends to broaden the retroreflected beam even further and to hide colour fringes.

Because of several broadening effects, glass beaded sheeting materials have fairly wide retroreflected beams. Additionally, the corona corresponds to a substantial loss and causes the retroreflectance values to become fairly low. Because of the aberrations, the above-mentioned colour fringes cannot be seen, except in a single product (Super Engineering Grade) with glass beads sorted to approximately the same size.

The construction and the consequences also explain that the retroreflective properties are simple. It is often assumed that there is symmetry with rotation of the material relative to the light (or vice versa) and that the retroreflected beam itself has rotational symmetry.

Glass beaded sheeting materials were developed fairly early and have lead to the almost general use of retroreflective sheeting materials for road signs and several other applications.

The first version of such materials is the enclosed lens, also called Engineering Grade, or just EG. It was developed into its present construction during the 50's. EG materials still have widespread use and are supplied by a number of manufacturers.

The second version is the encapsulated lens, also called High Intensity or just HI. A single manufacturer (3M) placed it on the market during the early 70's and had monopoly due to a patent until the 90's, when several more producers of the material emerged. EG and HI materials have been dominant on the market for a long time, and are probably still today.

The major difference between EG and HI materials is that the front parts of the glass beads are enclosed in a plastic layer in EG materials, while they are in air in HI materials. See figure 19.

A. EG materials

B. HI materials

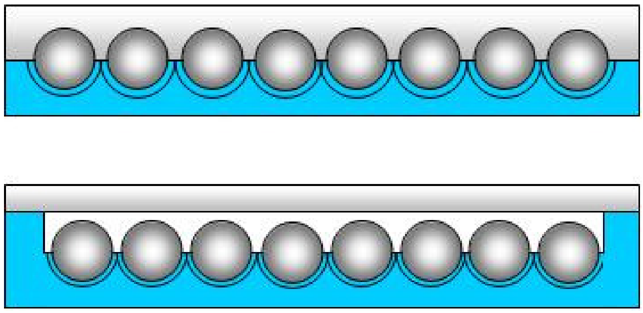


Figure 19: The construction of EG and HI materials.

EG materials have a continuous surface without features, except for trade marks and similar, while HI materials are divided into cells by ribs that support the front layer. These ribs are made to appear white in order to add to the daylight reflection. The ribs are shaped in distinctive patterns that are characteristic for the different products.

A particular EG material with glass beads sorted to approximately the same size is called Super Engineering Grade or just SEG by the producer.

EG materials provide a fairly large width of the retroreflected beam, while HI materials provide a beam which is less wide and more suitable for most purposes. Because of this; the R_A value of white materials in the centre of the beam is of the order of 75 $cd \cdot m^{-2} \cdot lx^{-1}$ for EG materials and above 200 $cd \cdot m^{-2} \cdot lx^{-1}$ for HI materials. The entrance angularity is good for EG materials and very good for HI materials – with some variation among the individual products.

The above-mentioned corona represents a loss of light as it does not add to neither the retroreflection nor to the luminance factor for daylight reflection as measured at 45°. Therefore, the luminance factor values are modest, approximately 0,45 for white EG materials and 0,3 for white HI materials – again with some variation among products. The lower value for HI materials is probably due to a more dense packing of glass beads, and is in spite of the above-mentioned contribution from the supporting ribs.

In practice, the materials look more bright in daylight than indicated by the luminance factor values. This is because of contributions from retroreflection, the above-mentioned corona and some specular reflection in the front surface.

1.10 Microprismatic sheeting materials

A microprismatic sheeting material has a plastic layer with prisms imprinted on the backside and a further white reflecting layer behind this layer with supporting ribs between the two. The prisms are small so as to make the sheeting materials thin and flexible.

The smallness of the prisms tends to cause diffraction into a hexagonal pattern that would tend to shape the retroreflected beam and add colour fringes. However, these effects are not seen in most materials because of deliberate introduction of aberrations that broaden the retroreflected beam and, thereby, hide the effects.

This is the only broadening effect of microprismatic sheeting materials as compared to a number of such for glass beaded sheeting materials. Accordingly, microprismatic sheeting materials have a potential for more narrow retroreflected beams than glass beaded sheeting materials.

Additionally, microprismatic materials do not have a loss like the corona mentioned for glass bead materials and, therefore, a potential for a higher retroreflectance. With a suitable lay-out, the luminance factor can be reasonably high as well.

The prisms have the same geometrical configurations as accounted for prismatic retroreflectors and, therefore, the same sources of variation of the retroreflection:

- loss of total reflection of some prisms at moderate entrance angles
- variation of the active area with the illumination direction.

Therefore, the entrance angularity is less good and the practical rotational symmetries of glass beaded sheeting materials are lost and replaced with lower grades of symmetries. One producer (Avery Dennison) have attempted to re-establish these symmetries by the use of small fields of prisms with different rotations.

There are two additional negative effects that can be observed for microprismatic sheeting materials. These effects are caused by light that falls on non-active areas and undergoes complex paths before it is reflected back to become:

- diffusely reflected
- mirror reflected
- Newton refracted.

Diffuse reflection occurs for light that has penetrated through the prism layer to the white back layer, been reflected there and penetrated back through the prism layer. This light adds to the luminance factor and is beneficial in that sense.

Mirror reflection occurs for light that has been mirror reflected in two out of the three faces of a prism, then mirror reflected in the front surface, once again mirror reflected in two faces – but of another prism - and finally been transmitted back through the front surface.

This mirror reflection adds to the mirror reflection from the front surface and can in total be quite strong, for instance 20 %. This can be disturbing for the perception of a sign at daytime ,when it shows a fairly strong overlay mirror image of the surroundings, for instance of the sky with clouds.

Newton refraction is obtained for light that has penetrated through the prism layer at one prism, and then found its way back into the prism layer at another prism and finally been transmitted back through the front surface. These paths make a driver observe an overlay image with colour distortion of specific locations of the surroundings in front of the sign. Mostly there is no harm in that, but when the sun happens to be at one of the locations the sign becomes unreadable. This is described as ”flares” or ”sparkles” with a more kind word.

Figure 20 shows the distribution of reflected light from a vertical sign with a particular type of microprismatic material, when illuminated in a 5° upwards direction. All the features of retroreflection, diffuse reflection, mirror reflection and sparkles are clearly visible.

If the sun is at one of the sparkle points, a driver will see the flare when looking in this particular direction (5° upwards).

The distribution of figure 20 is generated by ray tracing, which can be made to show that all the features shift in intensity and location when changing the illumination (or observation) direction. The complexity is too high to allow simple predictions of when flares will occur in practice.

Figure 20: the distribution of reflected light from a vertical sign with a particular type of microprismatic material.

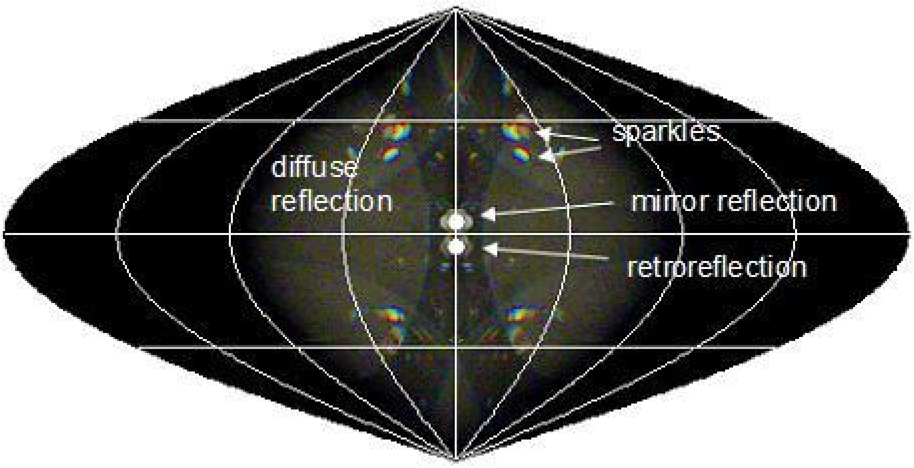
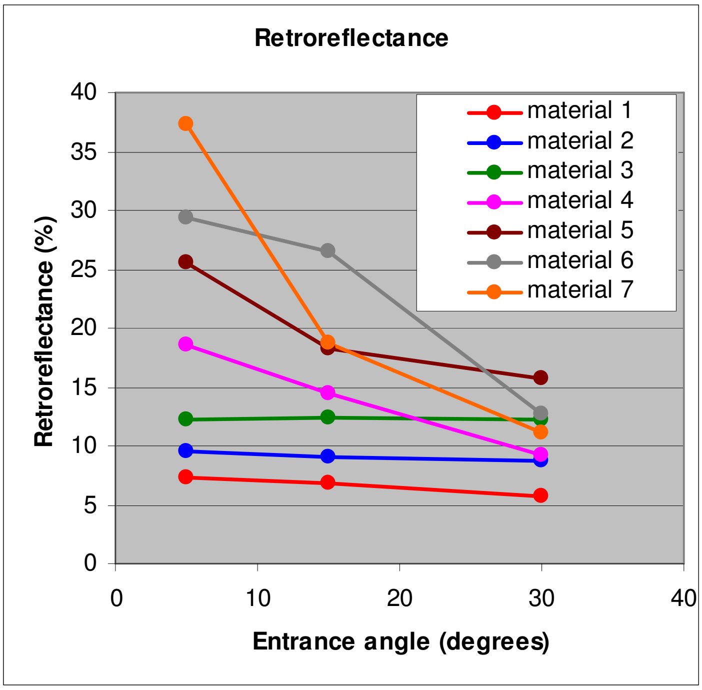


Figure 21 shows the retroreflectance of some sheeting materials as a function of the entrance angle. The materials 1, 2 and 3 in this figure are glass sheeting beaded materials, while the materials 4 to 7 are microprismatic materials.

Figure 21: The retroreflectance of a number of sheeting materials as a function of the entrance angle.



It is seen from figure 21 that the microprismatic sheeting materials have larger retroreflectance values than glass beaded materials at small entrance angles. This matter, and the more narrow retroreflected beams, explains that the R_A values of microprismatic sheeting materials can run into several hundreds of $cd \cdot m^{-2} \cdot lx^{-1}$.

Figure 21 also shows that the retroreflectance of the microprismatic materials decreases strongly with the entrance angle so that the advantage over glass beaded sheeting materials is limited at the largest entrance angle of 30° of the diagram. In practice, the comprehensive test as described in 2.4 may introduce a further reduction for microprismatic materials.

In conclusion, microprismatic sheeting materials are best suited for road signs on motorways and other high speed roads, where signs need to be read at long distance ranges and relatively small entrance angles.

This is a conclusion for most of the microprismatic sheeting materials that are on the market to-day, but this might change as new types of microprismatic sheeting materials are developed.

There should actually be room for the development of microprismatic materials with a variety of properties, and they are potentially more cheap to produce than glass beaded sheeting materials. Because of this, it may be expected that microprismatic materials will eventually become dominating.

The first microprismatic sheeting materials were developed early 70's, but substantial use for road signs and other road equipment did not start until the 80's, and did not gain momentum until the 90's. There is a variety of such materials available from a number of manufacturers and the use is increasing.

2. The performance of retroreflective road signs

2.1 Introduction

It is by headlamp illumination that retroreflective road signs obtain their performance. The most relevant case is the low beam and, accordingly, low beam headlamp light distributions are considered in 2.2.

This is followed by a general consideration of the interplay between retroreflection and headlamp illumination in 2.3. Two different approaches are used, one of which allows some simple deductions about retroreflection and sign luminance.

The basis for performance requirements for retroreflective road signs is considered in 2.4 which, by and large, is an account of the methods of prEN 12899-6 " Fixed vertical road traffic signs — Part 6: Retroreflective sign face materials".

Finally, an example of performance requirements is presented in 2.5.

The example is the performance requirements for retroreflective road signs of the Danish tender specifications "Almindelig arbejdsbeskrivelse (AAB) afmærkningsmateriel" for marking equipment, various road standards for road signs and the regulations "Bekendtgørelse om anvendelse af vejafmærkning" and "Bekendtgørelse om vejvisning på almindelige veje".

The account includes the types of sign faces that are used, their possible redefinition in accordance with prEN 12899-6, the sizes of character legends, symbols and signs needed to provide legibility and the use of the sign face types to create luminance balance with promotion of only a few signs.

2.2 Low beam headlamp light distributions

Only the low beam of headlamps is considered as it is critical in terms of sign illuminance and as the high beam can mostly not be used. When the high beam is used, it results in a much higher sign illuminance than accounted for in the following and sometimes to a degree that makes the signs glaring.

The light output of a low beam headlamp is described by a intensity distribution, which in principle is a table of intensities in candela (cd) for directions in space described by a horizontal and a vertical angle. In general, however, intensity distributions are illustrated by diagrams.

The intensity distributions of low beam headlamps are subject to ECE regulations. These regulations are specific for the various types of headlamps including the conventional headlamps using H4 halogen incandescent lamps and for the more recent types using HID (High Intensity Discharge) lamps or lens optics instead of parabolic reflectors. Additionally, the regulations are not precise regarding light emitted in upwards directions towards signs. This has lead to large variations among the headlamps of various types of cars.

Studies of new and clean headlamps have been carried out by the University of Michigan at a number of occasions and are published in UMTRI reports. One of these is UMTRI-2001-19 "High-beam and low-beam headlighting patterns in the U.S. and Europe at the turn of the millennium", which among else provides a 50 % fractile intensity distribution for European cars. By 50 % is meant the medium distribution (half of the headlamps provide more and half less).

The latest UMTRI study of this nature is reported in UMTRI-93-36 "Light output of U.S., European, and Japanese low-beam headlamps". This study also provides a 50 % fractile intensity distribution for European cars.

The two light distributions are quite similar. The UMTRI 2001 distribution covers the largest angular range and is, therefore, used for the illustration in figure 22.

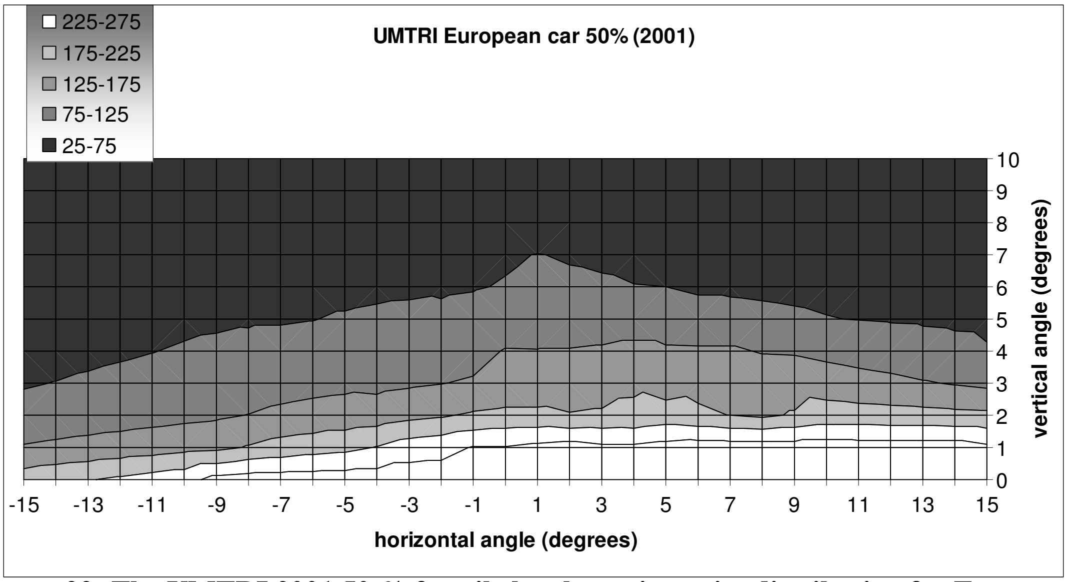


Figure 22: The UMTRI 2001 50 % fractile low beam intensity distribution for European cars.

The UMTRI studies are for new and clean headlamps. Studies of old and dirty headlamps are more numerous, but smaller and less well documented.

The age of headlamps seems to have little effect, as older - but clean - headlamps have intensity distributions that are similar to those of new and clean headlamps.

However, the normal thin traffic film on the front glass of headlamps raises the intensity in directions above the cut-off from 75 cd to 150 cd on the average and thereby raises the illumination on signs above the cut-off by a factor of two. The mechanism is scattering of a small percentage of the light emitted in the beam below the cut-off accompanied by a loss of beam power that is too small to be noticed.

Accordingly, intensity distributions of new and clean headlamps are pessimistic in terms of the predicted illumination of signs above the low beam cut-off.

This was understood by the CEN/TC 226 WG3 on vertical signs, which made a couple of attempts during the 90's to set up performance requirements for retroreflective signs. To this purpose, the 'standard' intensity distribution for the low beam headlamp as shown in figure 23 was developed on the basis of rather meagre data.

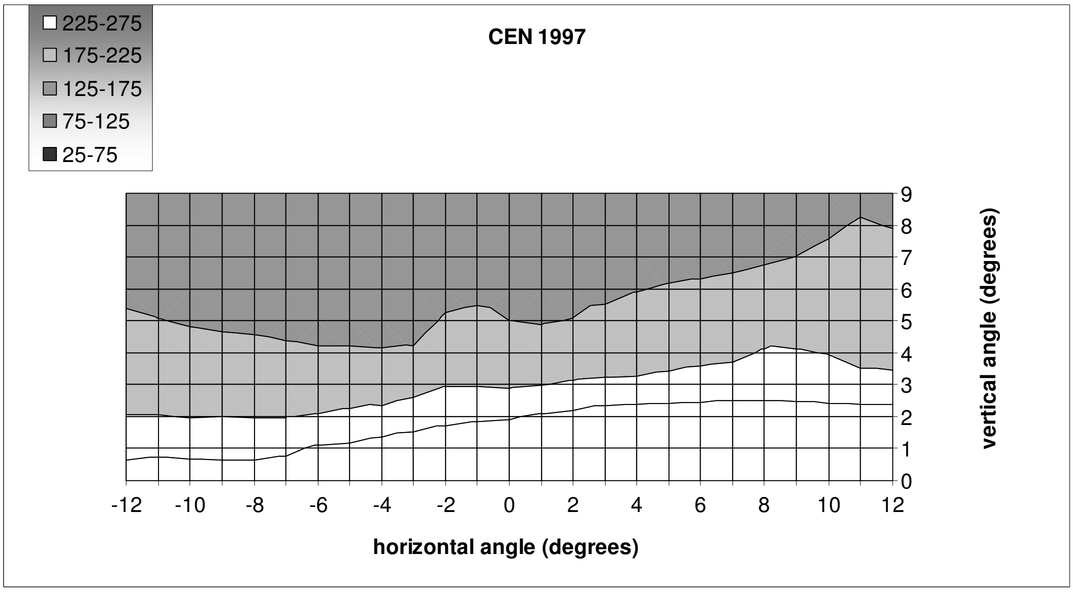


Figure 23: The intensity distribution derived by CEN/TC 226 WG3 in 1997.

A new attempt by the WG3 was started in the middle of the 2000's. As a preparation for that, DELTA performed some laboratory measurements on old and dirty headlamps and these measurements show an even higher intensity level than for the CEN 1997 distribution. Refer to "European low beam headlamps in view of retroreflective road signs", draft report by Kai Sørensen and Bent Rasmussen, DELTA, August 2003.

The average intensity distribution for dirty headlamps in use is shown in figure 24.

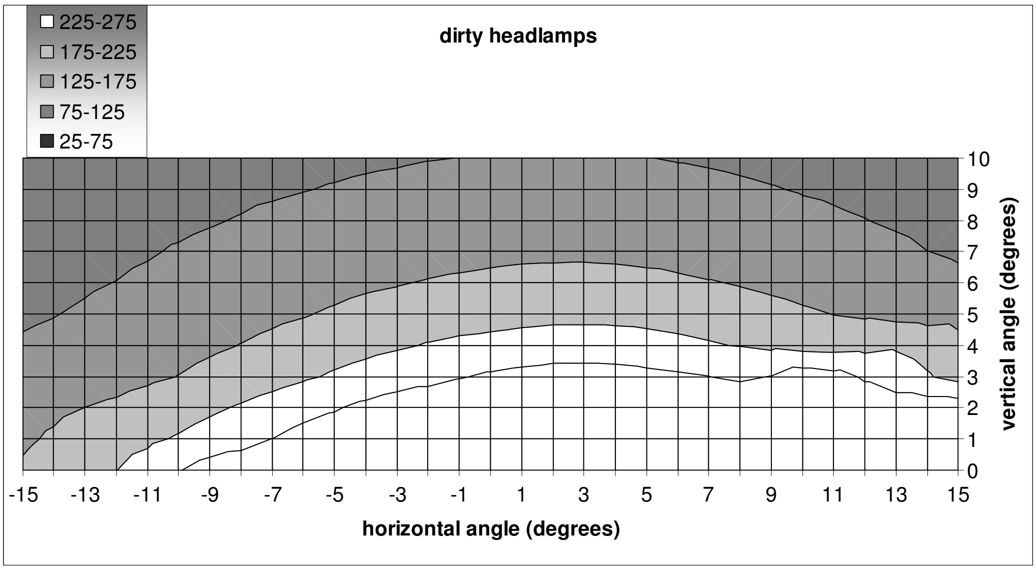


Figure 24: The average intensity distribution for dirty headlamps in use.

However, it was preferred to adopt the UMTRI 2003 distribution as the basis for developing the performance requirements provided in prEN 12899-6.

As a consequence, the luminance levels of retroreflective signs estimated on the basis of prEN 12899-6 are pessimistic. The real levels will often be twice as high, corresponding to two steps upwards in the retroreflection performance classes P1 to P8 introduced in prEN 12899-6.

The advice is not to be frightened by the low performance classes of conventional glass beaded sheeting materials, but still use them for the purposes for which they are adequate.

2.3 General consideration of the interplay between retroreflection and headlamp illumination

Figure 25 shows a driver in front of a retroreflective road sign at night. Each of the headlamps illuminate the road sign and some of the incident light is retroreflected into a narrow beam back towards the headlamp.

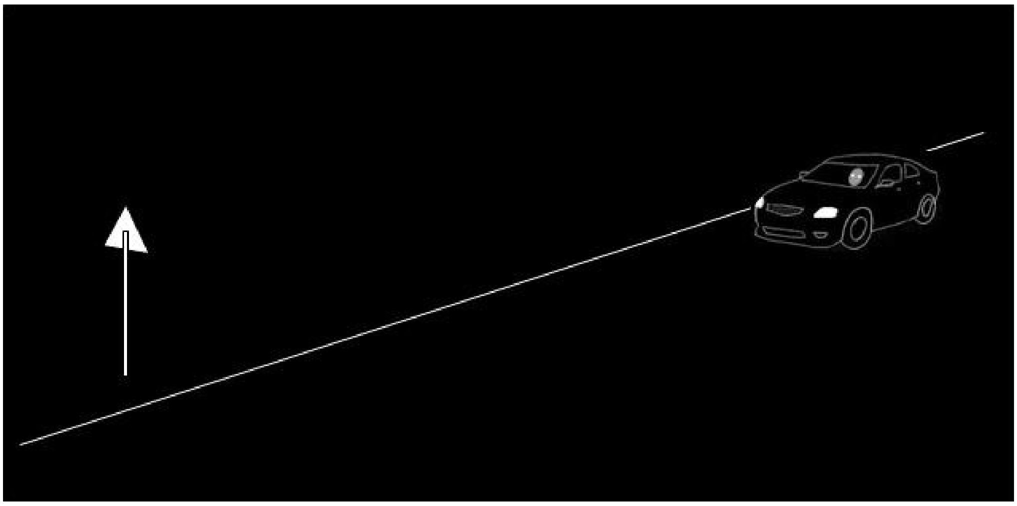


Figure 25: A driver approaching a retroreflective road sign.

Figure 26 illustrates the two illuminated fields caused by each of the retroreflected beams on a plane at the vehicle, and also the total field resulting from the overlay of the two fields.

The driver will see the road sign with some luminance, because the fields are sufficiently wide to provide illumination at the driver's eyes. This shows that the retroreflected beams need to have some width in order to provide sign luminance to the driver.

The figure illustrates the procedure used when calculating the sign illuminance. The contributions from the two headlamps are calculated separately and then added. The two contributions are generally not equal as the headlamp closest to the observer's eyes tend to provide the highest luminance.

Calculations of road sign illuminance involve all the geometrical details of the situation, the luminous intensities provided by the headlamps and data for the retroreflectivity of the particular sheeting material in dependence of the directionality of illumination and observation.

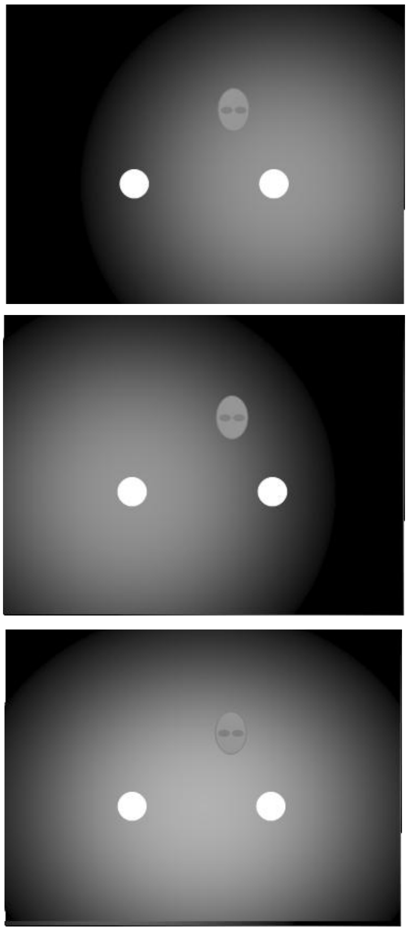


Figure 26: Illuminated fields caused by the retroreflected beams on a plane at the vehicle for the right headlamp (top), left headlamp (middle) and both headlamps combined (bottom).

Figure 27 illustrates a different approach to retroreflection.

The driver's direction of view to the road sign is retroreflected into a beam towards the vehicle and forms an observed field on a plane at the vehicle. In general, the sign shows a luminance in the direction towards the driver that is a weighted average of the luminance within the observed field. In this case, there is a luminance because the headlamps are within the field.

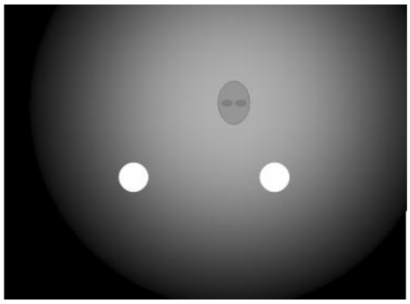


Figure 27: The observed field on a plane at the vehicle.

The observed field represents the area covered by the retroreflected beam, when the sign is illuminated in the direction of the drivers view. The approach relies on the principle of reversibility, which is generally applied in optics and lighting although probably never proved in detail.

The integral of the weights over the observed field represents the retroreflectance and has a maximum value of 1. In practice the value is significantly less than 1, down to approximately 0,1 even for white materials - depending on the particular sheeting material used on the road sign.

The contribution to the sign luminance from a headlamp is the area A of the headlamp within the observed field times the luminance L(headlamp) of that area times the weight W at the position of the headlamp. The area of the headlamp is to be measured as the solid angle seen from the road sign.

The product of the solid area A and the luminance L is the illuminance at the road sign E. Therefore, the contribution to the sign luminance is given by E×W. The total sign luminance is given by ΣE×W, where Σ stands for summation for the two headlamps.

In view of this; the last-mentioned approach allows some simple deductions about retroreflection and sign luminance:

- the maximum average R_L value of retroreflection within a cone of ±2° is 261 $cd \cdot m^{-2} \cdot lx^{-1}$
- when the R_L value is varied within the retroreflected beam, so that it is highest in the centre and decreases towards the edges, it is possible to achieve an approximately constant sign luminance over a range of distances
- the width of the retroreflected beam should be adapted to the range of distances at which the signs are to be read, so as to be narrow, medium and wide for respectively for long, medium and short distance reading
- with a retroreflected beam as described above, the driver of a large vehicle will see the road signs with a lower luminance than the driver of a small vehicle
- other light sources in the vicinity of the driver, like marker lights on trucks and headlamps of other vehicles, will add to the sign luminance.

2.4 The basis for performance requirements

2.4.1 The standard condition

It is clear that the sign luminance is in direct proportion to the level of luminous intensity of the headlamps.

It is also clear that the sign luminance depends on the vehicle geometry; in particular that the luminance is lower for the driver of a large vehicle than the driver of a passenger car, unless the large vehicle has other lamps in addition to the headlamps to assist in producing sign luminance.

Finally, the sign luminance depends on the sign position. This is illustrated in figure 28, which shows some typical sign positions indicated in the intensity diagram for the UMTRI 2001 50 % European car. Low mounting means a higher luminance than a higher mounting, and mounting to the right means a higher sign luminance than mounting to the left.

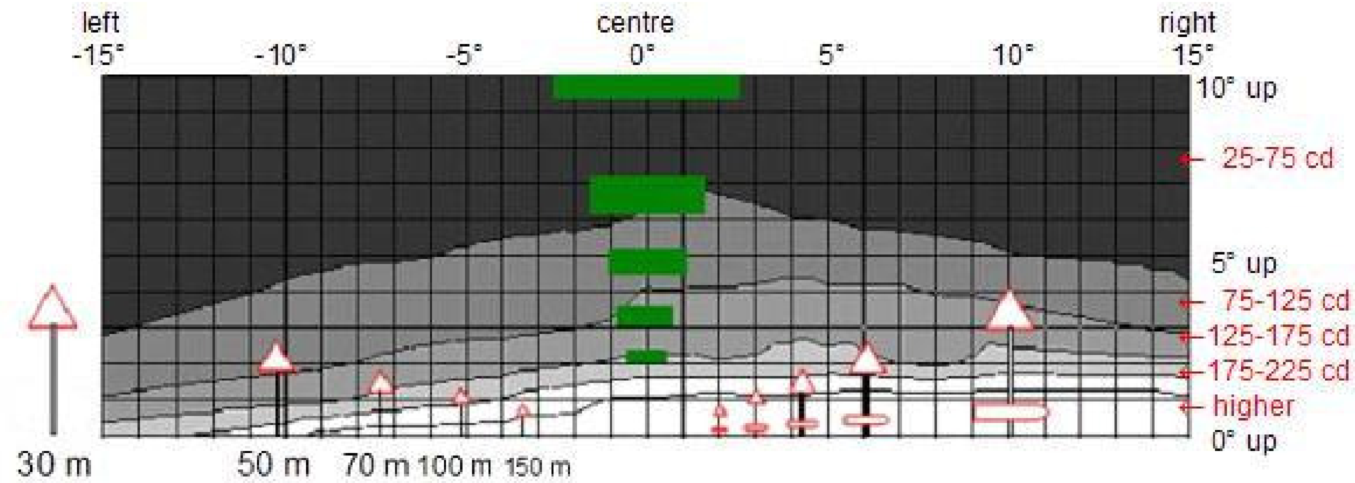


Figure 28: Typical sign positions indicated in the intensity diagram for the UMTRI 2001 50 % European car.

prEN 12899-6 copes with these variations by introcing a standard condition, in which the low beam headlamp is assigned the UMTRI 2003 distribution, the vehicle is a passenger car with a specified geometry and the sign is mounted on the right shoulder at a height of 2,5 m and a distance of 5 m to the right of the centre of the vehicle.

It is for this standard condition that prEN 12899-6 introduces a luminance level as a characteristic for particular sheeting materials. The luminance level is expressed by an R_A index.

This R_A index is only the starting point for an evaluation of the sign luminance. In particular, the actual sign luminance can be set higher if a more realistic level of headlamp light intensity is assumed.

2.4.2 Variation with the distance and the observation angle α

The major assumption behind performance requirements for retroreflective road signs is that the drivers need to see road signs with a particular luminance and that this luminance should be available for all distances within a relevant range.

The luminance provided by two headlamps is $L = \Sigma E \times R_L$, where E is the illuminance at the road sign as caused by a headlamp, R_L is the coefficient of retroreflected luminance and Σ indicates summation over the two headlamps of a vehicle.

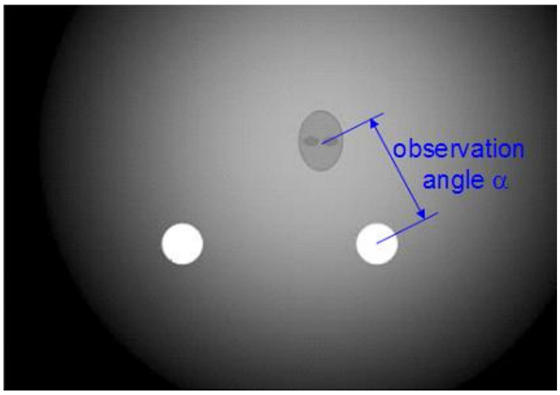
The illuminance on a road sign produced by a headlamp is given by $E = I \times D^{-2}$, where I is the luminous intensity of the headlamp in the direction towards the sign and D is the distance. Accordingly, the sign luminance is given by $L = (\Sigma I \times R_L) \times D^{-2}$. This shows that the sign luminance tends to vary in proportion with D^{-2}, which represents the distance law of illumination. However, the luminous intensity I tends also to vary with the distance.

Figure 28 shows that a sign moves to a smaller vertical angle, where the luminous intensity is higher, when the distance increases. The change is roughly in proportion with $D^{0,6}$ as an average for different locations of the sign. The net change in illumination is, therefore, roughly in proportion with $D^{0,6} \times D^{-2} = D^{-1,4}$.

This implies a decrease in illumination with increasing distance, although a smaller decrease than indicated by the distance law of illumination alone. In order to compensate for that, so as to maintain a roughly constant luminance over some range of distance, the R_L value should increase with distance in proportion to $D^{1,4}$.

The observation angle α measures the angular distance between the observer and a headlamp as shown in figure 29. This angle tends to be in inverse proportion to the distance, i.e.: $\alpha \propto D^{-1}$. Accordingly, the R_L value should roughly in proportion to $\alpha^{1,4}$.

Figure 29: The observation angle α.



The above-mentioned line of reasoning is a bit simplified because of the two headlamps on a vehicle and because the relationship between α and D does not quite abide to the above-mentioned relationship ($\alpha \propto D^{-1}$). However, calculations indicate that the sign luminance remains approximately constant with distance, when the R_L value varies in proportion to $\alpha^{1,4}$.

prEN 12899-6 introduces three ranges of distances each of which are defined by sets of standard values of the observation angle α. Refer to table 1.

Table 1: Sets of standard values for the observation angle α.

Complete set of values	2,00°	1,50°	1,00°	0,70°	0,50°	0,33°	0,20°
A1y: Long distance			1,00°	0,70°	0,50°	0,33°	0,20°
A2y: Medium distance		1,50°	1,00°	0,70°	0,50°	0,33°	
A3y: Short distance	2,00°	1,50°	1,00°	0,70°	0,50°		

For the standard condition, a sign luminance level of 1 cd/m^2 corresponds to a basic R_L value of $6{,}99 \times \alpha^{-1,4}$. The basic R_L values for the standard values of α are indicated in table 2.

Table 2: Basic R_L values corresponding to a sign luminance of 1 cd/m^2.

Values of α	2,00°	1,50°	1,00°	0,70°	0,50°	0,33°	0,20°
R_L ($mcd \cdot m^{-2} \cdot lx^{-1}$)	2,65	3,96	6,99	11,5	18,4	33,0	66,5

A particular sheeting material is assigned an R_A index value that reflects how many times larger its R_L values are than the basic R_L values. If for instance 5 times higher, the R_A index is 5. The comparison is done for the five values of α for a particular distance class, so that the R_A index is specific for that distance class.

The actual method is to form the five ratios between actual R_L values and basic R_L values and then derive the harmonic mean of the five ratios. The harmonic mean is the reciprocal of the average of the reciprocal values. When there is a variation of values, the harmonic mean is larger than the minimum value but smaller than the average.

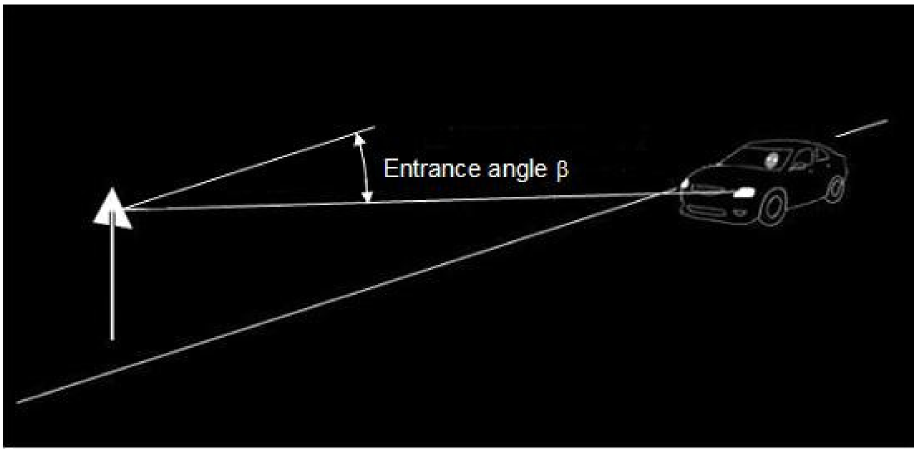
EXAMPLE: The five values of 5, 6, 7, 8 and 9 have the
- Average of: 7,0
- Minimum of: 5,0
- Harmonic mean of: 6,7.

The R_A index may be derived for more than one of the distance classes .

2.4.3 Variation with the entrance angle β

It is another assumption behind performance requirements for retroreflective road signs that the drivers need to see road signs with the particular luminance at all relevant values of the entrance angle β illustrated in figure 30.

Figure 30: The entrance angle β.



prEN 12899-6 introduces four sets of entrance angles, refer to table 3.

Table 3: Sets of standard values for the entrance angle β.

Complete set of values	5°	15°	30°	40°
Ax1: Narrow	5°			
Ax2: Medium	5°	15°		
Ax3: Wide	5°	15°	30°	
Ax4: Extra wide	5°	15°	30°	40°

The procedure described in the previous section is actually carried out for each value of β in the relevant set, after which the R_A index is determined as the smallest of the values obtained.

The sets of α and β are combined into application classes Axy, where x ranges over the three distance classes and y ranges over the four entrance angularity classes. Not all of these combinations are permissible and, in truth, only a few of them are relevant in practice.

The R_A index of a sheeting material will in general depend on the application class.

It may be noted that the R_A index is explained by means of R_L values in the above, while prEN 12899-6 actually uses R_A values. The relationship between the two characteristics is given by $R_A = R_L \times \cos(\beta)$.

2.4.4 Influence of additional angles and symmetries

It takes two angles, in addition to α and β, to describe the geometry of retroreflection in full detail. These angles are the rotation angle ε and the orientation angle ω_S as illustrated in figures 31 and 32 respectively.

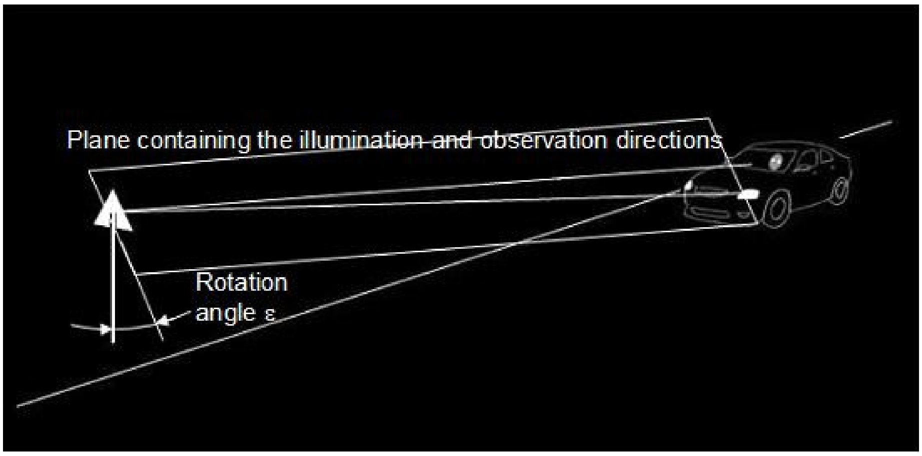


Figure 31: The rotation angle ε.

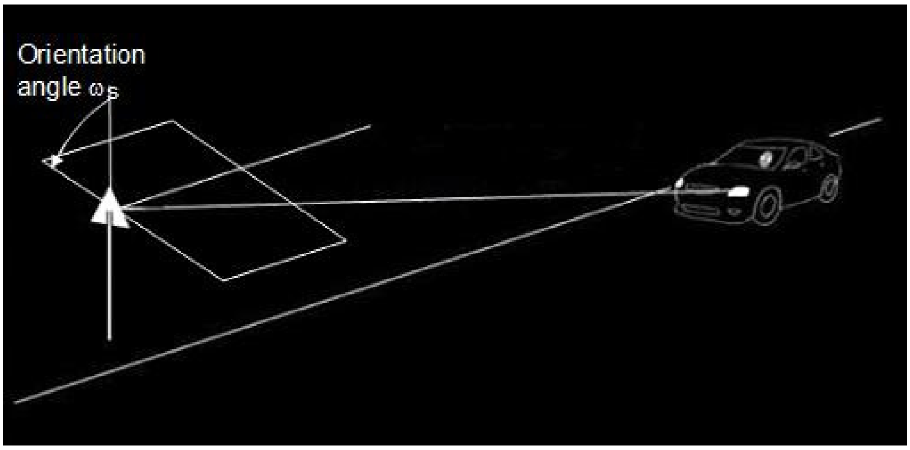


Figure 32: The orientation angle ω_S.

The rotation angle ε relates to the angle of location of a headlamp relative to the driver. It is individual for the two headlamps, and it varies with the sign position and distance. An influence of this angle reflects a possible lack of rotational symmetry of the retroreflected beam.

As this angle is not really under control, prEN 12899-6 defines a comprehensive test in which the R_A value at a particular combination of α and β is measured at ε = -45°, 0° and 45°. The average of the three R_A values is used as an R_A value cleaned of the influence of ε.

The orientation angle ω_S relates to the angle of location of the sign relative to the driver – for instance to the left, above or to the right. An influence of this angle reflects a possible lack of rotational symmetry of the retroreflection of the sheeting material.

As it is not really under control for which sign locations a sheeting material is used, the R_A value at a particular combination of α and β - as cleaned for the influence of ε in accordance with the above - is determined in up to 5 cases of ω_S of -90°, -75°, 0°, 75° and 90° referring to the sign positions respectively low to the left, high to the left, above, high to the right and low to the right. The smallest of these values is used to represent the sheeting material, when determining the R_A index.

This value is called the calculated coefficient of retroreflection and designated $R_{A,C}(\alpha,\beta)$.

The comprehensive test is used for only one white material of a family of sheeting materials. Other signal colours are measured in a more simple way, while contrast colours are measured in an even more simple way.

Symmetries up/down and/or right left; and also rotational symmetry, can be established by particular tests.

Refer to prEN 12899-6 for details.

2.5 An example of performance requirements

2.5.1 Introduction to the example

The example is the Danish performance requirements for retroreflective road signs described in the Danish tender specifications "Almindelig arbejdsbeskrivelse (AAB) afmærkningsmateriel" for marking equipment, various road standards for road signs and the regulations "Bekendtgørelse om anvendelse af vejafmærkning" and "Bekendtgørelse om vejvisning på almindelige veje".

These performance requirements are based on three types of retroreflective sign faces that are introduced in 2.5.2. The types have actually a long history, but the requirements for retroreflection were redefined on the basis that was obtained by the CEN/TC 226 WG3 in its first attempt to establish performance requirements late in the 90's.

It is the intention to redefine these types in accordance with prEN 12899-6, once this proposal appears as an EN. It is discussed in 2.5.2 how this can be done.

The performance requirements themselves are considered to have two aspects.

One aspect is the sizes of character legends, symbols and signs needed for legibility, which is considered in 2.5.3 on the basis of levels of retroreflective performance, the legibility of retroreflective signs at night and the legibility distances needed for particular signs. The other aspect is the balance of sign luminance among different signs, which is considered in 2.5.4 in terms of rules for the use of the three types of retroreflective sign faces.

2.5.2 Types of sign faces and their possible redefinition in accordance with prEN 12899-6

The Danish tender specifications for marking equipment "Almindelig arbejdsbeskrivelse (AAB) afmærkningsmateriel" define five types of sign faces:

- Type 1: transmitting and intended for transilluminated signs
- Type 2: ordinary reflection intending for non-retroreflective signs
- Type 3: retroreflective at short distance
- Type 4: retroreflective at medium distance
- Type 5: retroreflective at long distance.

Only the sign face types 3, 4 and 5 that are intended for retroreflective signs need to be considered. These are assumed to correspond to sign luminance values of white parts of signs of respectively 3, 5 and 10 cd/m^2.

The requirements for retroreflection are expressed as minimum requirements for a calculated value of the coefficient of retroreflection R_A for a combination of the observation angle α and the entrance angle β.

The calculated value is derived in a comprehensive test, which is similar but not identical to the comprehensive test defined in prEN 12899-6.

The types, including the comprehensive test, are confirmed in an annex to a regulation "Bekendtgørelse om anvendelse af vejafmærkning".

However, it is sensible and practical to introduce the comprehensive test of prEN 12899-6 and also to apply it for only one white material and allow reduced testing for other materials of signal colours in accordance with prEN 12899-6.

It is also sensible and practical to evaluate the retroreflective performance in terms of the R_A index defined in prEN 12899-1 instead of applying minimum requirements for each of the relevant $R_{A,C}(\alpha,\beta)$ values.

However, because of these changes of the test procedure and the method of evaluation, the nominal luminance levels of the types 3, 4 and 5 of respectively 3, 5 and 10 cd/m^2 are seemingly not provided by the R_A index of prEN 12899-6. The most important change is that the luminance levels of the types 3, 4 and 5 are based on the CEN 1997 headlamp distribution, while the R_A index of prEN 12899-6 are based on the UMTRI 2003 headlamp distribution with only half the luminous intensities.

As an example, a white EG material that meets the present requirements for type 3 with a nominal luminance level of 3 cd/m^2 obtains an R_A index of approximately 2 cd/m^2. A HI material that meets the present requirements for type 4 with a nominal luminance level of 5 cd/m^2 obtains an R_A index of approximately 4 cd/m^2. Finally, a white microprismatic sheeting material that meets the present requirements for type 5 with a nominal luminance level of 10 cd/m^2 obtains an R_A index of approximately 8 cd/m^2.

This seems like lowering the expectation of the sign luminance, but this is not really the case when trusting that the CEN 1997 distribution is more relevant than the UMTRI 2003 distribution. On the contrary, after multiplying the above-mentioned R_A index values by a factor of 2, they are actually higher than the present luminance values of the types.

There should be no problem in introducing the retroreflection requirements of prEN 12899-6 for other colours than white.

For type 3 there is the special matter of an additional requirement for the observation angle α of 0,33°. This requirement is intended for situ testing with portable instruments and could be replaced with a different requirement. The most suitable requirement is probably that the R_A value at an α of 0,33° and a β of 5° is minimum 50 cd·lx^{-1}·m^{-2} for a white surfaces of a new sign and to allow some depreciation during the warranty period to minimum 40 cd·lx^{-1}·m^{-2}. These are the minimum values used traditionally for EG materials.

For type 3 there is the additional special matter that there is an optional requirement for the entrance angle of 40° at the observation angle α of 2°. This requirement can be applied for signs that must be read at a short distance and under a large entrance angle. This can for instance be the case for directional arrow signs at roundabouts.

This optional requirement is sensible in itself, but does not fit into the application classes of prEN 12899-6. The obvious solution is to maintain such an optional requirement.

The requirements for daylight reflection and chromaticity are not identical to those of prEN 12899-6, but it is probably safe to introduce the requirements of prEN 12899-6.

In conclusion, it should be fairly simple and safe to re-define the types 3, 4 and 5 in accordance with prEN 12899-6, but some testing may be needed in order to determine the proper retroreflective performance classes of types 3 and 4.

2.5.3 The sizes of character legends, symbols and signs needed to provide legibility

It is a typical connection that signs that are intended for legibility at short distances are placed relatively low on the right shoulder, while signs that are intended for legibility at medium and long distances are placed at higher positions or in otherwise less favourable positions regarding sign luminance.

Simultaneously, signs that are intended for legibility at short, medium and long distances are primarily equipped with sign face materials of respectively types 3, 4 and 5. This shows that the luminance levels will not be the nominal luminance levels of the three types of respectively 3, 5 and 10 cd/m^2, but rather a uniform luminance level of 5 to 10 cd/m^2.

Drivers visual performance can be described by the legibility index TI, which measures the maximum legibility distance in proportion to the letter height of character legends. The legibility index for persons with normal visual acuity is approximately 7 m per cm in optimum conditions of luminance and contrast.

NOTE: The letter height is described by the height of upper case letters as lower case letter are as legible as upper case letters.

In less good conditions, the legibility index is reduced.

The best contrast is supplied by white as the signal colour and black as the contrast colour. This combination provides a legibility index of approximately 6 m per cm at the optimum luminance, which is normally considered to be in the region of 30 tor 100 cd/m^2. At the above-mentioned realistic luminance levels of retroreflective signs at night the legibility index is reduced to 4 to 4,5 m per cm.

A less good contrast is supplied with an often used combination of white and green, which provides a legibility index at realistic luminance levels of only approximately 4 m per cm

This illustrates that the night situation is the more critical for the legibility of retroreflective signs and that these should be designed so that they offer the necessary legibility distances at night.

It is normally assumed that a driver needs a time interval to read a sign of $t = 2 + N/3$ seconds, where N is the number of legends displayed on the sign. A legend may be a symbol, a number or a word such a city name.

The driver has to stop reading at some distance D_2 in front of the sign, either because he gets to close to the sign or he has to start acting on the message displayed on the sign. It is often assumed that a driver gets too close to a sign at a distance of 25 m, when the sign is shoulder mounted, and 50 m, when it is overhead mounted. When an action is needed, such a reducing speed, the reading of the sign may need to be completed at larger distances.

The driver moves a distance $D_1 = t \times V$ metres during t seconds, where V is the driving speed in metres per second. This shows that the legibility distance must be minimum $D = D_1 + D_2$ metres. Accordingly the letter height of character legends must be minimum $H = D/LI$ centimetres.

EXAMPLE: An overhead sign with three legends has to be read at a driving speed of 30 m/s (108 km/h) in the condition that reading must stop at $D_2 = 50$ m in front of the sign and the legibility index is 4 m per cm. The time needed is 3 seconds in which the driver drives a distance D_1 of s times 30 m/s equal to 90 m. The legibility distance must be minimum D = 90 + 50 m = 140 m and the letter height minimum H = 140 m divided by 4 m/cm = 35 cm.

This is the basis for choosing the sizes of character legends and thereby the sizes of the signs on which they are placed. A similar basis can be used for the sizes of symbols, when considering the smallest details that need to be discriminated in order that the symbols can be identified.

Standard shape signs (triangular, circular, octagonal and rectangular signs such as danger warning signs, priority signs, prohibitory and restrictive signs) are covered by a small number of sizes such as mini, reduced, standard, oversize and megasize.

Character legends on for instance direction signs are covered by a number of character heights in the sequence of 101 mm, 120 mm, 143 mm, 170 mm, 202 mm, 240 mm, 286 mm, 340 mm and 404 mm. It may be noted that each step is by a fixed factor and the height doubles in 4 steps. The character font has been developed with the aim of good legibility.

Direction signs on ordinary roads are covered by a regulation ”Bekendtgørelse om vejvisning på almindelige veje”.

Road standards give rules for the size and character height that is permissible in specific cases in order to ensure sufficient legibility distances.

2.5.4 The use of sign face types to create luminance balance with promotion of only a few signs

The general rule is that traffic signs (danger warning signs, priority signs, prohibitory or restrictive signs and mandatory signs) shall be retroreflective or illuminated. As an exception from this rule, give way signs, stop signs and all traffic signs on motorways shall be retroreflective, even if illuminated.

It is an additional rule that retroreflection or illumination must not be used in such a way that a particular traffic sign reduces the perception of other traffic signs. Give way and stop signs in particular must have at least as strong a retroreflection or illumination as other signs in the vicinity.

As a consequence of this rule, signs mounted on the same pole shall – with a few specified exceptions – have the same type of material.

As accounted for in the above, the types 3, 4 and 5 are mainly intended for use on retroreflective road signs that are to be read at respectively short, medium and long distance ranges and that the distance range is mostly related to the mounting height of the sign. Because of this, and because car headlamp illumination decreases with the mounting height, the level of required retroreflection is raised in the sequence of types 3, 4 and 5.

For this reason, it is a general rule that sign faces of traffic signs on ordinary roads must be type 3 while sign faces of traffic signs on motorways must be of type 4.

There is a number of exceptions from the general rule as based on these observations:

- There are cases where more than one of the types can be applied for a particular sign. In such cases the sign achieves a higher luminance level when having a sign face with a higher type number.
- A few signs are of such importance that they are promoted by the use of type 4 instead of type 3.
- Some signs are generally placed to the left, where they receive less headlamp illumination and, therefore, must be equipped with type 4 instead of type 3 in order to obtain as much luminance as signs placed on the right kerb.
- Signs with large white surfaces that are placed low to the right must be equipped with type 3 in order not to become glaring.

The exceptions for ordinary roads are shown in figure 33. The reader may be able to identify which of the above-mentioned observations that is relevant in the individual case. The exceptions for motorways are few and not accounted for.

In accordance with this, a particular traffic sign may need to be of type 3 for ordinary roads and type 4 for motorways. However, traffic signs on ordinary road are of the normal size or a reduced size, while traffic signs on motorways are of an oversize.

Therefore, each individual traffic sign of a particular size always has a particular type of sign face. This is highly practical and acts as a safeguard against mistakes.

The road standards addresses other signs in a similar manner. As an example, specific direction signs are to be type 3 on ordinary roads and type 4 on motorways.

A particular type of direction sign may be of either type 3 or 4, with a one step reduction of the character height if it is of type 4 which provides a higher sign luminance and, therefore, a higher legibility index.

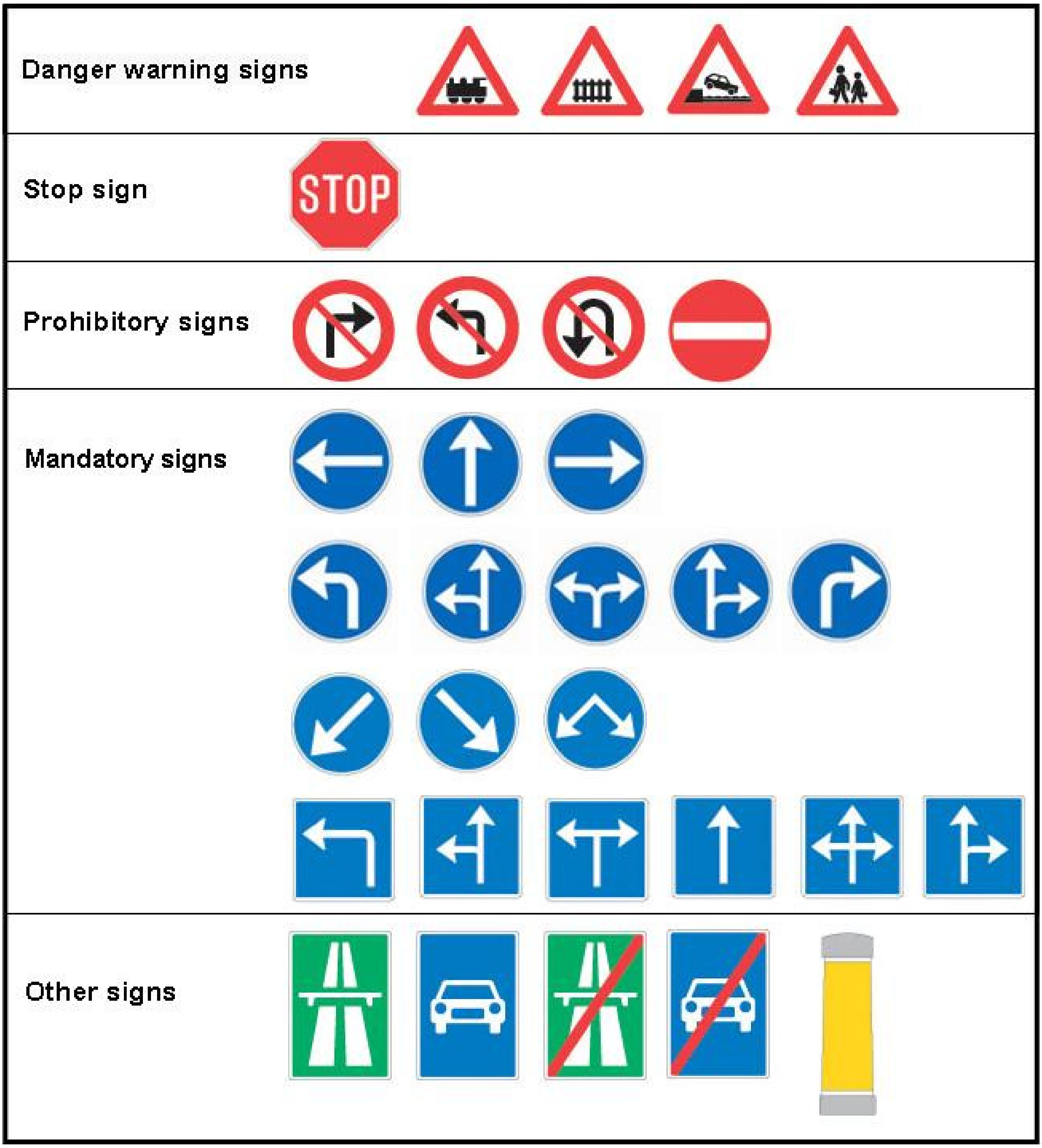


Figure 33: Signs for ordinary roads that use sign face type 4.

3. Measurement of retroreflection

3.1 Introduction and summary

The directly measured value of a retroreflective object is the ratio between the retroreflected luminous intensity I (candela, cd) and the illuminance E (lux, lx) at the object on a plane perpendicular to the illumination direction. When the retroreflective object is a retroreflector, this ratio is also the final result of the measurement. It is called the coefficient of luminous intensity CIL. The unit is candela per lux.

When the retroreflective object is a sample of a retroreflective surface, the CIL value is converted to the coefficient of retroreflection R_A by division with the surface area A (square metres) of the sample. The unit is candela per lux per square metres ($cd \cdot lx^{-1} \cdot m^{-2}$).

CIL values are small, because retroreflectors generally are small. For this reason, CIL values are normally presented with the 1000 times smaller unit of millicandela per lux ($mcd \cdot lx^{-1}$) in order to provide convenient values. This is not the case with R_A values for which the full unit in itself provides convenient values. A value of the CIL or the R_A applies for a specific geometrical situation.

Laboratory measurement of retroreflection is presented in 3.2 in terms of laboratory equipment for retroreflection measurement, calibration methods and testing in accordance with specifications for retroreflection.

Retroreflection measurement with handheld retroreflectometers is considered in 3.3. It is explained that the optical principles of handheld retroreflectometers are relatively simple and that the requirements concerning accuracy of the angles, angular apertures, spectral correction etc. are in general the same as for laboratory measurements.

The particular matter for handheld retroreflectometers is that they use only one, or at most a few, of the geometrical situations that can be set in laboratory conditions. Handheld retroreflectometers can, therefore, be used for simplified testing only and involve typically geometrical situations that provide sensitivity to ageing of the sheeting material or retroreflector.

Some handheld retroreflectometers for the measurement of R_A values of road signs or samples of sign sheeting materials are mentioned and their uses are considered:

- Measurements of samples of sign sheeting materials are carried out mainly as part of factory production control at producers of sheeting materials and road sign.
- Measurement on road signs has the purpose to reveal if warranties are complied with within the warranty period, or to decide if the road signs still offer sufficient retroreflection to drivers.

There is no real tradition of systematic in situ testing the retroreflectivity of road signs, but it is assumed that the 2008 revision of the "Manual on Uniform Traffic Control Devices", or MUTCD may lead to more testing of road signs in the USA.

It would be a breakthrough if testing of the retroreflection of installed road signs could be done with mobile equipment from a vehicle at normal driving speeds. Such mobile equipment is currently not available, but it is explored in 3.4 how it could possibly be designed.

3.2 Laboratory measurement of retroreflection

3.2.1 Introduction to laboratory measurement

Laboratory measurements of retroreflection can be made with a good accuracy and are generally considered to reliable. This is because of the high signals provided by retroreflection, convenient measurement directions and sound methods of calibration, Laboratory equipment for multi purpose measurements is introduced in 3.2.2, while the specialised use for retroreflection measurements are discussed in 3.2.3 and calibration methods in 3.2.4.

Laboratory measurement of retroreflection serves often for testing in accordance with specifications for retroreflection. This is discussed in 3.2.5 on the basis of a few specifications for retroreflection, which serve as examples among a multitude of specifications for retroreflection.

3.2.2 General about laboratory equipment

Laboratory measurements are carried out in a darkened room with black surfaces equipped with black curtains and other means to reduce offset of measured values by reflection. The room temperature is normally kept at 25 °C in order to keep light sources, photometers and electronics stable.

The main equipment is a photometer bench, which defines a horizontal axis, and a goniometer at the end of the bench.

A goniometer is illustrated in figure 34. It has a two axes of rotation that are perpendicular to each other. The first axis is vertical and fixed in space, while the second axis changes direction with rotation about the first axis, but stays in the horizontal plane.

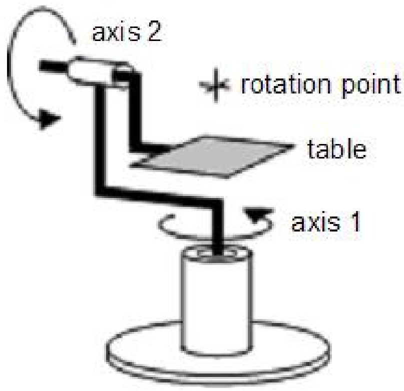


Figure 34: A goniometer.

The second axis carries a table on which the object to be measured is mounted. The orientation of the object changes in space, when the rotations of the axes are changed. The sequence of changing the two rotations is without consequence for the final orientation of the object, which is therefore defined by the two angles of rotation.

The two angles of rotation are monitored by precise instrumentation. The origin for axis 1 (where the angle is 0°) is so that the axis 2 is perpendicular to the direction of the photometer bench, while the origin for axis 2 is so that table is horizontal. The two angles can mostly be monitored and set by a computer.

The directions of the two axes meet in a point, which is marked as the rotation point in figure 34. An object mounted on the table is rotated about this point, when the angles of rotation of the axes are changed.

Therefore, in order to avoid change of measuring distance by rotation, the object is mounted so that its optical centre coincides with the rotation point. The optical centre can be the centre of the light emitting surface of a lamp, luminaire or signal light, or the centre of the surface of a reflecting or retroreflecting object.

Additionally, the object is mounted so that its reference direction points into the axis of the optical bench, when the goniometer angles are 0°. The reference direction is normally the direction perpendicular to a characteristic surface of the object, which can be the light emitting surface of a lamp, a luminaire, a signal light, or the surface of a reflecting or retroreflecting object.

A goniometer is shown again in figure 35 together with a photometer bench.

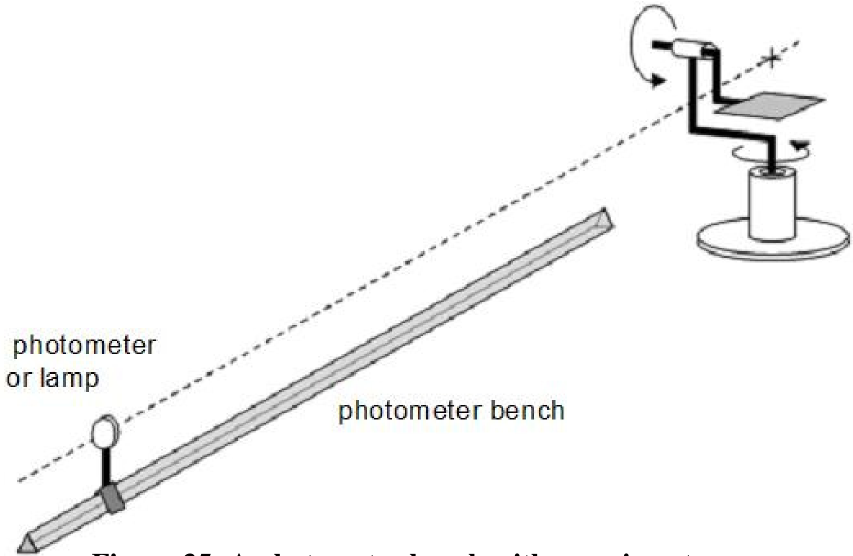


Figure 35: A photometer bench with a goniometer.

The photometer bench defines the direction of the optical axis, but is lower so that equipment mounted on the bench can be placed in the axis.

The characteristic value to be measured for a light emitting object is mostly the luminous intensity in one or more specified directions. To this purpose a photometer is mounted in the bench at a distance D. The measured value is the illuminance E which is converted to luminous intensity I by means of the distance law of illumination $E = I/D^2$ or $I = E \times D^2$.

There are different characteristic values to be measured for a reflecting or retroreflecting object depending of the object itself and other circumstances. However, in most cases it is a lamp that is mounted on the bench while a photometer is mounted in a different direction at an angle that depends on the characteristic value to be measured.

The photometer can be a luxmeter, a luminance meter or a spectrocolourimeter depending on the characteristic to be measured. Additional equipment includes calibration standards, standard lamps, stabilized power supplies and means to define the rotation point, the measuring axis, distances along the bench axis, etc.

The distance along the bench at which the equipment is mounted is the measuring distance. This distance and the sizes of the optical parts of the object and of the photometer and/or lamp being used defines the angular apertures of measurement.

EXAMPLE: The angular aperture of a lamp of a diameter of 30 mm at a distance of 20 m is approximately 0,085° or 5 minutes of arc.

The angular apertures represent an averaging over directions within the angular ranges of the apertures. Therefore, they need to be sufficiently small depending on the angular resolution that is needed for the measurement of particular objects, and are often specified in standards or regulations.

Sometimes, goniometers are defined as A, B and C, and even X and Y. However, all such goniometers are of the type as illustrated is figure C35 and differ only by different origins of the angles.

3.2.3 Retroreflection measurement in the laboratory

Figure 36 illustrates the use of laboratory equipment for the measurement of retroreflection. A retroreflector or a sample of a retroreflective surface is mounted in the goniometer, a lamp for illumination is mounted in the axis of the photometer bench and a photometer for the measurement is mounted at a location above the lamp.

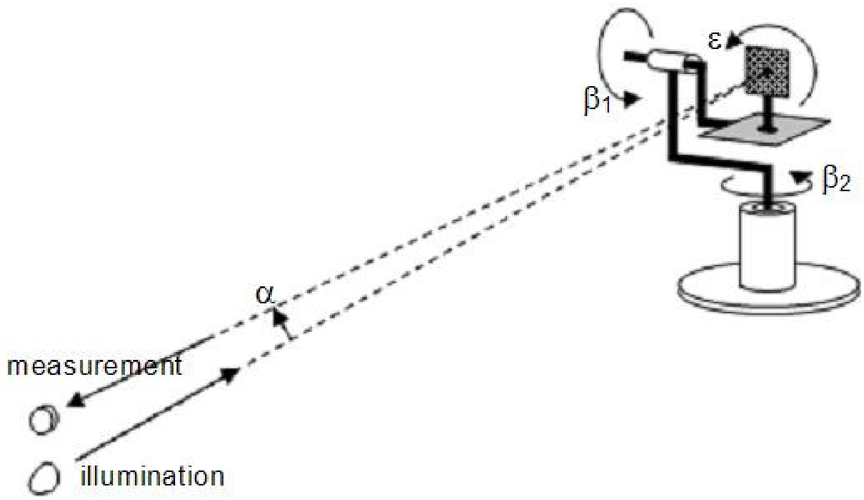


Figure 36: Use of laboratory equipment for the measurement of retroreflection.

The set of angles indicated in the figure 36 are:

α	the observation angle (the angular separation between the directions of illumination and measurement)
β_1 and β_2	the two components of the angle of the entrance angle β (the angle of incidence)
ε	the rotation angle.

The retroreflected beam is often narrow and, therefore, it is necessary that the observation angle α is set accurately and that the angular apertures for measurement and illumination are small. The normal specification for apertures is 6 ± 0,5 minutes of arc, refer to CIE 54.2 "Retroreflection: Definition and measurement". The sample of the retroreflective surface need, on the other hand, not to be very small.

3.2.4 Calibration methods for laboratory measurement

CIE 54.2 provides also some advice on calibration for which there is at least three approaches:

a. to measure the illuminance E_O at the retroreflective object with a calibrated photometer and also to measure the illuminance of the retroreflected light E_R at a distance D with another calibrated photometer
b. to use the same photometer to measure first the illuminance E_O at the retroreflective object and then the illuminance of the retroreflected light E_R at the distance D. CIL and R_A values are calculated as described above
c. to use a retroreflection standard with a known CIL value in the actual measuring geometry.

In approach a, the retroreflected luminous intensity is given by $I = E_R \times D^2$, the CIL value of a retroreflector by $CIL = I/E_O$ and the R_A value of a retroreflecting surface by $R_A = CIL./A$, where A is the surface area of the sample mounted in goniometer.

This approach has the advantage that no reflection standard is needed, and also that the photometers can be calibrated at the approximate levels of the signals. However, it is a disadvantage that the measurement relies on the calibration of two photometers.

In the second approach, the photometer need not be calibrated, because the calculations involve the illuminance values E_R and E_O only as the ratio E_R/E_O. Any error of scale cancels out.

It is an advantage that no reflection standard is needed and that the measurement does not rely on a calibration of the photometer. However, the two measured illuminance values differ by decades and, therefore, the measurement relies on the linearity of the photometer over a large range. It is difficult to verify this linearity over a large range, and this is the disadvantage of this approach.

In the third approach, the retroreflected illuminance value E_O is measured for the retroreflective object and also for the standard E_S. The CIL value of the object is then E_O/E_S times the CIL value of the standard.

If the object is a surface, the R_A value is obtained by division of the CIL value with the surface area of the object. Similarly, if the retroreflection standard is a surface with a known R_A value, the CIL value is obtained by multiplication with the surface area of the standard.

The advantage of this approach is that the measurement does not rely on the calibration of the photometer. It is sometimes a further advantage that traceability is obtained to the institute at which the calibration standard was measured. However, the dependence of an institute for calibration may also be seen as a disadvantage.

It is sometimes best to provide calibration by more than one of the above-mentioned approaches so that each of them are tested against one or two other approaches.

Reflection in the room contributes to the measured illuminance values, in particular to the smaller value measured at a distance. This contribution needs to be measured with a black surface placed in the goniometer (instead of the retroreflective object or covering the retroreflective object) and to be subtracted from the total measured illuminance.

It is often an advantage to use a photometer of the luminance meter type, which excludes almost all the light from outside of the optically defined measuring field, and also provides a high sensitivity by collecting light from a relatively large objective lens onto a relatively small photodiode. The luminance meter is to be aimed, focussed and set with a measuring field that encloses the object.

3.2.5 Laboratory testing of retroreflection in accordance with specifications for retroreflection

In most specifications for retroreflection, the rotation angle ε is fixed at 0°, so that the test can be carried out with the retroreflector mounted in a fixed position on the goniometer table. Further, in these specifications it is not necessary to set a combination of the components β_1 and β_2, but only to set one of the components and keep the other component fixed at 0°.

An example of such a specification is given by the classes RA1 and RA2 for glass beaded sheeting materials of EN 12899:2007 “Fixed, vertical road traffic signs - Part 1: Fixed signs”. There are three cases for the component β_1 of 5°, 30° and 40°, while ε and β_2 can both be kept at 0°. The situation is like being in front of an overhead sign.

Another example is found in EN 1463-1:2009 “Road marking materials – Retroreflecting road studs – Part 1: Initial performance requirements”. In various classes of retroreflection, there are two or three cases for the component β_2 of 5°, 10° and 15°, while ε and β_1 can both be kept at 0°. The situation is like being next to a low mounted sign.

In such specifications, the value of the actual component of the entrance angle, whether it is β_1 or β_2, is also the value of the entrance angle β. The difference is the direction of the incident light, from below or from the side. Additionally, the observation angle α is varied in some steps in order to simulate different distances to the retroreflector.

prEN 12899-6 “Fixed vertical road traffic signs — Part 6: Performance of retroreflective sign face materials”, on the other hand, describes a comprehensive test in which all the four angles are varied.

The intention is really to vary the four angles set (α, β, ε, ω_S) shown in figure 37. These angles relate to traffic situations, but cannot be set directly in a goniometer. Instead, the angles are set indirectly by setting (α, β_1, β_2, ε) so that the identical geometrical situation is obtained.

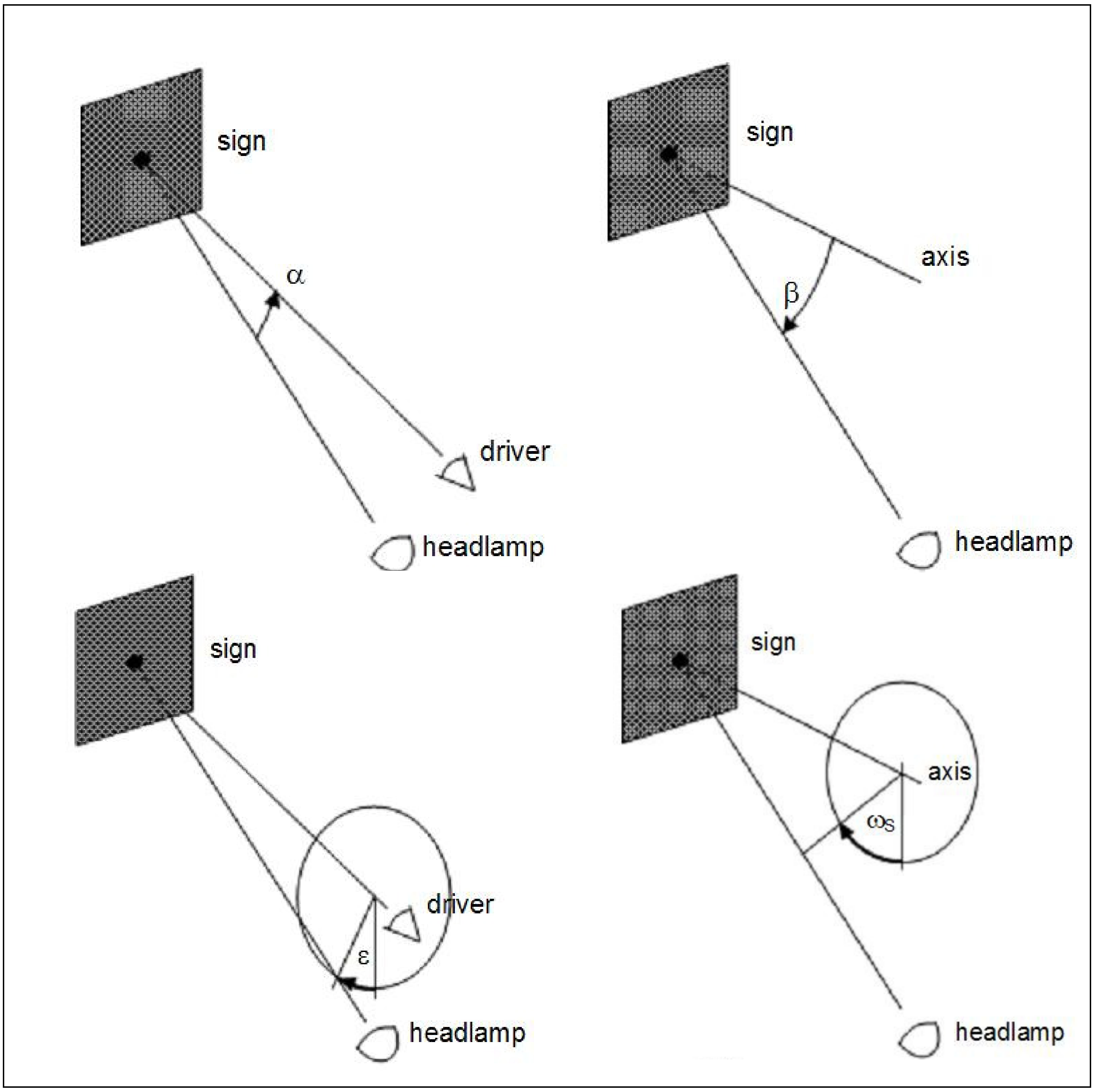


Figure 37: Angles related to traffic situations.

In most specifications, the requirements are formulated directly in terms of the measured values as minimum requirements for each combination of α and β.

For the specifications of prEN 12899-6, a generalized situation is also expressed in terms of a combination of α and β, but a comprehensive test involves setting a number of values of ε and ω_S.

3.3 Retroreflection measurement with handheld retroreflectometers

3.3.1 Introduction to retroreflection measurement with handheld retroreflectometers

The optical principles of handheld retroreflectometers are introduced in 3.3.2. These principles are relatively simple and the signal is high.

Some specifications for handheld retroreflectometers are discussed in 3.3.3. The requirements concerning accuracy of the angles, angular apertures, spectral correction etc. are in general the same as for laboratory measurement.

The particular matter for handheld retroreflectometers is therefore that they use only one, or at most a few, of the geometrical situations that can be set in laboratory conditions. Handheld retroreflectometers can, therefore, be used for simplified testing only and involve typically geometrical situations that provide sensitivity to ageing of the sheeting material or retroreflector.

The most commonly used handheld retroreflectometers are introduced in 3.3.4. These are intended for the measurement of R_A values of road signs or samples of sign sheeting materials.

Measurement on road signs has the purpose to reveal if warranties are complied with within the warranty period, or to decide if the road signs still offer sufficient retroreflection to drivers.

The retroreflectometer is to be held vertically and placed in contact with the road sign to be tested at a number of locations on the sign. Only low mounted signs, such as directional arrow signs or background signs, are within easy reach. Sign at low to medium height, such as warning sign, can be reached by the use of a pole supplied with the retroreflectometer. Gantry signs and portions of high signs, such as directional signs at motorways, can only be reached by an operator in a lift.

Measurement on road signs is tedious work and may involve personal danger, and blocking the traffic in some cases – in particular on motorways or when using a lift.

For this reason, and because sign sheeting materials are durable, there is no real tradition of systematic testing of the retroreflectivity of road signs. On the contrary, road signs are often left for decades and only replaced when damaged or obviously not functioning or obsolete.

The 2008 revision of the “Manual on Uniform Traffic Control Devices”, or MUTCD, may lead to more testing of road signs in the USA.

Measurements of samples of sign sheeting materials may be done to give a first impression of the retroreflection properties of the materials, but are carried out mainly as part of factory production control at sheeting material and sign producers. The retroreflectometer is to be placed in contact with the sample with an orientation corresponding to vertical for the intended application of the material on road signs as provided by a datum mark on the material.

A retroreflectometer designed to measure the CIL values of retroreflectors on road studs is also mentioned in 3.3.4. As for road signs, there is probably no real tradition for testing road studs.

3.3.2 Optical principles of handheld retroreflectometers

A handheld retroreflectometer has a housing with a lamp that illuminates a retroreflective surface, a detector that measures the light reflected from the retroreflective surface and a lens that reduces the angular spreads of illumination and measurement. Figure 38 shows these essential parts.

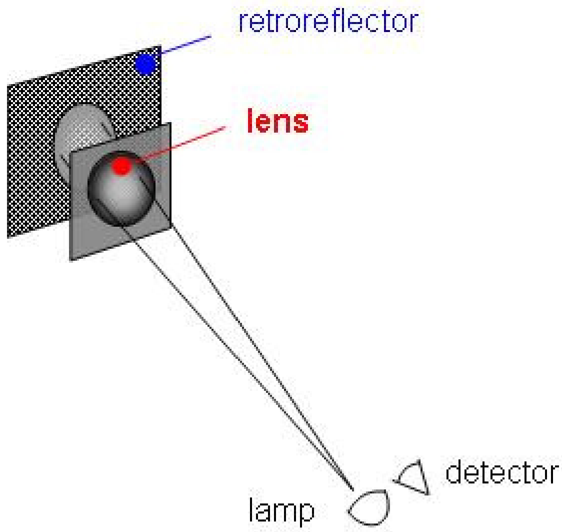


Figure 38: The essential parts of a handheld retroreflectometer.

The lamp and the detector are placed in the focal plane of the lens, so that the angular spreads of illumination and measurement are defined by the angular sizes of the lamp and the detector as seen from the lens. With this arrangement, the observation angle is determined by the angular separation between the lamp and the detector as seen from the lens.

The focal width of the lens needs to be relatively small so as to provide for a compact instrument and, therefore, the lamp and detector both need to be small and placed close together.

EXAMPLE: A retroreflectometer uses a collimating lens with a focal width of 150 mm and is designed to provide an observation angle of 0,33° and angular apertures of illumination and measurement of 6' (minutes of arc). The distance between the lamp and the detector is therefore 150 mm times tan(0,33°) equal to 0,86 mm, and the diameters are 150 mm times tan(6') equal to 0,26 mm.

For this reason, handheld retroreflectometers use arrangements like shown in figure 38, where light guides fitted into a small block take the roles the lamp and the detector. In this case, there are three light guides to detectors, so that this particular retroreflectometer provides measurement with three different observation angles.

Additionally, handheld retroreflectometers need to have a nozzle with an aperture, and to be placed so that the nozzle has contact with the retroreflective surface. In this way, the illumination direction of the narrow beam created by the lens relative to the aperture of the nozzle defines the entrance angle.

When the retroreflectometer is held with contact to the retroreflective surface, the aperture of the nozzle is at the retroreflective surface, or close to it. For this reason, the aperture serves to define both of the areas of illumination and measurement and actually to make them coincide, or very nearly coincide.

If the retroreflectometer is not in contact with the retroreflective surface, the two fields will separate somewhat and grow un-sharp edges, and this will cause a decrease of the measured signal with the distance.

However, there is actually a good tolerance in this matter, because the observation angle and the angular spreads are generally small so that separation and blur develop slowly with distance.

This is illustrated in figure 39, where one of the fields is shown in yellow, the other field in blue and the overlapping part in the mixed colour of a bluish white. The illustration applies for an observation angle of 0,33° and angular apertures of illumination and measurement of 6' (minutes of arc).

As the lens diameter D is 25 to 30 mm in existing handheld retroreflectometers, the loss of signal is insignificant even at distances of several centimetres.

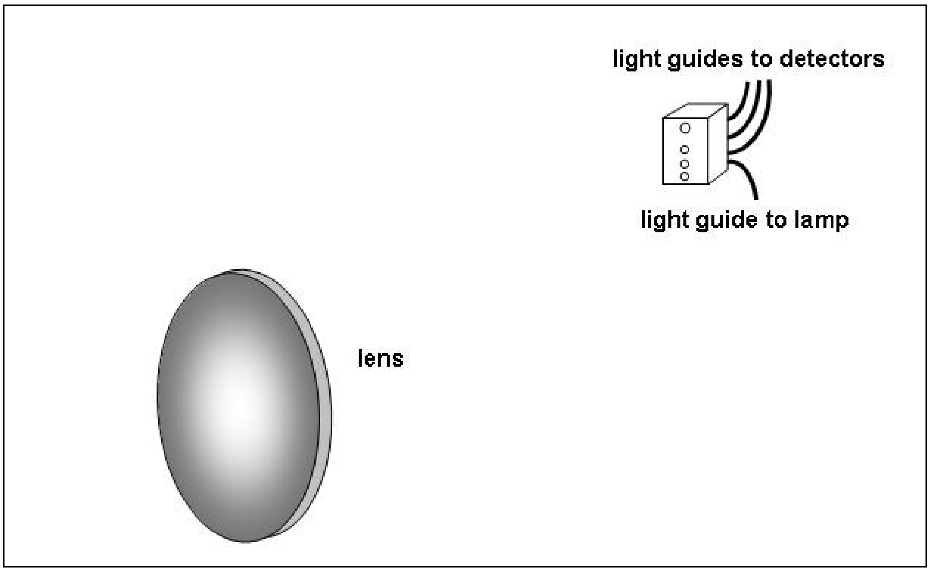


Figure 38: A small block with three light guides leading to detectors, and one light guide leading to a lamp.

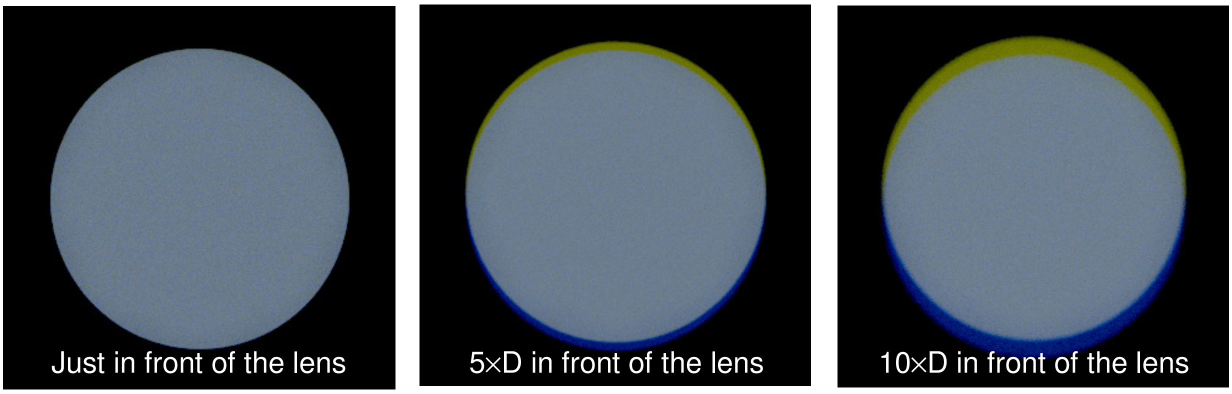


Figure 39: Relative shift of the fields of measurement and illumination with distance measured in the diameter of the lens D.

3.3.3 Specifications for handheld retroreflectometers

There are no direct European standards for handheld retroreflectors, only indirectly through this requirements for testing after accelerated weathering as provided in EN 12899-1 “Fixed, vertical road traffic signs - Part 1: Fixed signs”:

> “When tested at an observation angle (α) of 20' and entrance angles (β_1 = 5° and 30°, with β_2 = 0°) the coefficient of retroreflection shall be not less than 80 % of the values required in 4.1.1.4 as appropriate”.

This tests can be done be done in the laboratory, but is normally done with handheld retroreflectometers. There are no specific requirements to the testing instrumentation and procedure, but it is natural to apply the requirements of CIE 54.2 “Retroreflection: Definition and measurement”.

The ASTM, on the other hand, provides detailed requirements in ASTM E 1709 “Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.2 Degree Observation Angle”. This standard has a long history, with the latest version being dated 2009.

The title of ASTM E 1709 reveals that the observation angle is 0,2° as opposed to the value of 0,33° that is used for road signs in Europe. Another difference is that the entrance angle is given by β_1 = -4° with β_2 = 0° instead of the above-mentioned values used in Europe. Other requirements deal with the accuracy of angles, angular apertures, linearity, spectral correction, calibration etc.

Another ASTM standard is more recent and almost identical to ASTM E 1709, except that the observation angle is 0,5°. This is ASTM E 2540 - 08 “Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.5 Degree Observation Angle”.

The reason for adding ASTM E 2540 is that the 0,5° observation angle is mentioned in a 2008 revision of the “Manual on Uniform Traffic Control Devices”, or MUTCD. The MUTCD is administered by the FHWA of the USA.

It is a curiosity, to be discussed later, that ASTM E 1709 and E 2540 allow for two different versions of retroreflectometers, so-called point and annular instruments.

EN 471 “High-visibility warning clothing for professional use - Test methods and requirements” defines a different test geometry for warning clothing. The observation angle is 0,2° as in ASTM E 1709, but the entrance angle is the one of 5° defined as in EN 12899-1.

ASTM E1696 - 04 “Standard Test Method for Field Measurement of Raised Retroreflective Pavement Markers Using a Portable Retroreflectometer” requires the observation angle of 0,2° for retroreflectors on road studs. The measuring direction is horizontal so that the actual entrance angle relative to the retroreflector surface depends on the tilt of the surface.

3.3.4 Some handheld retroreflectometers on the market

The main suppliers of handheld retroreflectometers are DELTA and Road Vista. DELTA offers some versions of RetroSign while Road Vista offers some versions of model 922.

These handheld retroreflectometers are calibrated by means of calibration standards with retroreflective sheeting materials. These are generally of the type encapsulated lens (also called High Intensity or just HI) for the reason that this type has simple retroreflection properties and a suitable R_A value that is stable over time and insensitive to temperature and moisture. The R_A calibration values of standards are determined in laboratory measurements.

There are other companies and products on the market, but only the above-mentioned instruments are mentioned in the following. Additional equipment like GPS, bar code readers, extension poles etc. is not mentioned.

A RetroSign is shown in figure 40.

Figure 40: A RetroSign.

Figure 38 illustrates actually the working principle GR3 models of RetroSign, which make simultaneous measurement of R_A values for three different observation angles. GR1 models have only one light guide leading to a detector and measures at only one observation angle. Different versions of the GR1 and the GR3 comply with one or more of the above-mentioned standards.

The GR1 and GR3 in the CEN versions incorporate an entrance angle of 5°, but not the entrance angle of 30° also defined in EN 12899-1. The second entrance angle is obtained by the use of an adaptor at the nozzle, that defines a contact surface with a tilt of the instrument of 25°.

The adaptor is simple, just leading to a tilt of the instrument that changes the entrance angle. The adaptor, when mounted, leads to an increase in the distance to the surface, but this is permissible in view of the insensitivity to relatively small changes in distance discussed in 3.3.1. There is a similar adaptor available for a 40° entrance angle.

A Road Vista model 922 is shown in figure 41. Different versions of the model 922 comply with one or more of the above-mentioned standards. In addition, Road Vista offers a model 932 in which the observation angle and the entrance angle both can be set continuously in fairly large ranges.

Further, a model 1200F aims at measuring retroreflectors on road studs in accordance with ASTM E 1696. A different version is called “European” in spite of lack of any European specification in this area.

Figure 41: A Road Vista Model 922.

It may be noted that ASTM E 1709 and E 2540 allows two types of instruments side by side, called point and annular, and that all versions of RetroSign are point instruments while all versions of Road Vista model 922 are annular instruments.

By point instrument is meant that a measured value represents a single illumination direction and a single measurement direction. This is as in laboratory measurements and probably what one would expect of a handheld retroreflectometer as well.

By annular instrument is meant that measurement is in an annulus of directions, so that the measured value is an average for those directions. The principle is illustrated in figure 42.

The two suppliers argue at intervals in the relevant ASTM E12.10 subcommittee about which type is best or more relevant. At least, it is questionable if the annular geometry of model 922D is acceptable for the purposes of EN 12899-1.

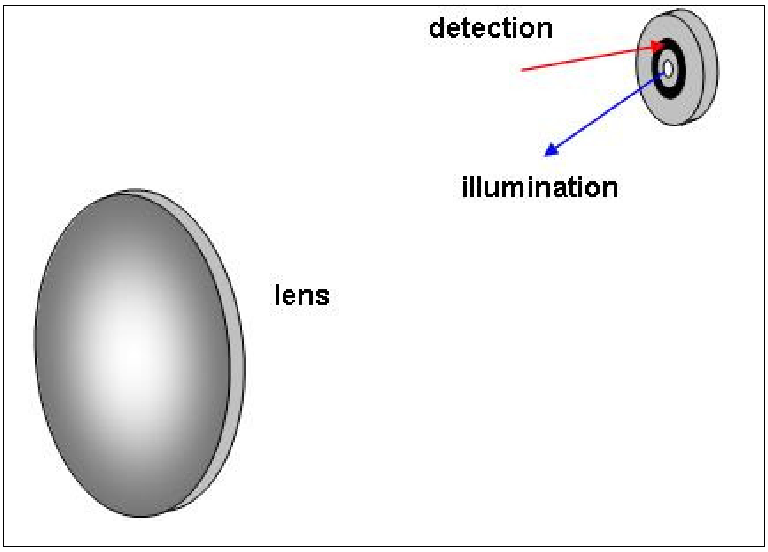


Figure 42: Principle of an annular instrument.

3.4 Mobile equipment for the testing of the retroreflection of installed road signs

It would be a breakthrough if the testing of the retroreflection of installed road signs could be done with mobile equipment from a vehicle at normal driving speeds. However, such equipment is currently not available, but it is explored in the following if it can possibly be made.

NOTE: The FHWA had mobile equipment developed and mounted on four vehicles at some point during the 90's. This equipment was based on a powerful flash lamp and a camera. It did not perform satisfactorily.

It is possible to deduce:

- It is only partly possible to include those geometrical situations that are used for specifications for retroreflection and for laboratory testing. However, it may be considered an advantage from a driver point of view that the measurements include situations that actually occur on the road.
- The detection system should be able to resolve details of a fraction of 1' (minute of arc), for instance 0,5'. A modern camera offers 1400 times 1000 pixel and probably a sufficient field of view to cover road signs intended for one driving direction.

- There is a need for sharpness of the image in spite of optical aberrations, forward movement of the vehicle and vibration. The camera lens needs to have a high F-number like f/11 or higher and the exposure time needs to be less than 0,001 s and possibly even shorter.
- It is probably not possible to outshine the sun without causing offense to drivers. This may not either be technically possible. The most promising option is probably to avoid conditions of strong daylight.
- It is probably necessary to introduce various means of stabilising the measuring signal such as using a part of the image to monitor the dark level and another part to show an image of the light source.

It is practical to refer to DELTA’s mobile equipment for road markings, the LTL-M, as the LTL-M does a job that is similar to a mobile equipment for road signs, and does it well. Some of the technical solutions for road markings may be applied also for road signs. At least the following modifications are necessary:
- The camera should probably be turned 90° so that 1000 pixels are available for the width of the field of view while a bit less than the 1400 pixels can be made available for the height of the field of view.
- The illuminated field, which form a low horizontal band, must be made much higher. This requires a Xenon flash lamp with a big bore and more energy per discharge.

The question is if such a modified LTL-M will work at the much larger distances of 100 or 150 m than the 6 m for which the LTL-M was designed.

The illuminance will of course be much less at the longer distances because of the distance law of illumination (inverse proportion to the distance squared); for instance 278 times less at 100 m and 625 times less at 150 m.

There is some compensation for the reduction of illumination by the much stronger retroreflection of road signs compared to road markings. This is by a factor of 100 or more, but not quite enough to compensate fully for the longer distances. It might be technically possible to raise the illumination so as to provide a full compensation, but this requires more power.

Further, the LTL-M does not outshine daylight and the sun in particular. The LTL-M has a good and accurate method of compensation for daylight by measurement and subtraction of the daylight contribution, but it is not obvious how to introduce a similar method for road signs.

In conclusion, the principles of the LTL-M can perhaps not be applied for road signs without some compromise, for instance by:
- avoiding to measure in strong daylight
- disregarding road signs at the longest distances
- or using a smaller field of view.

In any case, even when all the above-mentioned matters may be solved, the development of the software for analysing the images presents a large job. This proved to be the case for the LTL-M, and quite different and elaborate software will be needed for mobile equipment for road signs. The software needs among else to distinguish between legends and background, and probably to identify shapes and legends, and to derive dimensions of signs and legends.

Literature

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CIE 15 Colorimetry, 2004.

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prEN 12899-6 " Fixed vertical road traffic signs — Part 6: Retroreflective sign face materials".

ASTM E 1709 "Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.2 Degree Observation Angle".

ASTM E 2540 - 08 "Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.5 Degree Observation Angle".

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"Bekendtgørelse om anvendelse af vejafmærkning", the Danish Road Directorate, 2006.

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Annex A: Retroreflectors and retroreflective sheeting materials

A.1 Introduction and summary

Retroreflection of an object is the ability of the object to reflect incoming light in a narrow beam about the direction opposite to the direction of the incoming light. Retroreflection serves to make retroreflective objects much brighter in headlamp illumination at night than they would be with ordinary reflection, typically by a factor of 10 to 1000 compared to ordinary reflection.

The power of retroreflection can be explained by the narrow width of the reflected beam, which is of the order of ±2°-3° as compared to ±90° of ordinary reflection..

NOTE 1: The intensity of reflected light within a cone is in inverse proportion to the solid angle of the cone. The solid angle of a cone of a width of ±2°-3° is of the order of 1000 times smaller than a cone of a width of ±90°.

Small retroreflective objects used for instance on vehicles, in road studs and on delineators are called retroreflectors. Their brightness is expressed in luminous intensity I in the unit of candela (cd). However, the actual perceived brightness is in inverse proportion to the square of the observation distance.

Large retroreflective surfaces, such as retroreflective sign faces, obtain their retroreflection by means of retroreflective sheeting materials applied to substrates. Large retroreflective surfaces can therefore be discussed in terms of retroreflective sheeting materials. The brightness is expressed in luminance L in the unit of candela per square metres (cd/m^2). The actual perceived brightness is independent of the observation distance as long as the surface can be discriminated.

The two measures of brightness are related in the way the that luminous intensity is the luminance integrated over the surface area of the retroreflector, while luminance is the luminous intensity in proportion to the area of the retroreflective surface. By area is meant apparent area as seen in the observation direction.

The ability of a retroreflector to retroreflect in a particular geometrical situation is measured as the ratio between the luminous intensity and the illuminance E measured in lux (lx) produced by a headlamps at the location of the retroreflector. The ratio is called the coefficient of luminous intensity, CIL. It is normally expressed in millicandelas per lux ($mcd \cdot lx^{-1}$).

The measure of the ability of a retroreflective surface to retroreflect in a particular geometrical situation is the ratio between the luminance L and the illuminance E produced by a headlamp at the location of the retroreflective surface and measured perpendicular to the direction of illumination. This ratio is called the coefficient of retroreflected luminance R_L in the unit of candela per square metres per lux ($cd \cdot m^{-2} \cdot lx^{-1}$).

However, for some traditional reason, another measure is used, which is the CIL per square metres of the surface. This ratio is called the coefficient of retroreflection R_A in the unit of candela per lux per square metres ($cd \cdot lx^{-1} \cdot m^{-2}$).

The two measures are related by $R_A = R_L \times \cos(\beta)$ or $R_L = R_A/\cos(\beta)$ where β is the angle of incidence measured between the direction of illumination and the normal to the surface. This angle is normally called the entrance angle in connection with retroreflective surfaces.

The colour of retroreflected light is an essential characteristic for retroreflectors as these are generally used with specified colours. The colour is measured in a particular geometry assuming standard illuminant A, which represents an incandescent lamp, and is expressed by the CIE chromaticity coordinates x and y. Refer to CIE 15 Colorimetry, 2004.

In some cases the colour of retroreflected light is also used as a characteristic for large retroreflective surfaces such as retroreflective sign faces, but it is mostly assumed that an acceptable daylight colour ensures that the colour of retroreflected light is also acceptable.

Daylight reflection and colour is mostly unimportant for the retroreflective surface of retroreflectors, but may be a meaningful characteristic for the body holding the retroreflector. Daylight reflection and colour is an essential characteristic for large retroreflective surfaces such as retroreflective sign faces.

Daylight reflection and colour is measured the 0°/45° or 45°/0° geometry assuming standard illuminant D65, which represents daylight, and is expressed by the luminance factor on a scale from 0 to 1 and the CIE chromaticity coordinates x and y. Refer again to CIE 15.

Levels of retroreflection as mentioned in the following are for white retroreflectors or retroreflective surfaces. Other colours are associated with lower levels of retroreflection as other colours are created by selective absorption.

Colours of retroreflectors are normally obtained by inherent colours of the materials of which the retroreflectors are made.

Colours of large retroreflective surfaces are created either by inherent colours of the sheeting materials, use of coloured overlay films or screen printing.

The width of the beam of retroreflected light is important as the beam should be wide enough to include the eyes of the drivers in relevant traffic situations. The beam should, on the other hand, not be much wider than necessary as the brightness of the object would otherwise become unnecessarily low.

NOTE 2: With a given luminous flux within a cone, the luminous intensity or luminance is in inverse proportion to the square of the angular width of the cone.

There is no single optimum beam width as some retroreflective objects are intended to be visible at long distances, while others are intended to be visible at shorter distances. However, the beam should not be much wider than ±2° in general.

A good retroreflective object should retroreflect a sizeable proportion of the luminous flux that falls on the retroreflective surface. This proportion is called the retroreflectance and is expressed as a fraction or percentage. The concept of retroreflectance is used in the following in the sense that only light that is reflected within a useful width of the beam is included.

Another important feature is the ability of a retroreflective object to maintain retroreflection in a range of illumination directions that is sufficient in view of the relevant traffic situations. The range should not be just barely sufficient, but have a reserve for variations in the mounting and alignment of the retroreflective object.

This concept is in general called “entrance angularity. In some cases a range of ±10° would be sufficient, in other cases a much bigger range is needed, up to perhaps ±40°.

Simplicity of the retroreflective features is also a consideration. For instance that the retroreflected beam has a gradual variation like a bell shape, and that the beam intensity and shape and does not change unpredictably with the details of the geometry of the traffic situation.

It is with the above-mentioned loosely described quality measures in mind that different technologies for retroreflection are discussed in the following.

Surprisingly, there are two and only two methods to produce retroreflection in use – perhaps at all – and they are almost equally important in practice. The first method is to use a lens in combination with a mirror at the focal width of the lens, and the second is to use three mutually orthogonal mirrors that in general are three faces of a prism.

It is useful to distinguish between the two methods as they lead to different qualities. Further, it is useful to distinguish between retroreflectors and retroreflective sheeting materials for a couple of reasons:

- the measures of brightness are different
- the two methods of retroreflection are applied in different ways
- daylight reflection is unimportant for retroreflectors, but essential for retroreflective sheeting materials.

Accordingly, the discussion is divided into four sections; A.2 on lens based retroreflectors, A.3 on prism based retroreflectors, A.4 on glass beaded sheeting materials and A.5 on microprismatic sheeting materials.

A lens based retroreflector incorporates one or more "cats eyes" that are traditionally made in glass. This technology is old, from the childhood of car driving, but is still in use and competitive. Examples of use are road studs (raised pavement markers) and delineators.

Prism based retroreflectors are also called cube corner retroreflectors because the prism faces relate to each other as the adjourning sides at a corner of a cube. Cube corner retroreflectors were originally made in glass and has a history almost as long as cats eyes. Nowadays, these retroreflectors are in moulded in plastic and have a wide range of use on vehicles, on cycles, by pedestrians and in road equipment including road studs and delineators.

There is a fairly long description on how this method works in order to point to advantages and complications.

Glass beaded sheeting materials use high index glass beads as lenses and an aluminium layer shaped to each glass bead as reflector. Glass beaded sheeting materials has lead to the almost general use of retroreflective sheeting materials for road signs and several other applications.

The first version of such materials is the enclosed lens, also called Engineering Grade, or just EG. It was developed into its present construction during the 50's. EG materials still have widespread use and are supplied by a number of manufacturers.

The second and later version is the encapsulated lens, also called High Intensity or just HI. A single manufacturer (3M) placed it on the market during the early 70's and had monopoly due to a patent until the 90's, where several more producers of the material emerged. EG and HI materials have been dominant on the market for a long time, and are probably still today.

Retroreflection standards are mostly based on HI materials as their retroreflection is stable over time and insensitive to changes of temperature and air humidity.

Some special types of glass beaded materials are made so flexible that they can be applied on safety clothes, ordinary clothes and shoes etc. Some of these are of the open bead type comparable to beads in paint, but with good underlying reflectors and a fairly strong retroreflection.

Microprismatic sheeting materials are very similar in construction to prismatic retroreflectors, but have prisms of much smaller dimensions so as to make the sheeting materials flexible.

The first microprismatic sheeting materials were developed early 70's, but substantial use for road signs and other road equipment did not start until the 80's, and did not gain momentum until the 90's. There is a variety of such materials available from a number of manufacturers and the use is increasing.

Glass beaded materials have fairly low retroreflectance values, fairly wide beams, good or very good entrance angularity and simple properties.

Compared to this, most of the microprismatic products have relatively high retroreflectance values, narrow beams, medium or poor entrance angularity and complex properties. In many countries this has resulted in use of the materials according to three classes, for instance I, II and III, where I is EG, II is HI and III is some microprismatic material for use on high speed roads.

However, there is room for the development of microprismatic materials with a variety of properties, and they are potentially more cheap to produce than glass beaded materials. Because of this, it may be expected that microprismatic materials will become dominating.

The construction and properties of the sheeting materials are explained, and there is some additional account of other reflection properties with a view to daylight reflection.

The ideal sheeting material would convert about half of the incoming light to retroreflection for use at night, and reflect the rest of the light in a diffuse manner for use in daylight and external illumination.

Daylight reflection is measured by the luminance factor, which is the ratio of the luminance of a surface when illuminated and observed under certain conditions to that of a perfect diffuser under the same conditions. The conditions are defined by the 0°/45° or 45°/0° geometry, so as to exclude both retroreflection and mirror type reflection. Accordingly, the luminance factor values are fairly low and should indicate that a sign looks relatively dark in daylight – for instance that white parts look grey.

However, glass beaded materials have a rather strong corona of retroreflected light at fairly large angles and, unavoidably, some mirror reflection. Most microprismatic products have a strong mirror type reflection caused by particular paths of rays between prisms and some "sparkles" that are also caused by particular paths of rays.

Accordingly, a driver when looking at a road sign in daylight will see not only a diffuse representation of the ambient light.

If the sign has a glass beaded material, there will be an overlay of a moderately strong and blurred image of his own vehicle including wide parts of the surroundings, and also an overlay of a fairly weak image of whatever is mirror reflected with some blurring.

If the sign has a microprismatic material, there will be an overlay of a strong and blurred image of his own vehicle including narrow parts around it, an overlay of a fairly strong and partly blurred mirror image and some focus on locations causing sparkles.

These overlays do not cause any problem in most conditions, but add to the brightness of the road signs – white parts do look white. It could therefore be discussed if the 0°/45° or 45°/0° geometry gives enough credit to daylight reflection.

However, the overlays are undesirable because they cause problems in some situations. If the sun is in the mirror image, or close to, it will make the sign too bright to be readable. If the sun is at one of the sparkle locations, it will cause an overlay of colours that also makes the road sign unreadable.

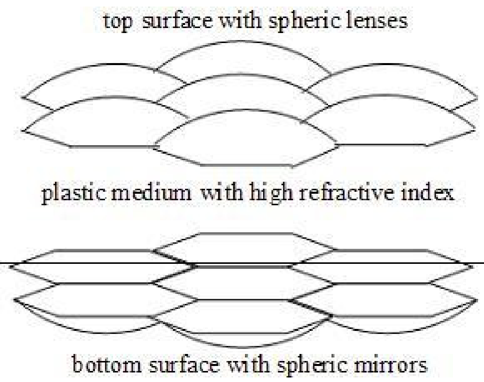
It is concluded that none of the technologies are perfect and that light is wasted. This should be seen with the understanding that retroreflection is a scarce resource that is not sufficient to create optimum night conditions.

It is as if glass beaded and microprismatic materials are opposites; the first type has the simple properties and the good entrance angularity, while the second type has the high retroreflectance.

NOTE 2: The question arises if it is practically or theoretically possible to achieve everything – high retroreflectance, good entrance angularity, simplicity and good daylight reflection.

The author is not able to answer that question. A glass bead with a particular volume variation of the refractive index could be used to make a perfect glass beaded material – but such a glass bead is perhaps only an idea of the mind. A microprismatic material made of a high refractive index material would show better entrance angularity – but not without disadvantages.

A perhaps good candidate is shown below. It is a hexagonal packing of spherical lenses in a top surface and the same packing of spherical mirrors in a bottom surface. In between the two surfaces there is a plastic medium with a high refractive index. It is like a HI material, but avoids the aberrations from the peripheral parts of glass beads and uses all of the incoming light up to an entrance angle of perhaps 40°.



A.2 Lens based retroreflectors

Figure A.1 shows a beam of incoming light that is focussed on a small area on a reflecting plane at the focal width of the lens. The figure also shows that some of the light that is reflected at the small area will be transmitted by the lens into a beam of retroreflected light.

This is the simple mechanism of lens based retroreflectors. The lens has a dual action with an intermediate reflection in a surface.

The retroreflectance is limited by losses that include surface reflection in the lens surfaces and absorption in the reflecting surface. It is an additional loss, as also shown in figure A.1, when reflected light does not fall on the lens.

The beam width of the retroreflected light depends on the quality of the lens and on the focus on the reflecting surface.

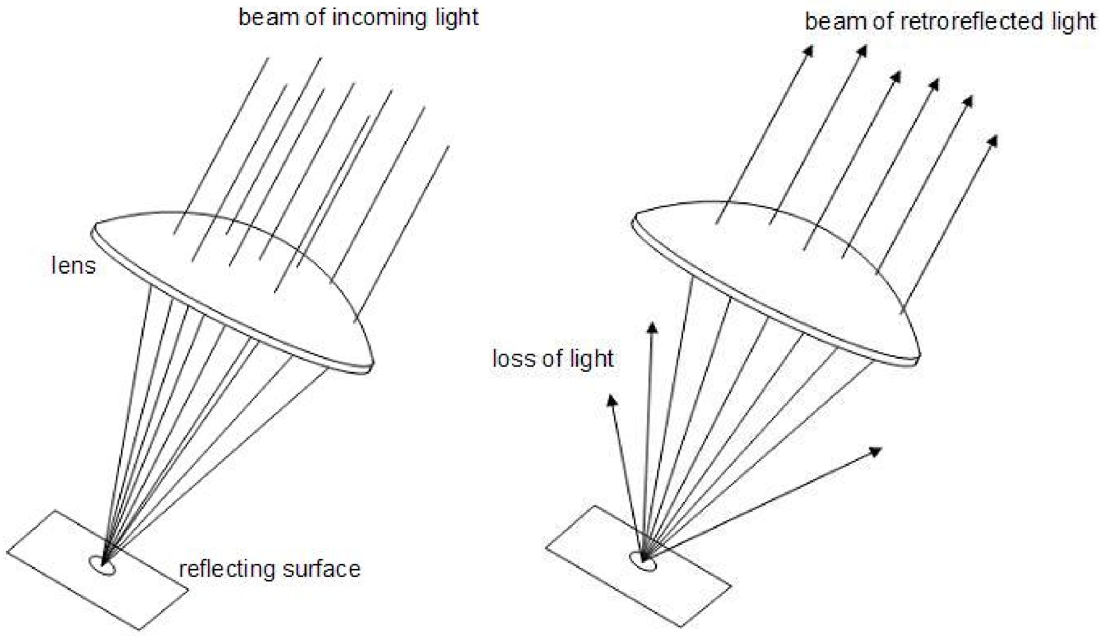


Figure A.1: Retroreflection by means of a lens and a reflecting surface.

Figure A.2 shows a cats eye retroreflector, which integrates the lens and the reflecting surface in a single body in glass. The mirror surface is normally created by “metalizing”, which means applying an aluminium coating.

A cats eye can have high retroreflectance, because the light has to pass a single surface only and because the reflectance of the mirror surface can be high. Additionally, the retroreflected beam can be narrow, and the cats eye can work out to fairly large entrance angles. See figure A.3.

Figure A.2: Cats eye retroreflector.

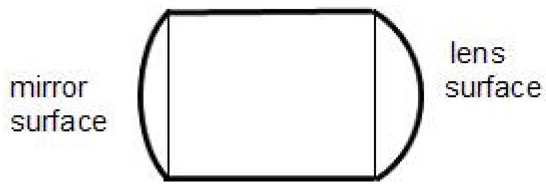


Figure A.3: Entrance angularity of the cats eye retroreflector.

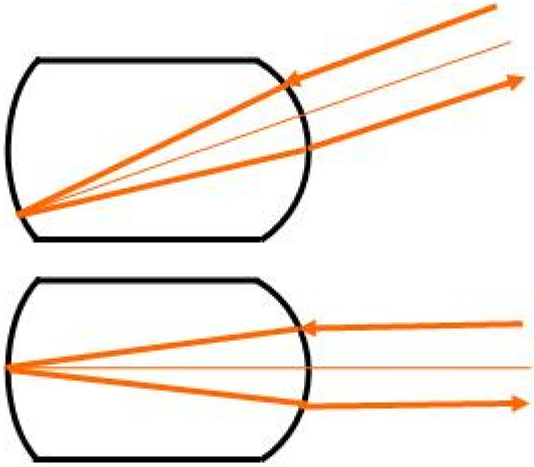


Figure A.4 shows a particular cats eye retroreflector with a diameter of approximately 10 mm. Figure A.5 shows two such cats eyes mounted in a road stud (raised pavement marker).

Figure A.4: A particular cats eye.

Figure A.5: Two cats eyes mounted in a road stud.

Cats eyes have a natural use for road studs. The retroreflective area is small, but the headlamp illumination is fairly strong at the low position at the road surface. Additionally, the cats eyes make good use of the incoming light to create a narrow beam that makes them visible at fairly long distances, and the entrance angularity is sufficient. Further, the cats eyes are in rugged glass.

There are many types of road studs with cats eyes on the market, often with a number of cats eyes forming a line. Other uses of cats eyes are as retroreflectors on delineators, either mounted on delineators posts or on guard rails. Figure A.6 shows a road equipped with road studs and delineators.

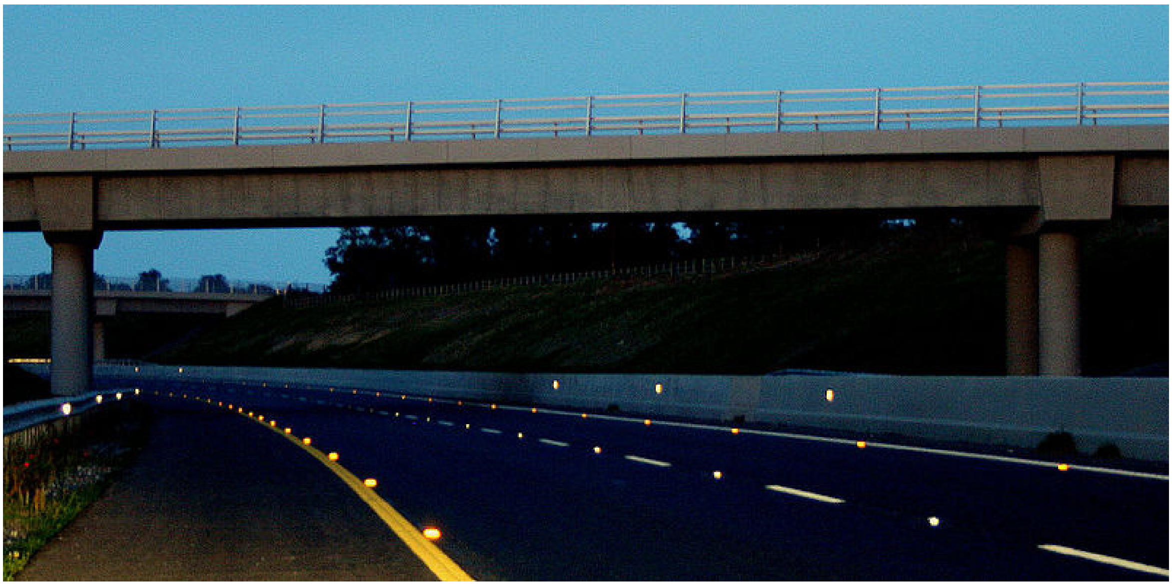


Figure A.6: A road equipped with road studs and delineators with cats eyes.

Some roads studs and delineators have retroreflectors based on prisms or retroreflective sheeting materials. Such retroreflectors are discussed in the next sections.

A.3 Prism based retroreflectors

A.3.1 General about prism based retroreflectors

Prism based retroreflectors are also called cube corner reflectors, because the prism faces relate to each other as the adjourning sides at a corner of a cube. A cube corner retroreflector is generally in moulded plastic with a smooth front and prisms sticking out at the back.

A classic lay-out is shown in figure A.7 and A.8. The faces are triangles with equal lengths of the catheters and form an aperture with the shape of an equilateral triangle (figure A.7). The prisms are placed so that the apertures are in the same plane and form a hexagonal pattern (figure A.8). The packing of the prisms seen from the back is shown in figure A.9.

Figure A.7: Three surfaces in a cube corner prism.

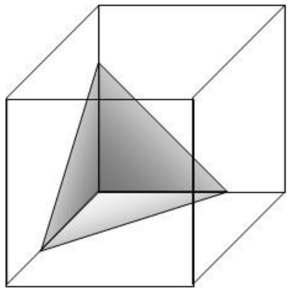


Figure A.8: The packing of prisms seen from the front.

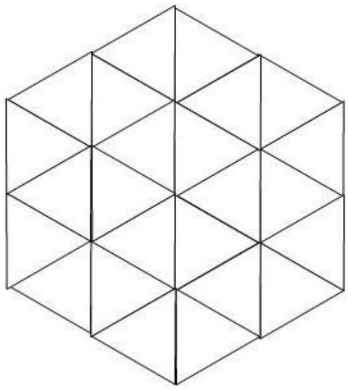
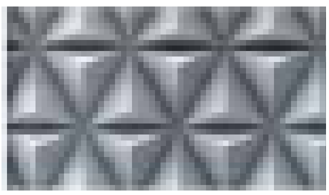


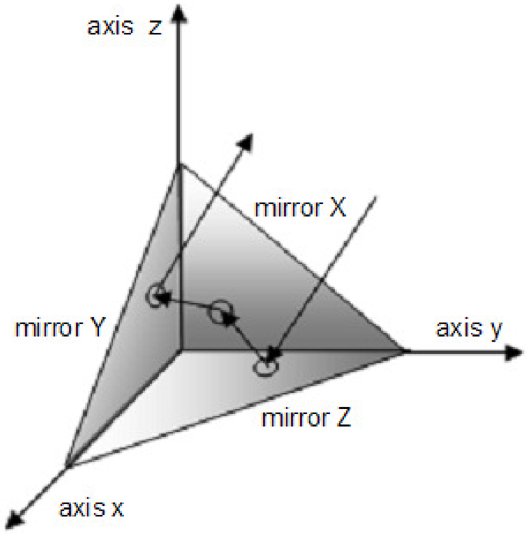
Figure A.9: The packing of prisms seen from the back.



A ray of light that is mirror reflected in all three prism faces is retroreflected. This is illustrated in figure A.10, where the three faces are placed in a coordinate system with the axes x, y and z. Assume that the incoming ray has a direction given by the vector (x,y,z). After reflection in the mirror Z, the vector changes to (x,y,-z). After further reflection in the mirror X, the vector changes to (x-x,y,-z) and finally, after reflection in mirror Y, to (-x,-y,-z).

The final vector is opposite to the vector of the incoming ray, which means that the ray of light has been retroreflected. The sequence of the three reflections is immaterial.

Figure A.10: Reflection in three orthogonal mirrors leads to retroreflection.



This defines two conditions for retroreflection that are considered in the next sections:

- that the ray of light is actually mirror reflected in the prism faces
- that the ray of light meets all three prism faces.

A.3.2 The condition of mirror reflection in the prism faces

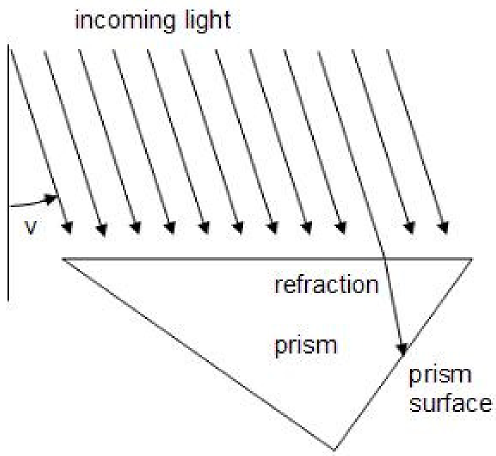
In some rare cases, the backsides of the prisms are metalized in order to ensure mirror reflection with, however, some loss. In the general case, the mirror reflection relies on total reflection in the interface from plastic to air.

Total reflection is ensured, whenever the angle of incidence on a surface exceeds the minimum angle for total reflection given by $\sin^{-1}(1/n)$, where n is the refractive index of the plastic material. With an refractive index of approximately 1,55 for the plastics normally used, this minimum angle is approximately 40°.

A ray of light in a direction perpendicular to the aperture meets any of the three prism faces at an angle of incidence of 54,7°, which ensures total reflection with some reserve.

However, when the light is directed an angle v towards one of the prism surfaces as shown in figure A.11, the angle of incidence on that surface decreases. The angle within the plastic medium changes by less than v because of refraction in the air-plastic interface, actually by $\sin^{-1}(\sin v/n)$ and v needs to be approximately 22° before total reflection fails.

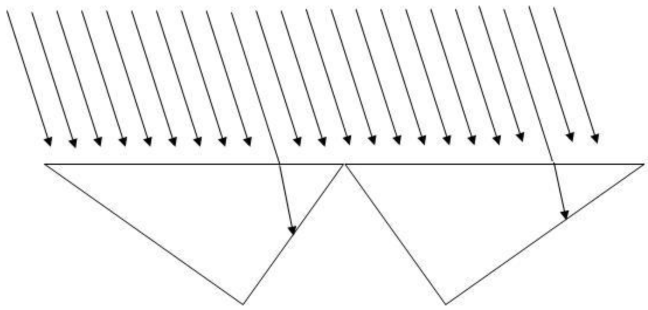
Figure A.11: Incoming light directed an angle v towards one of the prism surfaces.



In the classic lay-out, two prisms form a pair, and the whole packing is made up of such pairs. A pair is shown in figure A.12.

When the light is directed towards a prism face in one prism, it is directed away from the opposing face in the other prism. Therefore, when total reflection fails in one prism, it remains for the other prism regardless of the angle of the light.

Figure A.12: A pair of prisms.

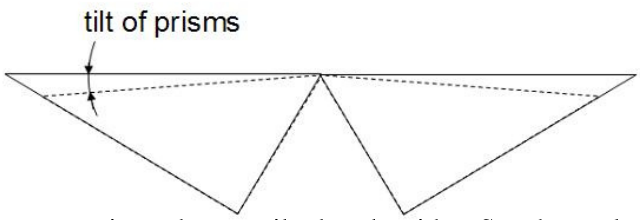


For this reason, the retroreflection does not fail for all of the prisms at an entrance angle of approximately 22°, only for half of them. This feature applies for every 60° rotation of the prismatic retroreflector relative to the light (or vice versa). At rotations in between, total reflection is maintained up to somewhat higher entrance angles.

However, an abrupt loss of half of the retroreflection at moderate entrance angles is bad enough and, therefore, various means are in use to counteract that.

One of these means is to tilt the prisms in the way indicated in figure A.13, so that total reflection is maintained in a somewhat wider range of entrance angles. This helps only when the light arrives from the sides, not if the light comes from other directions. However, many retroreflectors sit at about the same height as vehicle headlamps, so that the light can be expected to arrive from the sides.

Figure A.13: A pair of prisms with a tilt.



Another of these means is to provide fields of cube corner prisms that are tilted to the sides. See the cycle retroreflector in figure A.14.

Figure A.14: A cycle retroreflector with tilted fields of prisms.

A.3.3 The condition of reflection in all three prism surfaces

The condition of reflection in all three prism faces can be studied by means of figures A.15 and A.16.

When a ray of light falls on a mirror surface, one may study either the path of the ray after mirror reflection in the surface, or one may study an unchanged path through the surface into the mirror image of the prism. The two methods are equivalent, but in this case it is simplest to use the mirror image method.

The top drawing of figure A.15 shows the three prism faces placed in a coordinate system. It is assumed that a ray of light falls on the face orthogonal to axis z and, accordingly, the mirror image of the prism in this surface is shown in the second drawing. The double mirror image of this mirror image in the face orthogonal to axis x is shown in the third drawing. Finally, the triple mirror image in all three faces is shown in the bottom drawing.

If the ray of light is mirror reflected in all three faces, it enters first the mirror image, then the double mirror image, and finally the triple mirror image. Accordingly, the ray of light leaves through the triple mirror image of the aperture, and must point to it from the start.

If, on the other hand, the ray does not point to the triple mirror image of the aperture, it will leave through the first or the double mirror image of the aperture. If so, it cannot also enter the triple image.

In consequence, the ray is mirror reflected in all three faces when, and only when, it points to the triple mirror image of the aperture.

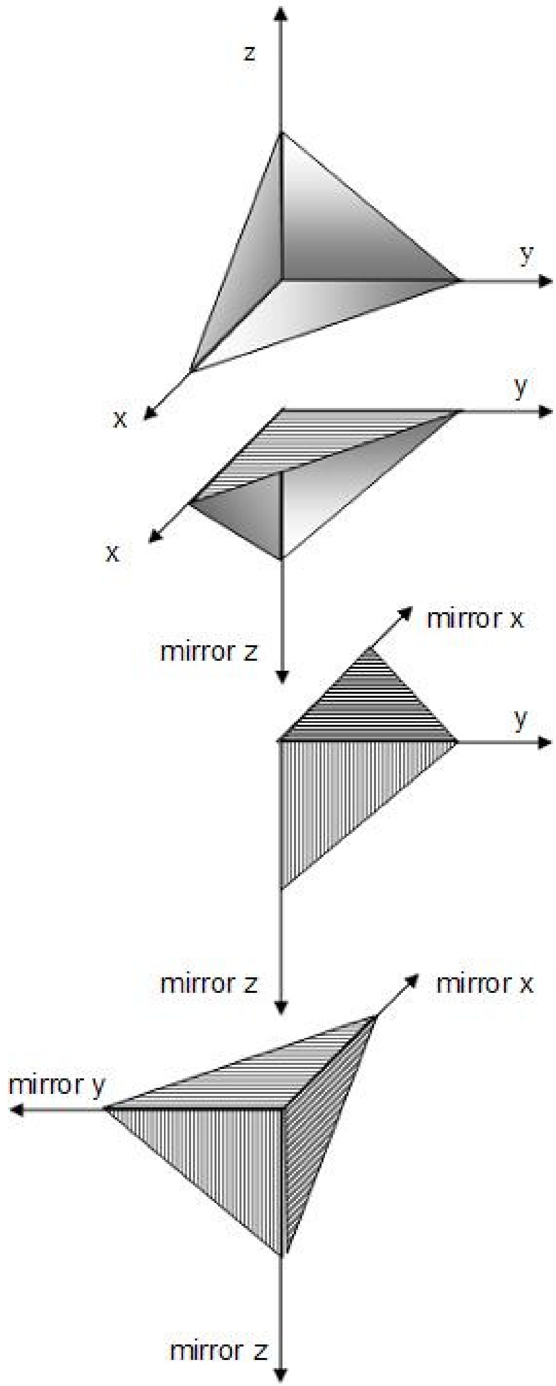


Figure A.15: Three prism faces (top) followed by a mirror image in one face, a double mirror image in two faces and a triple mirror image in all three faces (bottom).

Figure A.16 shows the three prism faces and the triple image put together in the right position relative to each other. The figure shows that a ray with the direction perpendicular to the paper points to the triple image of the aperture from some of the points in the aperture, but not from all.

Actually, only a part of the area of the aperture is active in the sense that it leads to reflection in all three prism faces (for the particular direction). The active area is shown in figure A.17.

It is more common to illustrate the active area as seen from the front, i.e. perpendicular to the aperture. This is done in figure A.18.

Figure A.16: Prism faces and their triple images.

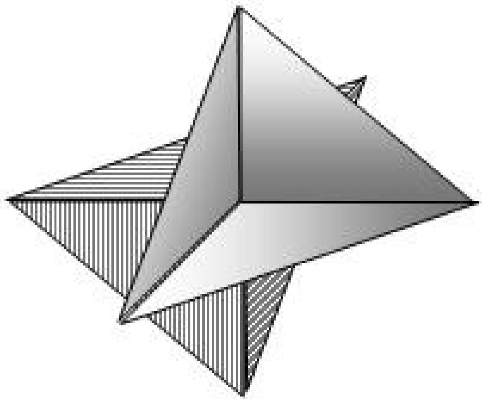


Figure A.17: The active area for the direction perpendicular to the paper.

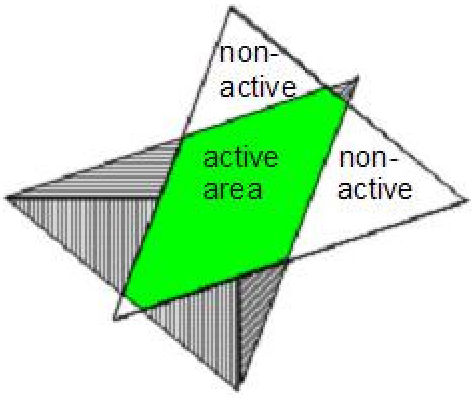
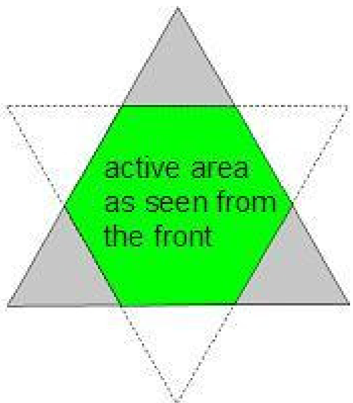


Figure A.18: The active area for the direction perpendicular to the aperture.



A ray of light that does not fall on the active area for its particular direction is only reflected in one or two of the prism surfaces – and is not retroreflected. Therefore, light falling on non-active areas is lost in terms of retroreflection.

The conclusion is that the active area depends on the direction. For this particular packing of prisms, a maximum active area of 2/3 of the aperture area is obtained for the direction perpendicular to the aperture. For other directions the active area is smaller and decreases with the entrance angle.

Another lay-out of the prisms has square instead of triangular prism faces as shown in figure A.19. Such prisms do not have a plane aperture, but this does not prevent that they are packed tightly like an incomplete stack of boxes as illustrated in figure A.20. A cube corner retroreflector with this lay-out is shown in figure A.21.

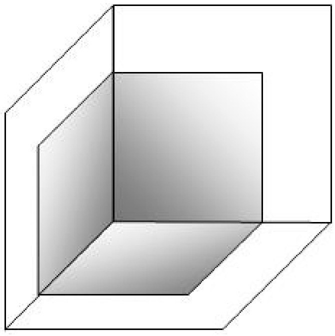


Figure A.19: Prism faces with the shape of squares.

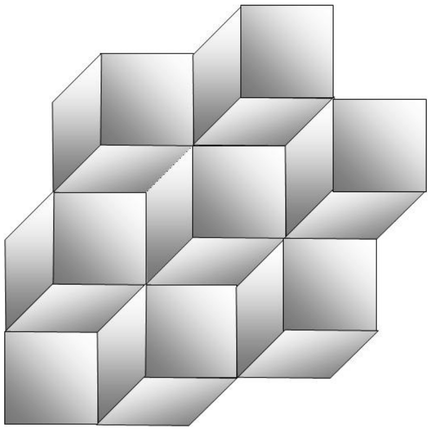


Figure A.20: Packing of square prism faces.

Figure A.21: A retroreflector with square prism faces.

Cube corner retroreflectors with square prism faces have the special feature that the whole front area is active for the direction perpendicular to the front. A retroreflector of this type looks almost black when observed face on – at least when it is of good quality. The reason is that the retroreflector reflects the black pupils of the observers own eyes.

Accordingly, the packing of squares is 50 % more efficient for the central direction than the packing of triangles. However, the active area decreases more quickly with the entrance angle, so that the gain is not big in practice when considering a range of entrance angles. In order to improve on that, retroreflectors of this kind are also sometimes divided into fields with different orientations. See the cycle retroreflector in figure A.22.

Figure A.22: A cycle retroreflector with square prism surfaces and three field of different orientations.

A.3.4 Use of prism based retroreflectors

Cube corner retroreflectors have a wide range of use on vehicles, by pedestrians and in road equipment.

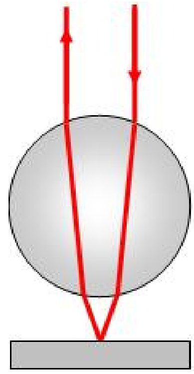
A.4 Retroreflective sheeting materials using glass beads

A.4.1 Glass beads as lenses

Glass beads have been produced since the 30's by spraying molten glass into an upstream of air. Glass beads can act as lenses and need therefore only to be combined with reflection is order to create retroreflection.

A glass bead of ordinary glass of a refractive index of approximately 1,55 has the focal point a bit behind the bead. It is therefore best that the reflection takes place a small distance, see figure A.23.

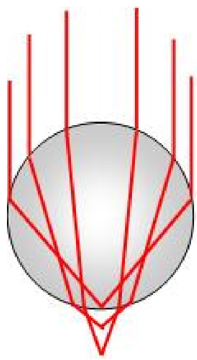
Figure A.23: A glass bead and a reflecting surface acting as a retroreflector.



However, before the advent of retroreflective sheeting materials, glass bead were often applied to wet paint so as to stick in the paint and enhance the reflection of the painted surface by a weak retroreflection.

This works because a glass bead is actually a poor lens with a focus that varies with the distance of the incoming ray from the centre of the bead as shown in figure A.24. The focus for light entering close to the periphery of the bead is close to the bead or even inside it.

Figure A.24: Paths of rays through a glass bead.



How it works is shown in figure A.25. Incoming light is collected on an area that is smaller than the glass bead and some of the light that is reflected in the paint is more or less collimated by the bead. However, the retroreflection is weak because the reflected beam is much wider than needed in traffic situations.

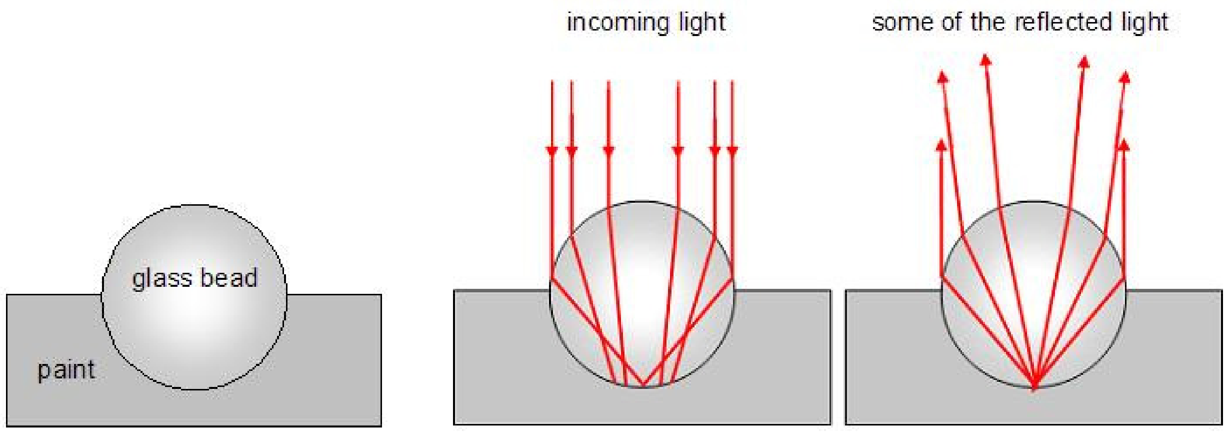


Figure A.25: A glass bead in paint with incoming light and some of the reflected light.

Figure A.26 shows the distribution of retroreflected light, as calculated for a glass bead with a refractive index of 1,55 subtended in white paint and with light falling perpendicular to the surface. The calculation is by ray tracing using a program called Pinball. Other calculations mentioned in the following are done in the same manner.

It is seen from figure A.26 that the beam is wide, of the order of ±20°. Because of this, and because of various losses, the R_A value is a couple of units only.

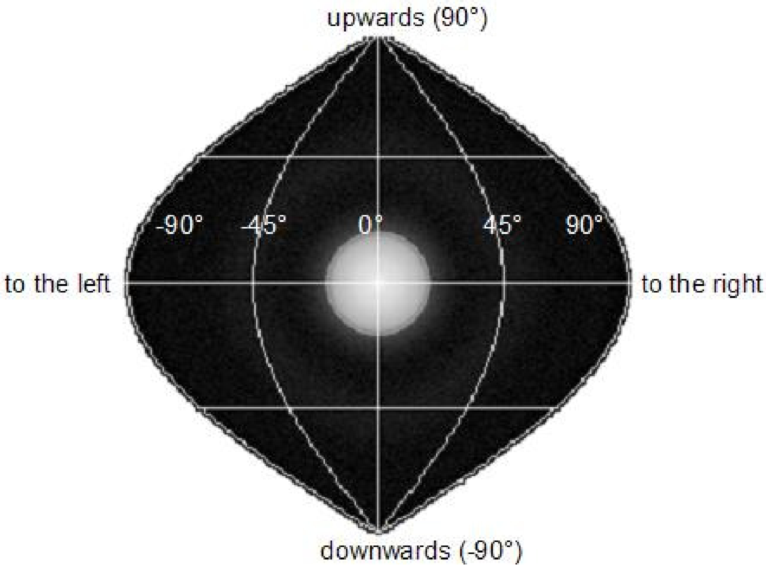


Figure A.26: Distribution of reflected light from a glass bead in paint shown in a sine projection of space.

Glass beads are still used in road marking paints as a drop-on material. Drop-on beads are also applied to other road marking materials such as thermoplastics, and often with pre-mix glass beads in the materials themselves.

The action of glass beads in road markings is particularly weak because of the awkward geometrical situation with illumination by headlamps in glancing direction and because of the erosion by traffic. Additionally, most of the retroreflection is lost in wet conditions for a number of reasons. One of them is that a bead covered by water has an apparently lower refractive index and a less good focus of the light.

Nevertheless, glass beads are generally used in road markings to improve their visibility as a simple and relatively inexpensive mean.

Sometimes the glass beads are high index glass beads with a refractive index of approximately 1,9. These beads are at a higher cost, but they do provide a better focus, a stronger retroreflection and some retroreflection in wet conditions.

High index glass beads became available in the 50's and were used for an early type of glass beaded sheeting material with a part of the glass beads exposed at the front.. This principle was, however, abandoned because of loss of retroreflection in rain. Later types have glass beads behind a flat surface in order not to be sensitive to rain.

NOTE: When a rain drop sticks to a flat surface, it does not disturb the retroreflection of a glass bead behind the surface for the reason that the glass bead is much smaller than the rain drop. There is refraction in the rain drop for both the incoming to a glass bead and the retroreflected light from the glass bead, but it is at the same location of the rain drop so that the light is still retroreflected. Dew, on the other hand, consists of drops as small as the glass beads and does reduce the retroreflection.

When a glass bead is equipped with a spherical mirror as shown in figure A.27, it is possible to obtain both a better collimation of the retroreflected beam and a good entrance angularity.

Figure A.27: A glass bead with a spherical mirror.

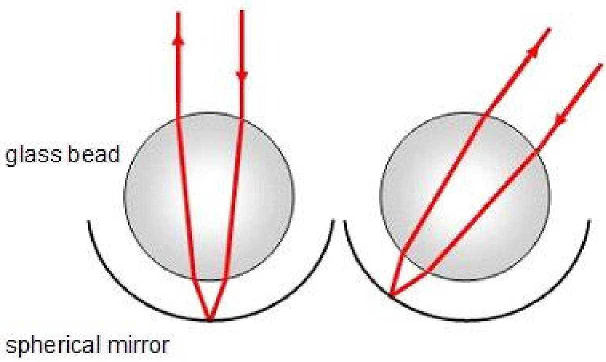


Figure A.28 shows a calculation model for a glass bead with refractive index of 1,55 equipped with a spherical mirror with a hemispherical mirror that has a diameter of 1,4 times the diameter of the glass bead.

The distribution of retroreflected light looks much like the one shown in figure A.26, except that it has a powerful central beam. This beam is shown in figure A.29 on a grid with a division of 1°.

Figure A.28: Calculation model for the Pinball program.

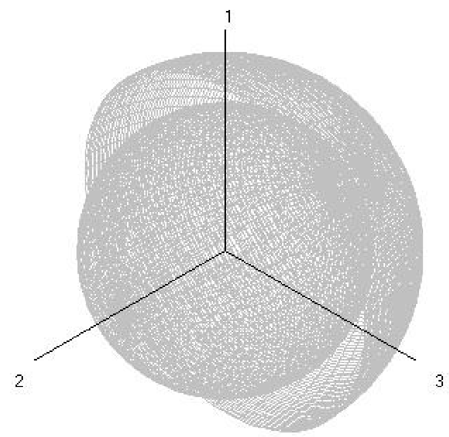
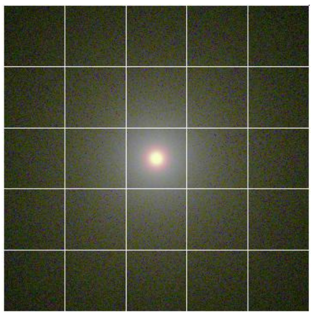


Figure A.29: The central beam of the retroreflected light shown on a grid with a division of 1°.

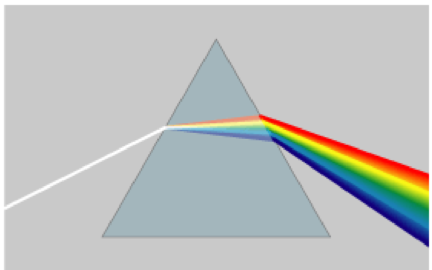


The central beam according to the calculations is narrow, with a width of only ±0,1°. This is clearly unrealistic as aberrations in the shape of the glass bead and the mirror will cause a widening of the beam in practical sheeting materials.

The central beam is associated with colour in the sense that it has a reddish corona. This is due to a normal assumption about glass that the refractive index is a few percent higher for blue light than for red light. This phenomenon is called dispersion and means that blue and red light cannot be in focus at the same time. In this case, the red light is slightly out of focus.

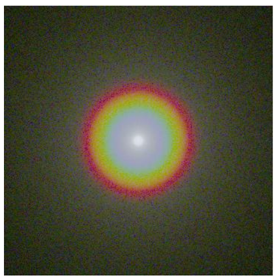
Dispersion is often explained by means a Newton prism, which can split white light into a rainbow of the different colours. See figure A.30.

Figure A.30: A Newton prism.



If the hemispherical mirror is brought a bit closer to the glass bead, by reducing its diameter, the separation of colours is more pronounced and the central beam gets wider. This is illustrated in figure A.31, which shows the central beam after reducing the diameter by approximately 5%. The width of the central beam is now more than ±1°.

Figure A.31: The central beam of the retroreflected light after reducing the diameter of the hemispherical mirror.



Increasing the diameter of the hemispherical mirror also causes a widening of the beam, but with the colours in the reverse order.

Variations in the precise location of the mirrors relative to the bead will obviously be a source of broadening the beam in practical glass beaded sheeting materials. It is a bit strange that colour effects are not observed in such materials, but that is probably because they partly cancel out and partly drown in broadening of the beam by other aberrations.

Another source of broadening the beam is by diffraction in combination with the small size of the glass beads of typically of 30 microns. In principle, an optical device of a diameter D cannot collimate light of a wavelength λ to a beam of a width of less than ±λ/D radians. Assuming a diameter of 30 microns and a wavelength of 0,5 microns, the minimum beam width is 1/60 radians or approximately ±1°.

Since the glass beads are spherical, the diffraction pattern is probably the one of the circular aperture diffraction, which is shown in figure A.32.

Figure A.32: Diffraction pattern of a circular aperture.

The central spot of the diffraction pattern has a diameter as described above, but the surrounding rings adds to the diameter, which should then be set somewhat higher. Additionally, the pattern is bigger for red light with a wavelength approaching 0,7 microns and smaller for blue light with a wavelength of 0,4 microns.

The total effect is a blurring to a wider beam with some colour fringes. The colours are not observed for the above-mentioned reasons (except possibly in one case to be mentioned later), but the total effect is a widening of the beam to a minimum of perhaps ±2°.

The above-mentioned effects of aberrations and diffraction explain why the retroreflected beams from glass beaded materials are fairly wide.

Further, the poor quality of a glass bead as a lens makes the retroreflectance, when counting only the central beam, rather small. The calculations indicate that 10 to 15 % of the light that hit a glass bead is reflected into the central beam.

Glass beaded materials use actually high index beads, but in one of the two main types the beads are enclosed in a plastic medium and act as if the refractive index is reduced. The above-mentioned calculations are relevant for this main type (EG materials).

Matters are more positive, when high index beads are not enclosed in plastic as in the other main type of glass beaded materials (HI). If so, approximately 20 % of the light that hits a glass bead is reflected into the main beam.

In practice the retroreflectance is smaller than the above-mentioned values when considering other losses – in particular that some light will fall in between glass beads.

A.4.2 EG and HI types of glass beaded sheeting materials

Glass beaded materials exists in two versions:

- enclosed lens, also called Engineering Grade or just EG
- encapsulated lens, also called High Intensity or just HI.

The glass beads are high index beads with a refractive index of approximately 1,9.

The major difference between EG and HI materials is that the front parts of the glass beads are enclosed in a plastic layer in EG materials, while they are in air in HI materials. See figure A.33.

A. EG materials

B. HI materials

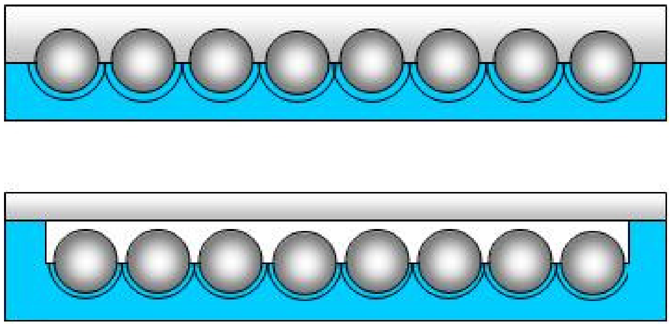


Figure A.33: The construction of EG and HI materials.

EG materials have a continuous surface without features, except for trade marks and similar, while HI materials are divided into cells by ribs that support the front layer. These ribs are made white in order to add to the daylight reflection. The ribs are shaped in distinctive patterns that are characteristic for the different products.

A.4.3 Some properties of glass beaded sheeting materials

EG materials have a rather low retroreflectance of 5 to 10 % and a fairly large width of the retroreflected beam.

This is because the beads are enclosed in plastic so that the effective refractive index is reduced. The R_A value in the centre of the beam is of the order of 75 $cd \cdot m^{-2} \cdot lx^{-1}$. The entrance angularity is fairly good with a luminance maintained to approximately 70 % out to an entrance angle of 30° and to approximately 50 % out to an entrance angle of 40°.

The air in HI materials provides focus closer to the beads and, thereby, better focus and allows a more dense distribution of the beads. Accordingly, HI materials have a higher retroreflectance 10 to 15 % and a more suitable beam width. The R_A value in the centre of the beam is of the order of 200 $cd \cdot m^{-2} \cdot lx^{-1}$. The entrance angularity is very good with a luminance fully maintained out to an entrance angle of 40° and sometimes further.

NOTE 1: These figures are averages for some EG and HI products, some are better and some worse.

NOTE 2: The true measure of the luminance is not the R_A value, but the R_L value obtained as the R_A value divided by the cosine to the entrance angle. This is what is meant by luminance in the above.

For both types of materials, the retroreflectance if fairly low as mentioned in the above, but this is when only counting the light that is reflected into the central retroreflected beam that is useful for traffic situations. Around the central beam there is a much weaker, but also much wider corona in a cone out to ±20° or more. The total amount of light reflected into that corona is a substantial fraction of the light that falls on glass beads. See the pattern in figure A.34 as calculated with Pinball.

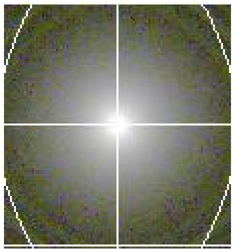


Figure A.34: Central retroreflected beam and wide corona.

The light in the corona is in a sense wasted as it does not contribute to retroreflection and as it does not contribute to the luminance factor in the 0°/45° or 45°/0° geometry either. An additional loss in this respect is surface reflection at the surface of the material, which can be set to 4 % for EG materials with a single air/plastic interface and to twice that for HI materials.

This shows that the luminance factor is smaller than for a surface of ordinary reflection. In agreement with this, the luminance factor value is 0,45 for EG materials and 0,3 for HI materials with some variation between products.

The lower value for HI materials is probably due to a more dense packing of glass beads, and is in spite of the above-mentioned contribution from the supporting ribs.

A.4.4 The pattern of retroreflected light of glass beaded sheeting materials

The pattern of the glass beads in the sheeting surface has some randomness and does not introduce any preference for particular rotations. Because of this, and because of rotational symmetry of the glass beads and their reflectors - at least on the average – the properties of glass beaded materials are insensitive to rotation.

Therefore, it does not matter in which rotation a material is mounted of a sign substrate, it can be upside down or at an angle. A roll of sheeting can be used almost fully. The exception may be when matching pieces of the material on a large sign face by avoiding that the left edge of a roll is joined to a right edge of the roll (there may be some variation across the width of the roll).

As the shape and the intensity of the retroreflected beam is insensitive to rotation, there is some obvious advantage for testing in terms of instrumentation and test regime. The same applies for the testing of the daylight luminance factor and chromaticity.

Additionally, the retroreflected beam is often assumed to possess rotational symmetry and a shape that is insensitive to a change of the entrance angle. This, however, involves some approximation.
It could be expected that the retroreflected beam would show colour fringes due to dispersion of the refractive index and due to diffraction as discussed in the previous section. However, such do not show up in practical materials, or at least they are not obvious. The underlying reason is probably that glass beaded sheeting materials have some variation of the gap between the beads and the underlying reflectors, and also that the beads have a range of sizes.

There is a single exception, which is a variant of EG materials, the Super Engineering Grade, or just SEG, supplied by one manufacturer. This material seems to have less variation of the sizes of the glass beads, which leads to a somewhat better focus and a somewhat higher R_A value in the centre of the beam. However, the retroreflected beam shows colour fringes - probably because diffraction effects do not cancel out for beads of almost the same size.

A.5 Microprismatic sheeting materials

A.5.1 Construction of microprismatic sheeting materials

A microprismatic sheeting material has a plastic layer with prisms imprinted on the backside as shown in figure A. 35. There is a further white reflecting layer behind this layer with supporting ribs between the two.

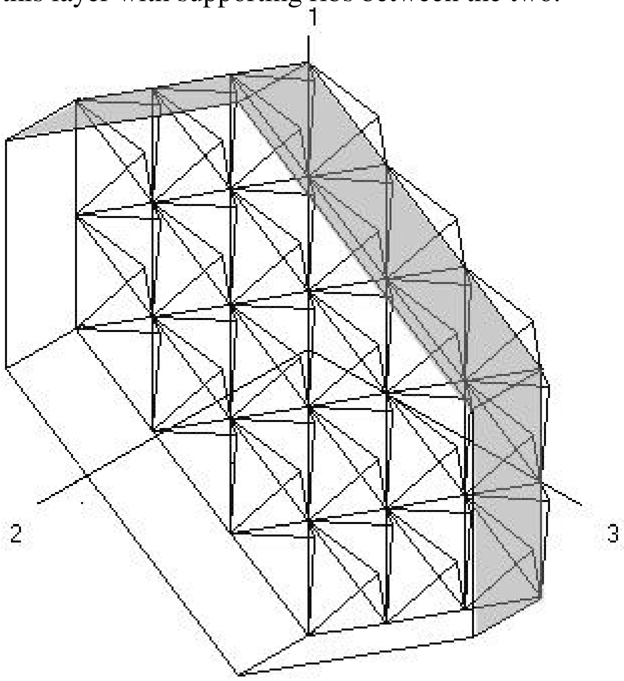


Figure A.35: A plastic layer with prisms on the backside.

The prisms have the same geometrical configurations as accounted for in A.3 for prismatic retroreflectors. Most of the products have prisms with triangular faces as illustrated in figures A.7 to A.18, and most of these have tilted prisms as illustrated in figure A.13. However, a recent product has prisms with square faces as illustrated in figures A.19 and A.20.

The construction is thin so as to be flexible with a thickness of the prism layer of the order of a small fraction of a mm and a depth of the prisms behind the layer of about 35 microns to about 150 microns depending on the product.

A.5.2 The active areas for different packings of prisms

It is made clear in A.3 that a ray of light, which is to be retroreflected, has to enter the aperture of a prism and also to point to the mirror image of the aperture. Because of this, a prism has an active area for a particular direction of illumination.

Figure A.36 illustrates a non-tilted prism and its mirror image, while figure A.37 illustrates the active area for the direction perpendicular to the prism aperture.

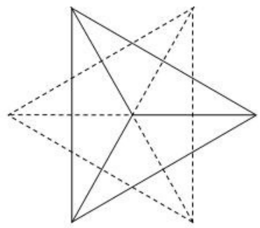


Figure A.36: A prism (full lines) and its mirror image (broken lines).

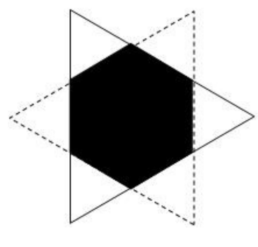


Figure A.37: The active area of a prism seen at 0°.

It was also made clear in A.3 that a field of prism can be considered to be made up of pairs of prisms. Figure A.38 shows such a pair of non-tilted prisms and its active area for the direction perpendicular to the apertures of the pair. The active area makes up a large fraction of the aperture area, actually of 2/3. The fraction depends on the actual lay-out of the prisms, but the fraction and thereby the retroreflectance can in general be expected to be high at 0° entrance angle.

Figure A.38: A pair of prisms and the active area seen at 0°.

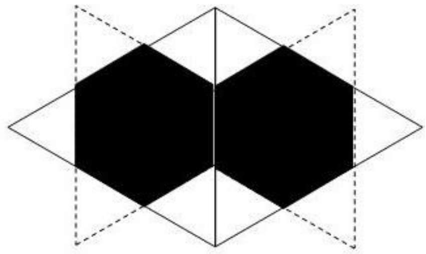


Figure A.39 shows the active area in a direction at an angle of 14° from below. It is seen that the active area is reduced, actually to 4/9 of the aperture area. The angle of 14° corresponds to an entrance angle of 22° for a refractive index of the medium of 1,55 (22° is changed to 14° by refraction in the plastic interface). The fraction depends on the actual lay-out of the prisms, but the fraction and thereby the retroreflectance can in general be expected to decrease significantly with increasing entrance angle.

Figure A.39: The active area seen at 14° (within the medium) from below.

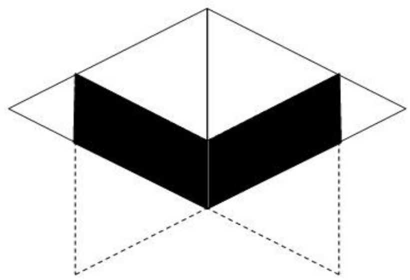
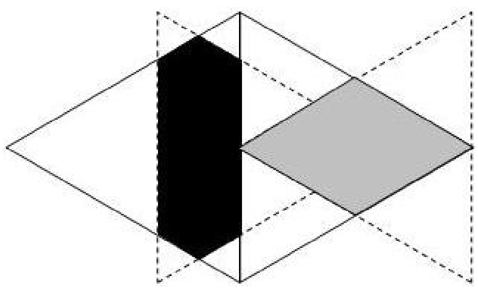


Figure A.40 shows the active area for the same entrance angle of 22° (14° within the medium), but with illumination from the right. In this case, the active area is also reduced, but to a different fraction of the aperture area of ½. This shows that there can be a variation of the fraction and thereby the retroreflectance with a rotation of the illumination direction about the normal to the sheeting material. In this case, the pattern repeats for every 60° of rotation, but with a fairly small variation (the fraction of the active area varies between 4/9 = 0,4444 and ½ = 0,5).

Figure A.40: The active area seen at 14° (within the medium) from the right.



The active area for the right hand prism is shown in grey in figure A.40. As pointed out in A.3, the total reflection will fail in one of the sides of that prism at 14°, when the refractive index is 1,55 or less. Therefore, there is a loss of total reflection at this particular entrance angle in the situation shown in figure

A.40, but not in the situation shown in figure A.39. Accordingly, loss of total reflection for some rotations can lead to a fairly strong variation of the retroreflectance with rotation.

It is in order to make the active area less dependant on the entrance angle, and to maintain total reflection out to larger entrance angles that many products have paired tilting of the prisms. angles. This works, but only for light entering essentially from the sides – not for light entering essentially from up or down. The above-mentioned 60° rotation symmetry is disturbed by tilting of the prisms, and the only remaining symmetries are right/left and up/down symmetries.

A different kind of symmetry is provided in some products from one manufacturer in which the prisms are arranged in fields of rotations of 0°, 30°, 60°, 90°, 120° and 150°. This is in order to provide an approximation to the simple rotational symmetry of glass beaded sheeting materials. This property is called “omni rotational”.

Another producer has abandoned paired tilting in one product, and use the structure of tightly packed prisms with square faces that is shown in figure A.20.

The square faces are shown in figure A.41 as seen perpendicular to the sheeting material. The reflecting surfaces are shown again in figure A.41B with a weak indication of the mirror images of the reflecting surfaces. The outlines of the faces form a hexagon and the outlines of the mirror images of the faces form a coinciding hexagon. This shows that all of the area of the square faces is active at an entrance angle of 0° so that the retroreflectance is potentially the highest possible.

A.

B.

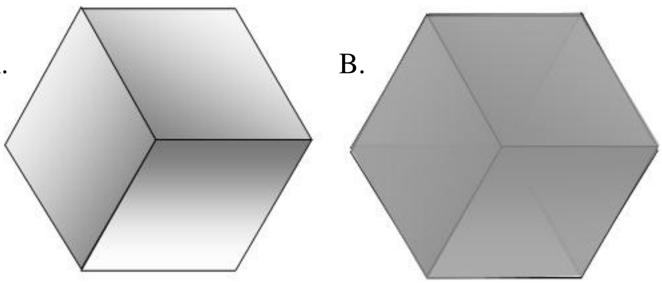


Figure A.41: A prism with square surfaces seen at 0° (A) and with its mirror image (B).

Figure A.42A shows the same prism surfaces when viewed at an angle of 14° from the right corresponding to an entrance angle of 22° (14° within the medium), and figure A42B has an additional weak indication of the mirror images of the surfaces. The active area is now only approximately 1/3 of the apparent areas of the prism faces.

A.

B.

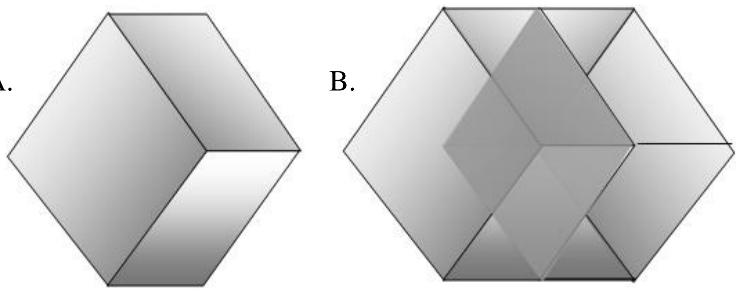


Figure A.42: A prism with square surfaces seen at 14° from the right (A) and with its mirror image (B).

Accordingly, this structure of tightly packed prisms with square faces has a 100 % active area at 0°, but a particularly quick reduction of the active area with increasing entrance angle. Failure of total reflection occurs at the same entrance angle as for non-tilted prisms with triangular reflecting surfaces (22° for a refractive index of 1,55). The symmetry is reduced to a 120° rotation symmetry.

It noted that the above-mentioned refractive index of 1,55 is a typical value, but that some products are based on plastic materials with higher or lower values and that this has an impact on the variation of the retroreflectance with the entrance angle, and in particular on the angle where total reflection is lost.

A.5.3 The pattern of retroreflected light from microprismatic materials

It is possible to shape the prism surfaces of microprismatic sheeting materials so accurately that the retroreflected beam can be narrow.

A lower limit is set by diffraction in view of the size of the micro prisms. In principle, diffraction will widen any beam to a minimum of $\pm\lambda/D$ radians where λ is the wavelength of the light and D is a smallest critical dimension of the micro prism.

It is probably a difficult task to compute the pattern of diffraction of a narrow retroreflected beam, but some main features can be guessed at.

Firstly, the pattern will have coloured fringes as red light with a wavelength of 0,7 microns will be diffracted to a wider beam than blue light with a wavelength of 0,4 microns. Secondly, the pattern will probably consist of a central dot with a halo of rings such as in the diffraction pattern of a circular aperture (refer to figure A.32 in A.4.1). Thirdly, the rings are probably broken up in a hexagonal pattern of weak dots due to the symmetries of the prisms. Additionally, there will be an overlaid fine pattern caused by the regularity of the packing of prisms.

A pattern like described above can be observed for a few microprismatic sheeting products.

NOTE: Use a slide projector with a slide having a small hole so as to define a narrow beam. Illuminate a sheeting material at a sufficiently large distance like 10 or 20 m and observe the retroreflected pattern on a screen placed around the lens of the slide projector. This requires a dark room.

It is guessed that the critical dimension D is a dimension of a reflecting face in the prisms, such as given by the depth of the prisms behind the plastic layer in which they are shaped. This depth is mostly 100 microns of less, down to 35 microns. The width of the diffraction pattern is then estimated to be in the range of ±0,4° to ±1,2° for red light.

It is not permissible that a general purpose sheeting material allows that the diffraction pattern shapes the beam, because it is non-uniform and coloured. Therefore, and in order to have control over the beam width and distribution, some sort of aberration is introduced. However, the retroreflected beam is typically still narrow compared with glass beaded sheeting materials, and it is typically not of rotational symmetry as for glass beaded materials. As an example, some microprismatic materials show a diamond shaped beam.

A.5.4 Other types of reflection in microprismatic materials

Figure A.43 shows the types of reflection that can be expected, when illuminating a field of a microprismatic material. These are retroreflection, mirror reflection, sparkle and diffuse reflection.

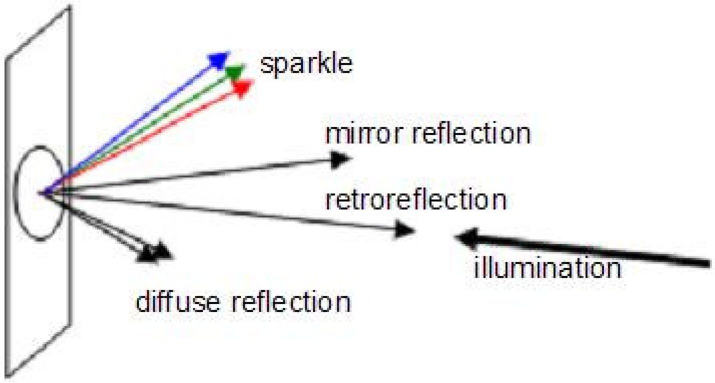


Figure A.43: Types of reflection from a microprismatic material.

Figures A.44, A.45 and A.46 show the results of ray tracing in models that are based on actual microprismatic materials regarding prism geometry, thickness of the layer on which the prisms are imprinted and the refractive index including dispersion. All three materials are of the types with triangular prisms tilted in pairs.

The results are the luminous intensities shown in a density scale with colour in a sine projection of directions in space. The incoming beam has been given a substantial width in order that various reflected beams can be seen as small areas in the projections,(else they would be single pixel points).

All the above-mentioned types of reflection are recognizable in the figures. The illumination is in the 5° upwards direction and, therefore, mirror reflection is also in a 5° upwards direction while retroreflection is in a 5° downwards direction.

Figure A.44: Results of ray tracing for a model of a first type of microprismatic material.

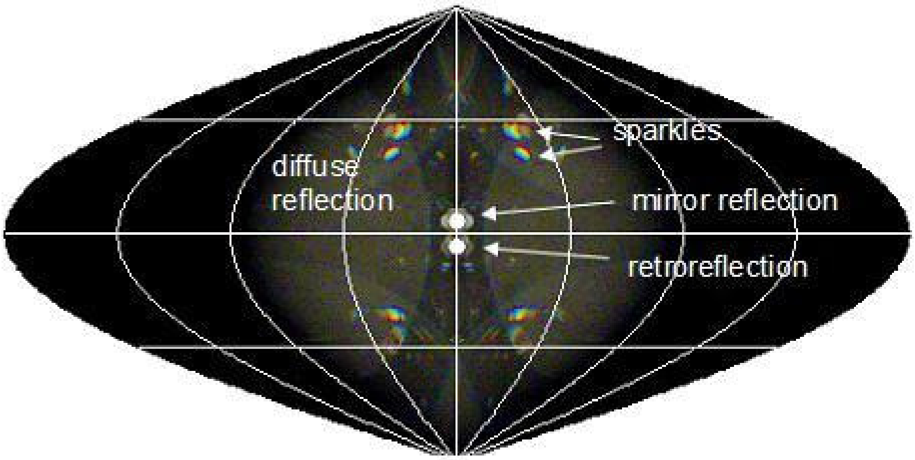


Figure A.45: Results of ray tracing for a model of a second type of microprismatic material.

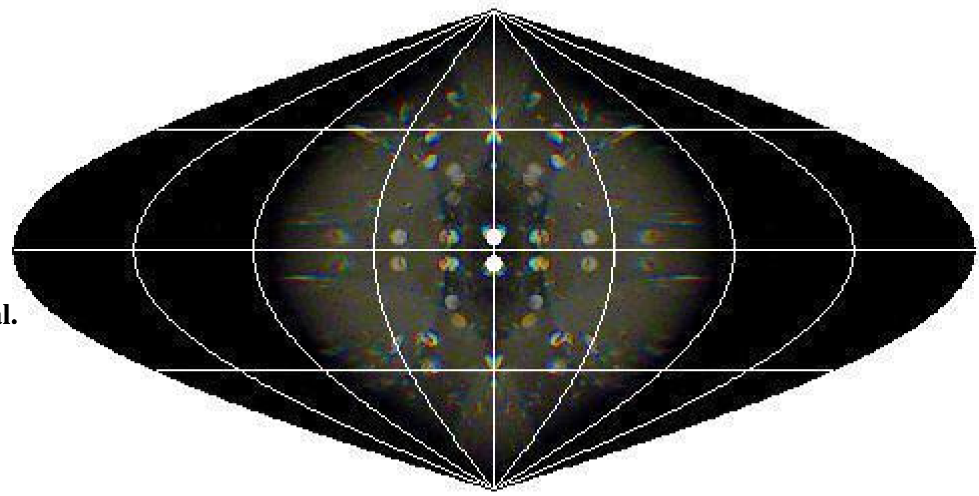
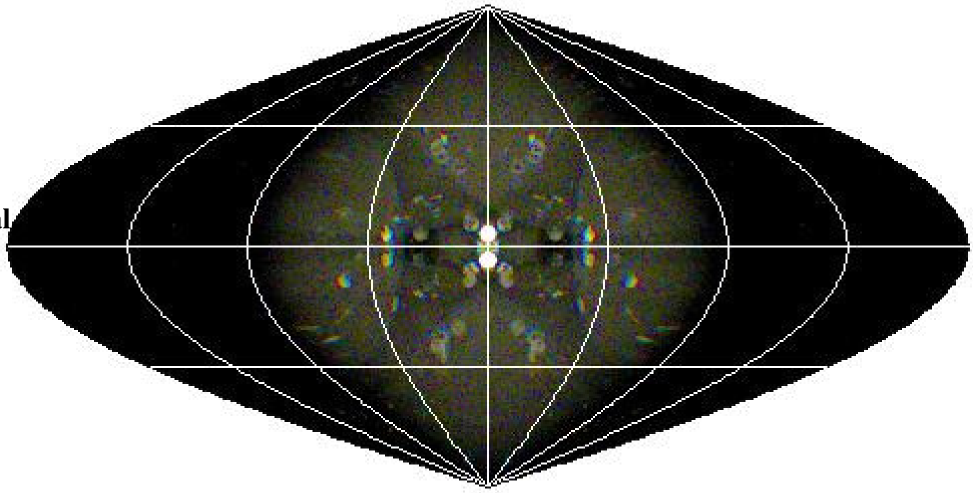


Figure A.46: Results of ray tracing for a model of a third type of microprismatic material



The luminous intensities, and the luminous flux in small fields, can be read of the images when they are live in the ray tracing program (Pinball). Therefore, a complete account can be made of the various reflections in terms of percentage of the incoming luminous flux. These account are given in table A.1.

Table A.1: Account of various reflections for three types of materials.

	type of material		
type of reflection	first	second	third
retroreflection	47,4 %	59,7 %	57,4 %
mirror reflection	31,4 %	19,3 %	19,4 %
sparkles	5,0 %	5,2 %	5,6 %
diffuse reflection	10,0 %	10,0 %	12,0 %
total	93,8 %	94,3 %	94,5 %

The total in table A.1 does not quite make 100 % because a few weak sparkles and absorption in the white layer behind the prisms are not included.

As expected, retroreflection accounts for a large percentage of the incoming light.
However, it needs some explanation that mirror reflection also accounts for a large percentage , more than 30 % for the first material and approximately 20 % for the two other materials.

One source of mirror reflection is of course a surface reflection that occurs when the incoming light meets the plastic interface. However, one surface reflection is no more than 4 %.

There is a further mirror reflection when the retroreflected light meets the interface from the inside, is surface reflected, retroreflected again and finally passes the interface. But this kind of mirror reflection requires two times retroreflection in addition to a surface reflection and should account for no more than 1 % of the incoming light.

For a further source of mirror reflection, attention is drawn to rays of light that enter non-active parts of prism apertures. A possible path is shown in figure A.47.

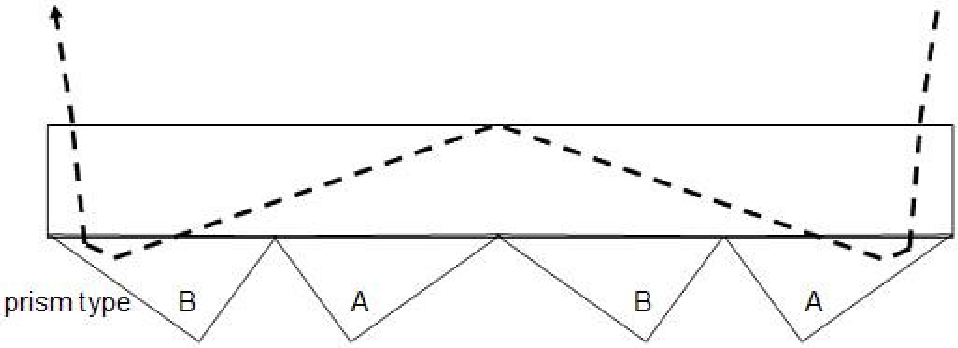


Figure A.47: A path of a ray that leads to mirror reflection.

The ray is reflected in two prism faces and leaves the aperture again without being reflected in the third prism face. Then the ray meets the interface from the inside at a large angle and is totally reflected into another prism. If the two prisms are of opposing types (A or B like the two prisms in a pair), the ray will be reflected in the two opposing prism faces and will thereafter be transmitted into a mirror reflected direction.

It is noted that a substantial part of the incoming light falls on non-active areas to be sent on the first steps on the path. The only necessary assumption is that a large part will fall into a prism of an opposing type and that is likely.

Accordingly, figure A.47 can explain that the mirror reflection values of table A.1 are large. It is noted that the actual value changes with the direction of the incoming light, which is also explicable in terms of figure A.47. The strong mirror reflection of some microprismatic materials is by the way easily confirmed by visual observation.

Mirror reflection represents a waste of light as it does not contribute to neither the retroreflection nor to the luminance factor in the 0°/45° or 45°/0° geometry.

The sparkles can also be explained by a similar path of a ray, when the ray after the same initial path enters a prism of the same type. This is illustrated in figure A.48. The result is a separation of colours as in a Newton prism.

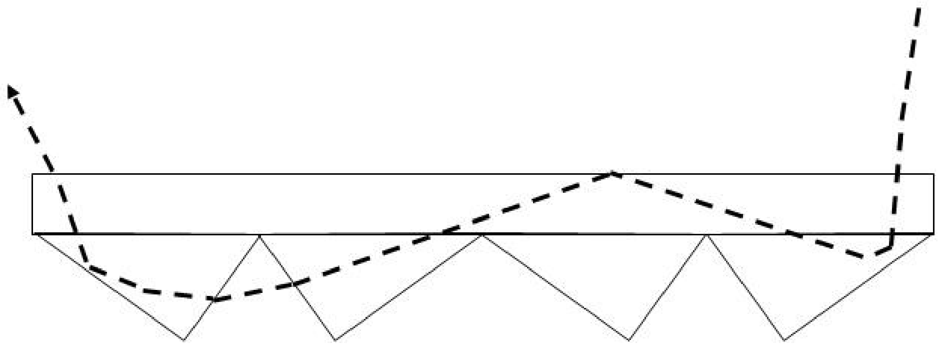


Figure A.48: A path of a ray that leads to sparkle.

Sparkles are complex because they change both intensity and location with the direction of incoming light. It is in fact virtually impossible to map the sparkles of a material for all interesting directions.

The above-mentioned paths of rays are not exhaustive, as there are other even more complex paths that lead to mirror reflection and sparkle.

As the ray-tracings were applied for products with triangular prisms faces only, they do not apply for products with tightly packed prisms with square faces.

It is a main difference that there is only one type of prisms with the same orientation in the dense packing, so that paths of rays as indicated in figure A.47 do not occur. Therefore, the mirror reflection is probably not strong for this packing of prisms. Sparkles may also be weaker.

Finally, diffuse reflection is caused by paths like those in figure A.48, where rays leave a prism without entering another and therefore hits on the white layer behind the prisms. Once the light is reflected at the white layer, it has various ways to be transmitted through the prisms.

It is not sufficient that only about 10 % of the incoming light is subject to diffuse reflection (refer to table A.1). An additional contribution to diffuse reflection comes from the ribs that support the layer with the prisms as these walls are generally white. The walls actually covers a substantial fraction of the area of a sheeting material in order that the luminance factor can reach a value of 30 to 40 %.

Consequently, there is a reduction of the retroreflectance, which in practice is in the range of approximately 20 to 35 % for small entrance angles, and decreases with increasing entrance angles.

Annex B: Retroreflective road signs

B.1 Introduction

At night, the optimum legibility of road signs is obtained when white parts of the sign faces have luminance levels of 30 to 100 cd/m^2. The road signs may still be legible at lower luminance levels, down to a few cd/m^2, but at a reduced legibility which tends to reduce the maximum legibility distance. The legibility fails at even lower luminance levels where the maximum legibility distance becomes too short to be useful. Further, colours can not be discriminated very low luminance levels.

In the case of ordinary reflection, it takes an illumination of 5 to 10 lx to produce a luminance of one cd/m^2. This means that optimum legibility requires an illumination to hundreds of lx, and that reduced legibility requires tens of lx.

NOTE 1: The road sign luminance L can be estimated by $L = E\times\rho/\pi$, where E is the illuminance on the sign face and ρ is the reflectance. Accordingly, $E/L = \pi/\rho$. A typical value of ρ is 0,7 for white parts with ordinary reflection and 0,35 for white retroreflective parts. Insertion of these values gives E/L equal to respectively 4,45 and 8,9.

Such illumination is not provided by the headlamps of a vehicle. When a road sign is within the powerful part of the beams, the total luminous intensity towards the road sign is of the order of 10.000 cd, but it is necessary to consider distances of 100 m or more. Accordingly, the illumination is of the order of 1 lx (10.000 divided by 100^2 in accordance with the distance law of illumination).

In fact, during driving it is mostly necessary to use the low beam, which has much smaller luminous intensities towards most road signs - of the order of 100 cd only. In these cases, the illumination is of the order of 0,01 lx and very far from sufficient.

Most road signs are placed at traffic roads and some of these have road lighting, which mostly provides illuminance levels of 5 to 15 lx on the road surface. The illuminance is less on vertical road signs, probably less than half on the average. Therefore, road lighting may give some contribution to the road sign luminance, but is not sufficient in itself.

This leaves the options of introducing a separate illumination of the road signs, or to make them retroreflective.

Separate illumination involves external illumination or transillumination. Illumination has the advantage of leading to optimum legibility, when it is sufficiently powerful. However, it also carries the disadvantages of requiring additional luminaires, electricity supply, usage of electricity and maintenance.

Retroreflection is established by the application of retroreflective sheeting materials to the sign faces.
The measure of the ability of a retroreflective surface to retroreflect in a particular geometrical situation is the ratio between the luminance L and the illuminance E produced by the headlamps at the location of the retroreflective surface and measured perpendicular to the direction of illumination. This ratio is called the coefficient of retroreflected luminance R_L in the unit of candela per square metres per lux ($cd\cdot m^{-2}\cdot lx^{-1}$). However, for some traditional reason, another measure is used, which is called the coefficient of retroreflection R_A in the unit of candela per lux per square metres ($cd\cdot lx^{-1}\cdot m^{-2}$).

The two measures are related by $R_A = R_L\times\cos(\beta)$ R_L or $R_A/\cos(\beta)$ where β is the angle of incidence measured between the direction of illumination and the normal to the surface. This angle is normally called the entrance angle in connection with retroreflective surfaces.

Retroreflection gives a very strong enhancement of the effect of low beam headlamp illumination, by a factor of typically 100 to 1000, but does not normally provide optimum legibility. Therefore, it is mostly necessary to compensate for the loss of legibility distance by making the legends of the road signs and, accordingly, the road signs themselves somewhat larger than necessary for daylight conditions. This implies an additional expense.

Separate illumination is used for a few road signs that are deemed to be sufficiently important to require added legibility and conspicuity. Such signs are often at locations with road lighting or other special lighting, so that the electricity supply is readily available.

EXAMPLE: In Denmark, illumination is requested for this sign at pedestrian crossings. Further, illumination is used on some gantry signs at motorway separations in order to ensure that they are legible even in case of dew. The illumination is to a relatively low level by narrow beam projector lamps placed outside of the road area for easy maintenance.

Retroreflection has become the preferred option for the vast majority of signs because it is much simpler and cheaper than the first option of separate illumination.

However, it has to be considered that it is useful to make the best of retroreflection and that no single type of sheeting material is suitable for all types and locations of road signs. It is, therefore, necessary to have a method for evaluating the retroreflective performance of particular sheeting materials in view of intended applications.

Such a method must be based on an account for the road sign luminance as created in an interplay between:
- the low beam headlamp luminous intensity distribution
- the geometry of illumination and observation and
- the detailed properties of the retroreflective sheeting material.

B.2 accounts for the light output of low beam headlamps in terms of their luminous intensity distributions.

NOTE 2: A luminous intensity distribution is in principle is a table of luminous intensities in candela (cd) for directions in space measured by a horizontal and a vertical angle. An example of a table is shown, but in other cases the intensity distributions are illustrated by diagrams.

It is stated that:
- there is a strong variation between different types of headlamps
- the luminous intensities in directions towards road signs are mostly small
- the normal dirt in the form of a traffic film causes a substantial raise of the luminous intensities in directions towards road signs.

B.3 explains the classic approach of thinking about retroreflection as the one used for calculations of sign luminance. However, B.3 also explains an additional approach in which the sign luminance is a weighted average of the luminance in a field about the observers eyes.

The additional approach is used to explain the limitations of retroreflection and also that:
- the sign luminance can be roughly constant over a range of distances
- the applicable distance range for a sheeting material depends on the width of the retroreflected beam
- the driver of a large vehicle will see the sign as if it has a lower retroreflection than the driver of a passenger car and, therefore, mostly with a lower luminance

- drivers of large vehicles will see the sign with some additional luminance because of marker lights and possible other lights on the top of the cabin
- the headlamps of other vehicles on the road contribute to the sign luminance.

B.4 accounts for the basis for performance requirements of prEN 12899-6 vertical road traffic signs — Part 6: Performance of retroreflective sign face materials.

Finally, B.5 provides an example of performance requirements as based on Danish tender specifications, road standards and regulations.

These performance requirements use three types of retroreflective sign faces that are described. Further, it is explained that the types and the underlying comprehensive test date back to 1998 and reflect essentially the status of the work of the CEN/TC 226 WG3 in an attempt to derive performance requirements for retroreflective road signs. It is also explained how the types can be re-defined in accordance with prEN 12899-6.

The types reflect a conservative strategy with an extended use of the glass beaded materials EG and HI and a restricted use of microprismatic materials. The practice is even more conservative, as HI materials of type 4 are used even for overhead signs on motorways in spite of the intention of using microprismatic materials of type 5.

Fluorescent materials have been given no use at all, not even at road works. This reflects a policy not to let some signs intrude unnecessarily in the road scene with strange colours and high levels of retroreflection (fluorescent materials are microprismatic) on the cost of other signs.

The performance requirements are expressed by means of the sizes of character legends, symbols and signs that are needed to provide sufficient legibility, and by the use of the sign face types to provide balance of luminance between the signs with promotion of only a few signs.

Among else, it is pointed out that each individual traffic sign (danger warning signs, priority signs, prohibitory or restrictive signs and mandatory signs) of a particular size always has a particular type of sign face. This is highly practical and acts as a safeguard against mistakes.

There is some simplification of the words used for concepts in the following. The word “luminous” is omitted from “luminous intensity distribution” and “luminous intensity”. Road signs are called just signs and retroreflective sheeting materials are called just sheeting materials or materials.

NOTE 3: It would simplify matters if vehicles had an additional light placed close to the observers eyes so as to assist with sign luminance at short and medium distance.

B.2 Low beam headlamp light distributions

B.2.1 General

Only the low beam of headlamps is considered as it is critical in terms of sign illuminance and as the high beam can mostly not be used. When the high beam is used, it results in a much higher sign illuminance than accounted for in the following and sometimes to a degree that makes the signs glaring.

The light output of a low beam headlamp is described by a intensity distribution, which is principle is a table of intensities in candela (cd) for directions in space measured by a horizontal and a vertical angle. An example of a table is shown in table B.3. In general, however, intensity distributions are illustrated by diagrams.

The intensity distributions of low beam headlamps are subject to ECE regulations. These regulations are specific for the various types of headlamps including the conventional headlamps using H4 halogen incandescent lamps or more recent types using HID (High Intensity Discharge) lamps or lens optics instead of parabolic reflectors. Additionally, the regulations are not precise regarding light emitted in upwards directions towards signs. This has lead to large variations among headlamps on various types of cars.

As an example, the intensity distribution of a particular headlamp is shown in figure B.1. The figure covers the interesting range of directions for signs of ±15° to the sides and from the horizontal at 0° up to 10° upwards.

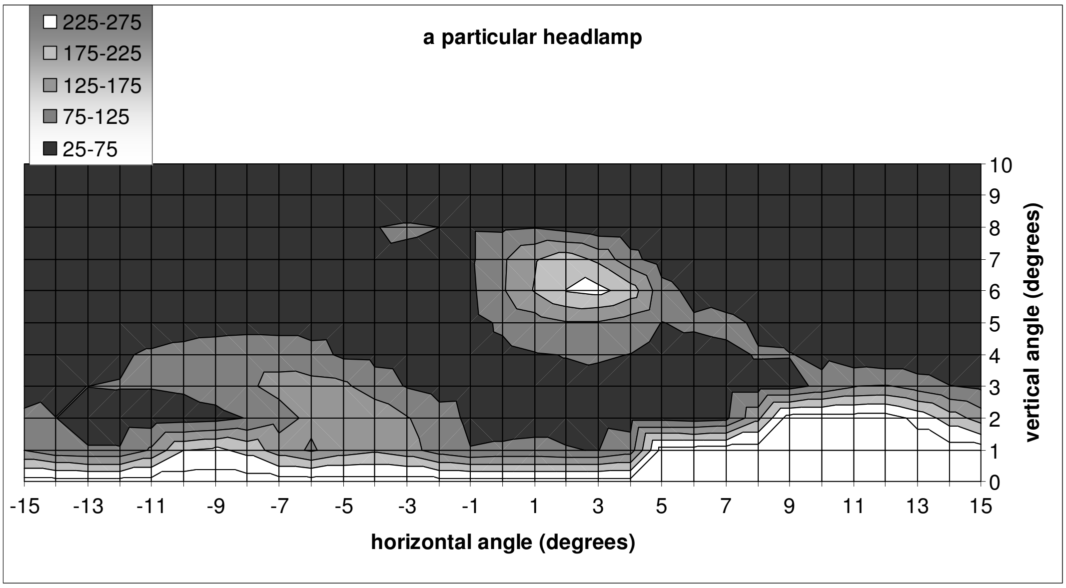


Figure B.1: The intensity distribution of a particular low beam headlamp.

The cut-off of the low beam is seen in figure B.1 as a strong gradient at the bottom left and bottom middle of the diagram, and at a few degrees above the bottom right of the diagram showing the lifted asymmetric part of the beam.

The cut-off serves to reduce glare of drivers of oncoming vehicles, but simultaneously causes a strong reduction of the intensities towards the vast majority of signs. The intensities are much larger below the cut-off, mostly up to 10.000 cd or more.

This particular headlamp has very low intensities above the cut-off; in the range of 25 to 75 cd except in a few seemingly random locations.

Other headlamps would show other features. Accordingly, it is necessary to study headlamps of different types in order to obtain an overall impression of the intensities available for the illumination of signs.

The largest studies are for new and clean headlamps. The most important are the UMTRI studies of 2001 and 2003, which are considered in B.2.2. Studies of old and dirty headlamps are more numerous, but smaller and not well documented; these are considered in B.2.3.

The age of headlamps seems to have little effect, as older - but clean - headlamps have intensity distributions that are similar to those of new and clean headlamps.

However, it is concluded that the normal thin traffic film on the front glass of headlamps raises the intensity in directions above the cut-off from 75 cd to 150 cd on the average and thereby raises the illumination on signs above the cut-off by a factor of two. It is assumed that the mechanism is scattering of a small percentage of the light emitted in the beam below the cut-off and that the corresponding loss of beam power is too small to be noticed.

Accordingly, intensity distributions of new and clean headlamps are pessimistic in terms of the predicted illumination of signs above the low beam cut-off.

This was understood by the CEN/TC 226 WG3 on vertical signs, which made a couple of attempts during the 90's to set up performance requirements for retroreflective signs. To this purpose, a 'standard' intensity distribution for the low beam headlamp was needed for use in driving scenarios to set up requirements for the coefficient of retroreflection R_A. An intensity distribution with much higher intensities above the cut-off than the UMTRI distributions for new and clean headlamps was developed on the basis of rather meagre data.

This intensity distribution is shown in figure B.4. The attempts by the WG3 failed, but the intensity distribution was used in Denmark as the background for a revision of the national standard for retroreflective signs.

A new attempt is being made by the WG3 with a start in the middle of the 2000's. As a preparation for that, DELTA performed some laboratory measurements on old and dirty headlamps as accounted for in B.2.3. These measurements confirm the intensity level of the above-mentioned intensity distribution. However, it was preferred by the WG3 to adopt the UMTRI 2003 distribution shown in figure B.3 as the standard for developing the performance requirements found in prEN 12899-6.

As a consequence, the luminance levels of retroreflective signs estimated on the basis of prEN 12899-6 are pessimistic. The real levels will often be twice as high. This corresponds to two steps upwards in the retroreflection performance classes P1 to P8 introduced in prEN 12899-6.

The advice is not to be frightened by the low performance classes of conventional glass beaded sheeting materials, but still use them for the purposes for which they are adequate.

B.2.2 Studies of new and clean headlamps

Studies of new and clean headlamps have been carried out by the University of Michigan at a number of occasions and are published in UMTRI reports. One of these is UMTRI-2001-19 "High-beam and low-beam headlighting patterns in the U.S. and Europe at the turn of the millennium", which among else provides a 50 % fractile intensity distribution for European cars. By 50 % is meant the medium distribution (half of the headlamps provide more and half less). This distribution is shown in figure B.2.

The latest UMTRI study of this nature is reported in UMTRI-93-36 'Light output of U.S., European, and Japanese low-beam headlamps'. The corresponding diagram for the UMTRI European car 50 % (2003) is shown in Figure B.3.

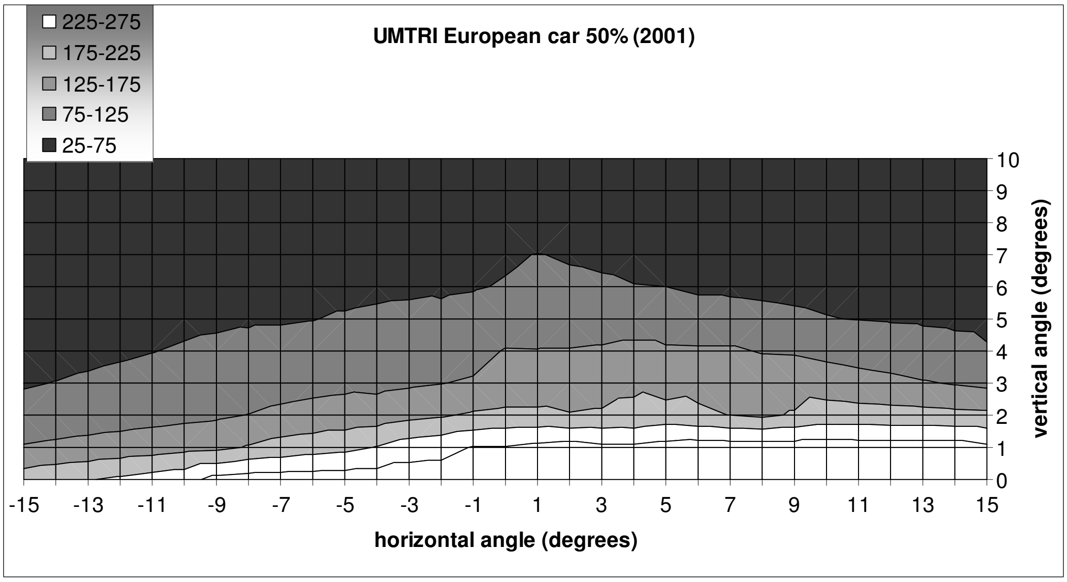


Figure B.2: The UMTRI 2001 50 % percentile intensity distribution for European cars.

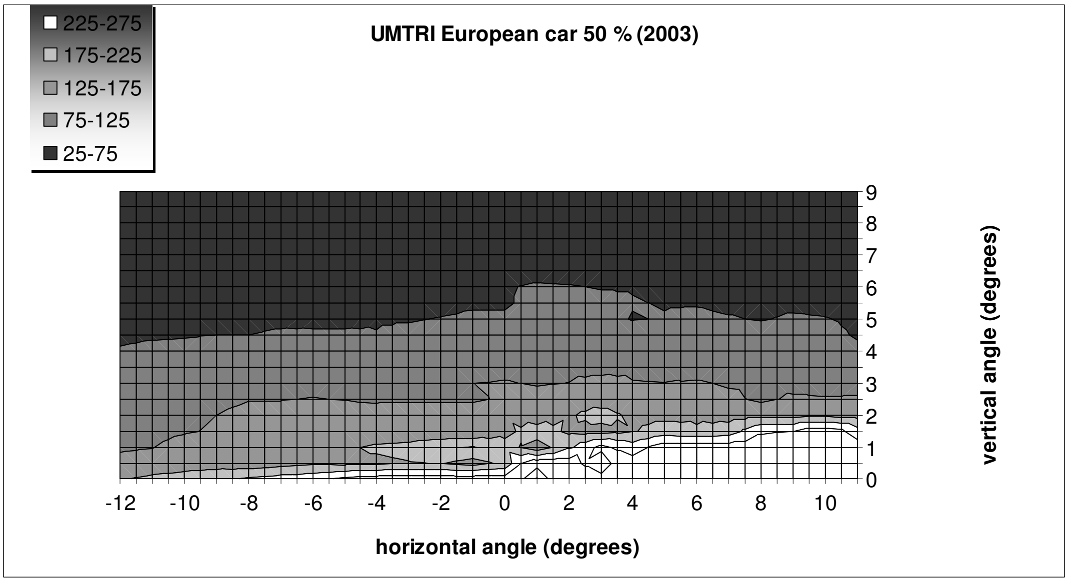


Figure B.3: The UMTRI 2003 50 % percentile intensity distribution for European cars.

Please note that figure B.3 covers a smaller angular region than figure B.2. When taking this into account, the two distributions are seen to differ in some details, but not by much in the overall features.

B.2.3 Studies of headlamps in use

As the UMTRI data are obtained for new and clean headlamps they do not give a true picture of headlamps in use of some age and degree of dirt.

In connection with the drafting of a Danish national standard for retroreflective signs, some simple measurements of headlamps were carried out at parking lots a couple of times. These involved cars in use and measurements in a few characteristic directions only, but they did indicate significantly higher intensities than in the UMTRI studies (which came later).

A similar, but larger, study by Paul Carlson at the TTI (Texan Transportation Institute) at around 2000 also gave this indication.

The same indication appeared in a study in Germany that was carried out with detectors at a motorway that measured the headlamps in a few directions on vehicles passing by.

NOTE: None of the above-mentioned studies were probably published.

These indications and a few distributions measured on headlamps in use were available for CEN/TC 226 WG3 on vertical signs, which made a couple of attempts during the 90's to set up performance requirements for retroreflective signs. To this purpose, a 'standard' intensity distribution for the low beam headlamp was needed for use in driving scenarios to set up requirements for the coefficient of retroreflection R_A. The attempts failed, but the intensity distribution shown in figure B.4 was the derived.

This distribution shows much higher intensities above the cut-off than the UMTRI distributions of figures B.2 and B.3. The distribution was used in Denmark as the background for a revision of the national standard for retroreflective signs.

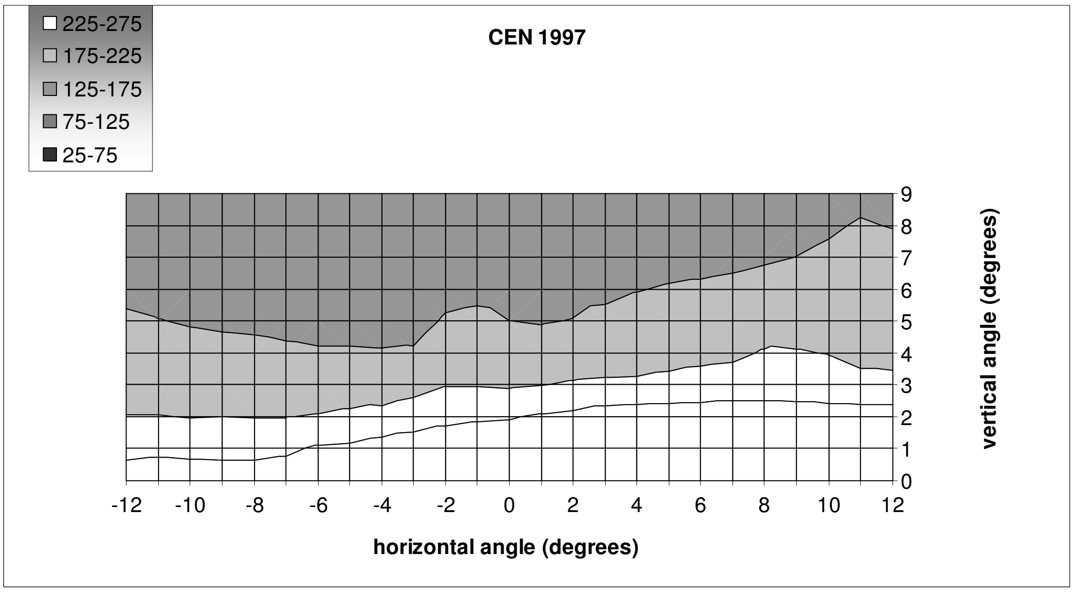


Figure B.4: The intensity distribution derived by CEN/TC 226 WG3 in 1997.

The work in CEN/TC 226 WG3 was restarted in the middle of the 2000's and as a preparation for that, DELTA performed some laboratory measurements on old and dirty headlamps. The old headlamps were bought as used spare parts and cleaned before measurement (they had been stored in dirty places), while the dirty headlamps were dismounted from cars in use and measured without cleaning. Refer to tables B.1. and B.2. An example of a measured tabular intensity distribution is given in table B.3.

Table B.1: Some data for old headlamps.

model	year
Mazda 323	1997
Nissan Sunny	1994
Opel Astra	unknown
VW Polo Fox	1980

Table B.2: Some data for headlamps taken from cars in use.

model	Year	time since last wash
Mitsibishi Colt	1997	2 months
Suzuki Swift	2001	1 year
Fiat Uno	1995	3 weeks
Hundai Accent	1999	2 weeks

Table B.3: Example of a measured intensity distribution (cd) (Suzuki Swift, year 2001, dirty).

	H=-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
V=10	83	88	90	92	96	98	102	106	109	113	117	121	124	128	130	133
9	88	91	94	97	101	104	109	113	118	122	127	131	136	139	143	145
8	92	96	99	103	107	112	117	122	128	133	138	143	147	152	157	160
7	97	100	105	109	114	120	125	131	137	143	149	155	161	168	172	176
6	102	106	111	116	122	128	134	141	149	156	163	170	177	184	190	195
5	108	114	120	125	131	139	147	155	163	172	181	190	198	206	214	222
4	116	121	128	136	142	152	161	171	182	194	204	216	227	238	248	258
3	124	136	145	153	161	170	183	194	207	220	235	248	261	273	287	303
2	147	157	165	174	184	194	208	224	240	259	275	290	304	321	342	366
1	162	180	198	209	216	223	235	252	271	289	308	327	349	374	403	437
0	171	187	204	216	222	235	256	282	312	344	369	402	438	478	537	642

	H=1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
V=10	134	136	136	137	136	134	132	130	127	124	121	117	115	111	110
9	147	149	150	150	149	147	145	143	139	136	132	129	126	122	118
8	162	164	165	165	164	162	161	157	152	149	143	140	135	132	128
7	179	182	184	184	182	181	178	173	168	162	157	151	147	139	135
6	201	203	206	206	205	202	198	192	186	179	174	166	157	150	143
5	228	233	237	237	235	232	225	218	211	202	193	185	173	162	153
4	270	284	290	288	278	270	261	252	240	228	216	205	192	178	168
3	323	339	344	339	328	316	305	291	277	261	246	236	229	221	206
2	391	411	412	401	389	387	389	395	426	461	418	346	292	256	226
1	476	504	532	572	650	827	986	962	808	654	518	408	337	291	256
0	811	1030	1369	1512	1517	1446	1329	1153	945	743	589	475	399	344	298

The average distribution for old headlamps is shown in figure B.5 and for dirty headlamps in figure B.6. The dirty headlamps were cleaned and measured again, with the average intensity distribution shown in figure B.7.

These distributions give the overall impression that dirt is the important factor as there is much more light above the horizon for the dirty headlamps in use, as in the headlamps after cleaning (compare figure B.6 and B.7).

Age, on the other hand, seems not to be as important. The old headlamps and the clean headlamps in use do have somewhat more light above the horizon than the new headlamps of the UMTRI studies, but not by very much (compare figures B.5 and B.7 to figures B.2 and B.3.).

It is to be stated that the dirty headlamps did not have layers of dirt or mud, only the normal thin traffic film on the front glass that develops quickly in normal conditions of traffic and weather. This film probably adds to the light above the horizon by scattering a small portion of the light in the main beam.

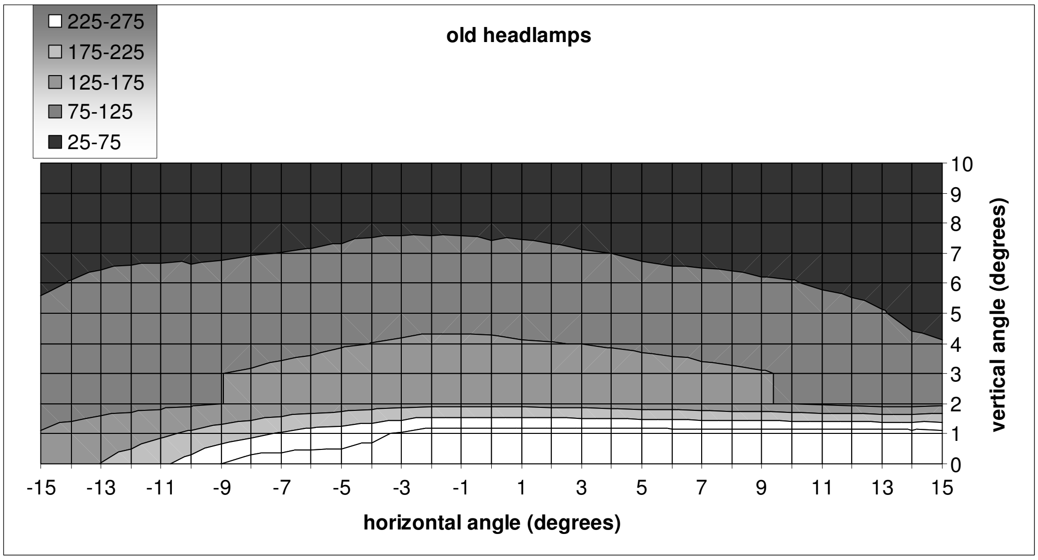


Figure B.5: The average intensity distribution for old headlamps.

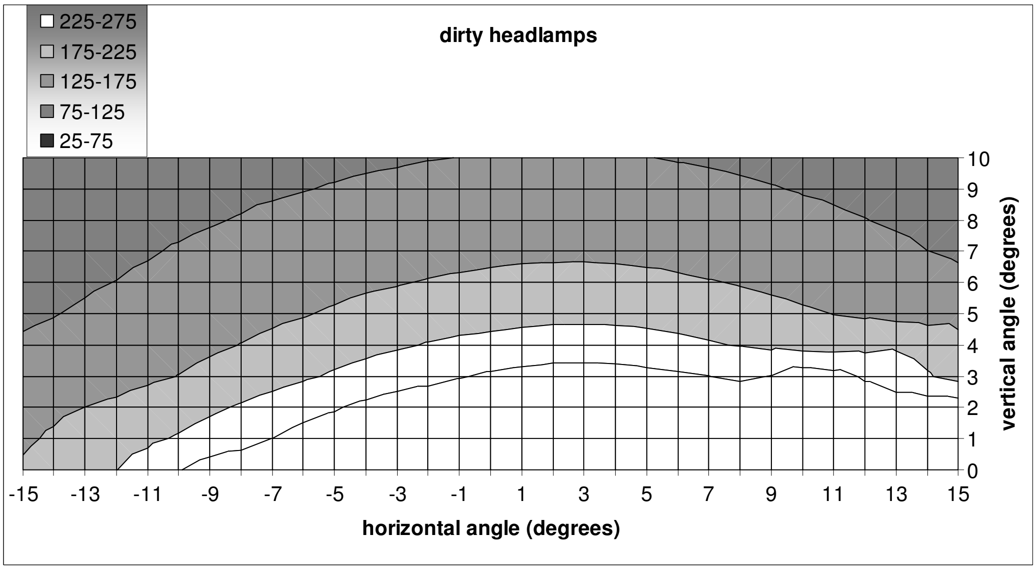


Figure B.6: The average intensity distribution for dirty headlamps in use.

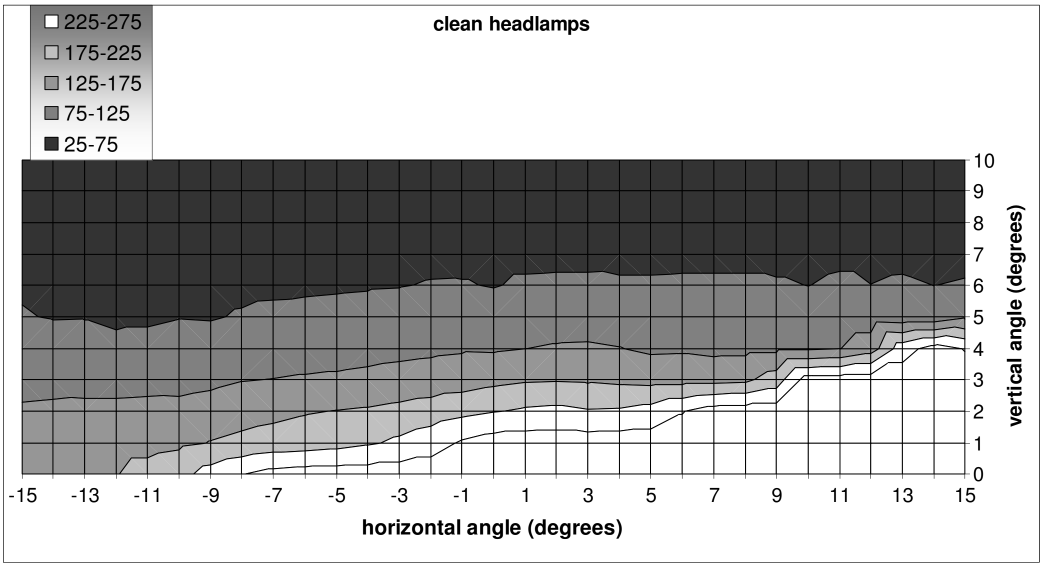


Figure B.7: The average intensity distribution for headlamps in use after cleaning.

The added light corresponds to only 1 or 2 % of the light emitted in the beam of the headlamp, which supports that the mechanism is scattering. This small loss of light in the beam cannot be noticed by the driver. However, the added light does raise the intensity above the horozontal by 75 cd to 150 cd on the average and thereby raises the illumination on signs above the cut-off by a factor of two.

NOTE: Assume that scattered light of an average intensity of 75 cd is emitted into a cone of ±10°, which has the solid angle of 0,096 sr. The flux of the scattered light is then 75×0,096 = 7,1 lm. A standard H4 lamp puts out 1100-1500 lumens, and a low beam headlamp with a standard H4 emits probably half of that into the beam. This shows that the scattered light is only 1 – 2 % of the light emitted in the beam.

B.3 Two approaches for considering retroreflection

B.3.1 General

B.3.2 explains the classic approach of thinking about retroreflection, which in principle is the approach used for calculations of sign luminance. The headlamps are considered one by one and their contributions are added. This involves several steps, but the procedure is not accounted for in detail.

B.3.3 explains a different approach of thinking, in which the sign luminance is a weighted average of the luminance in an observed field about the observers eyes. The sign luminance is much higher than for ordinary reflection because the field is relatively small, but includes the headlamps.

The field is the retroreflected beam of the observation direction on a plane at the vehicle. In terms of dimensions and shape it is comparable to the retroreflected beams created by headlamp illumination. This approach is used to explain the limitations of retroreflection and also to explain a number of other features is the following subsections.

B.3.4 deals with distance and explains why the sign luminance can be roughly constant over a range of distances.

B.3.5 deals with the width of the above-mentioned field, it explains that the width is a characteristic of the sheeting material and that materials with small, medium or large widths are best suited for respectively long, medium and short distances.

B.3.6 deals with the vehicle geometry and explains that the driver of a large vehicle will inevitably see the sign as if it has a lower retroreflection than the driver of a passenger car. This will mostly make him see the sign with a lower luminance, but with some compensation by marker lights and other lights on the top of the cabin.

Finally, B.3.7 explains that the headlamps of other vehicles on the road contributes to the sign luminance.

B.3.2 The classic approach used for calculations

Figure B.8 shows a driver in front of a retroreflective road sign at night. Each of the headlamps illuminate the road sign and some of the incident light is retroreflected into a narrow beam back towards the headlamp.

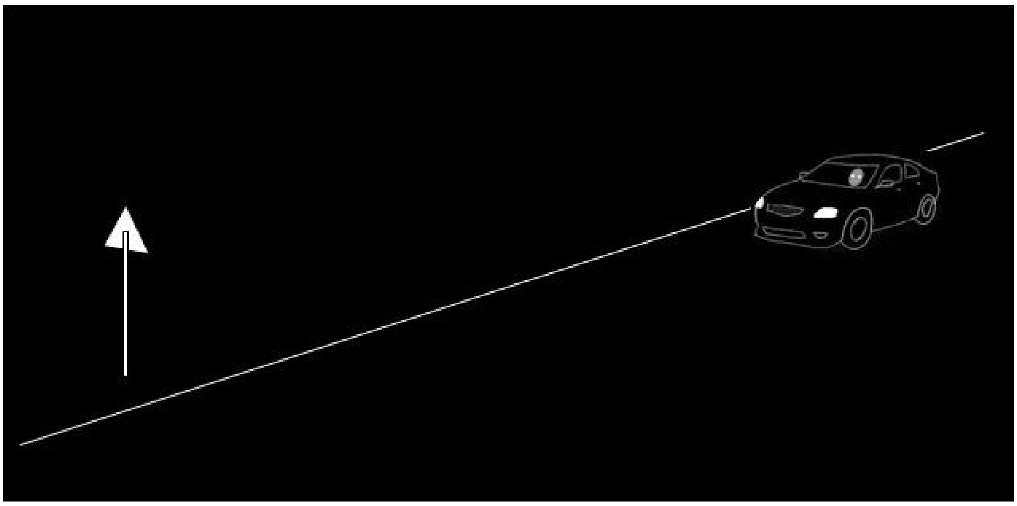
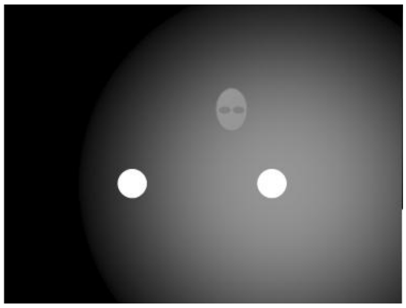
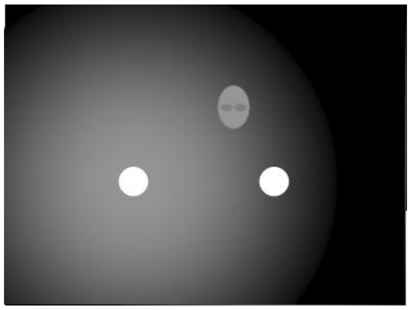
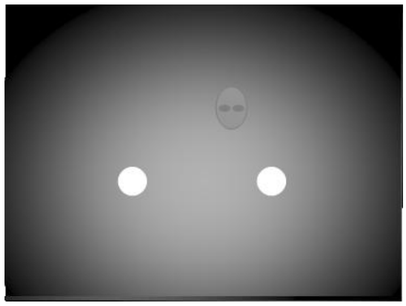


Figure B.8: A driver approaching a retroreflective road sign.

Figure B.9 illustrates the two illuminated fields caused by the each of the headlamps on a plane at the vehicle, and also the total field resulting from the overlay of the two fields.







The driver will see the road sign with some luminance, because the fields are sufficiently wide to provide illumination at the driver's eyes. This shows that the retroreflected beams need to have some width in order to provide a sign luminance to the driver.

The figure illustrates the procedure used when calculating the sign illuminance. The contributions from the two headlamps are calculated separately and then added. The two contributions are generally not equal as the headlamp closest to the observer's eyes tend to provide the highest luminance.

Calculations of road sign illuminance involve all the geometrical details of the situation, the luminous intensities provided by the headlamps and data for the retroreflectivity of the particular sheeting material in dependence of the directionality of illumination and observation.

Figure B.9: Illuminated fields caused by the retroreflected beams on a plane at the vehicle for the right headlamp (top), left headlamp (middle) and both headlamps combined (bottom).

It is to be noted that figure B.9 and other figures in this section show retroreflective beams of rotational symmetry with an intensity that is maximum at the centre and decreases smoothly towards the periphery. This is a simplification as the retroreflected beams from real sheeting materials do not generally have rotational symmetry and may show more complex variations.

B.3.3 A different approach to retroreflection

This approach is illustrated in figure B.10. The driver's direction of view to the road sign is retroreflected into a beam towards the vehicle and forms an observed field on a plane at the vehicle. In general, the sign shows a luminance in the direction towards the driver that is a weighted average of the luminance within the observed field. In this case, there is a luminance because the headlamps are within the field.

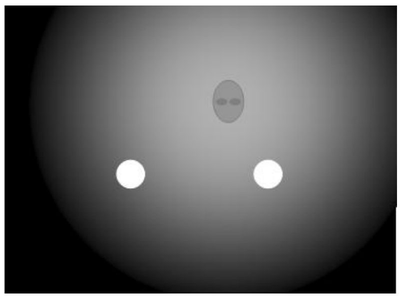


Figure B.10: The observed field on a plane at the vehicle.

The observed field represents the area covered by the retroreflected beam, when the sign is illuminated in the direction of the drivers view. The approach relies on the principle of reversibility, which is generally applied in optics and lighting although probably never proved in general.

The integral of the weights over the observed field represents the retroreflectance and has a maximum value of 1. In practice the value is significantly less than 1, down to approximately 0,1 even for white materials depending on the particular sheeting material used on the road sign. For coloured materials the value is lower as colours are produced by selective absorption. The integral is to be performed over the total solid angle of the observed field.

The contribution to the sign luminance from a headlamp is the area A of the headlamp within the observed field times the luminance L(headlamp) of that area times the weight W at the position of the headlamp. The area of the headlamp is to be measured as the solid angle seen from the road sign.

The product of the solid area A and the luminance L is the illuminance at the road sign E. Therefore, the contribution to the sign luminance is given by E×W. The total sign luminance is given by ΣE×W, where Σ stands for summation for the two headlamps.

As an example, assume that the weight W is constant within a cone of ±2° as illustrated in figure B.11. This cone has a solid angle of $2\pi(1 - \cos(2°)) = 0{,}00383$ sr, which indicates that W is at most 1/0,00383 = 261, and that the sign luminance is at most 261×E so that the maximum luminance coefficient is 261 $cd \cdot m^{-2} \cdot lx^{-1}$.

This is to be compared with a maximum luminance coefficient of a surface with ordinary reflection is $1/\pi$ equal to approximately 0,318 $cd \cdot m^{-2} \cdot lx^{-}1$ in the case of diffuse reflection.

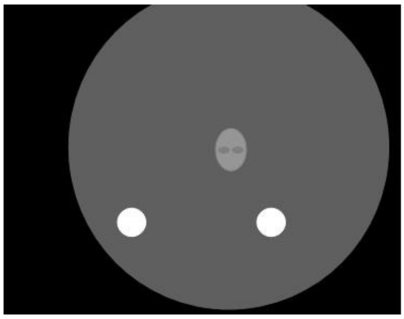


Figure B.11: A uniform observed field within a cone.

These values demonstrate that retroreflection can raise the luminance coefficient by a large factor by concentrating the reflected light within a narrow cone.

The example is, by the way, not convincing in terms of sign luminance.

Assume for instance that the luminous intensity of the headlamps is 100 cd, then each of them would contribute an illuminance of 1 lx at a distance of 10 m and a luminance of 2×261 = 522 cd/m^2. But at a realistic reading distance of for instance 100 m, it would be a hundred times less, and in practice less than that because the retroreflectance within a cone of ±2° is only a fraction. At even larger reading distances, as relevant on motorways, the sign luminance would clearly become too low.

In practice, the luminance coefficient will vary with the observation angle and this is actually a beneficial feature as explained in the next section.

B.3.4 The distance

Figure B.12 shows the observed field with headlamps at three distances between the road sign and the vehicle. It is seen that the headlamps get smaller with increasing distance, but simultaneously get closer to the centre at the field (at the observer) where the weight is larger.

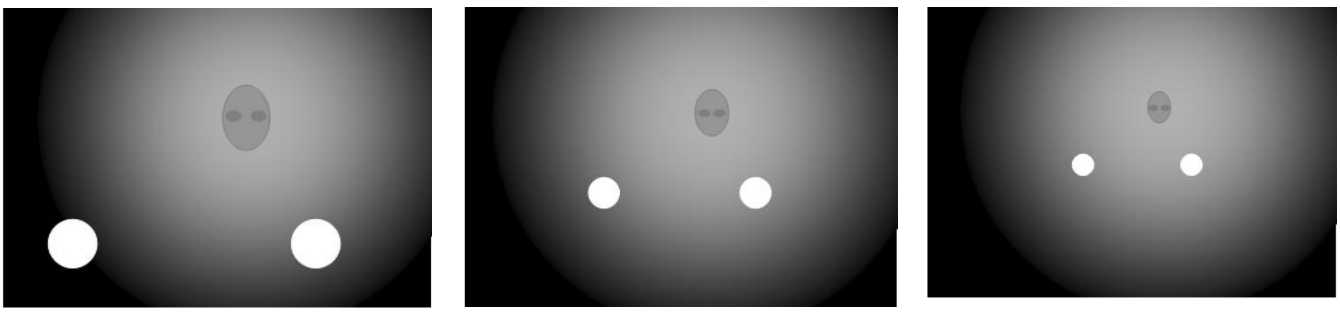


Figure B.12: The observed field with headlamps at increasing distance from left to right.

Accordingly, there are two factors to the road sign luminance that vary in opposite directions with distance. The result is that retroreflective road signs can show a roughly constant luminance over a range of distances. Outside of this range, the luminance is less, because the headlamps leave the field (at short distances) or get smaller without getting much more weight (at long distances).

The constant luminance over a range of distances is a surprising feature. It makes the road signs stand out in the night scenery as if self luminous.

The first of the above-mentioned factors is actually the illuminance at the sign, which decreases with distance, while the second factor is the luminance coefficient, which has to increase with distance in order to produce a roughly constant sign luminance. As the sign illuminance tends to decrease in inverse proportion to the distance squared, the luminance coefficient should increase with the distance squared.

The angular distance between the observer's eyes is the observation angle α that is presented in figure B.13. The observation angle is in inverse proportion to the distance and, therefore, the luminance coefficient should approximately be in inverse proportion to the square of the observation angle; i.e.: in proportion to α^{-2}.

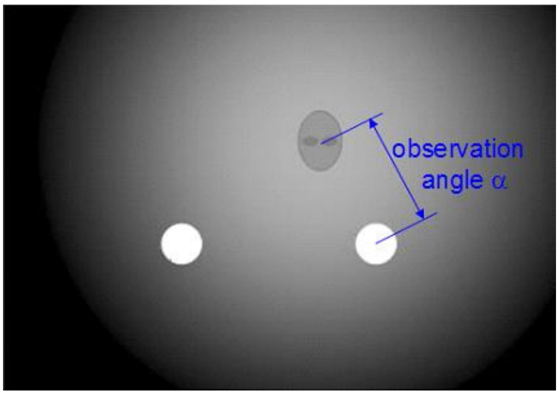


Figure B.13: The observation angle α.

If this variation is achieved for a large range of observation angles ranging from 0,2° to 2° and corresponding to a large range of distances, then the luminance coefficient can be approximately 47 $cd \cdot m^{-2} \cdot lx^{-1}$ at 2° and increase up to approximately 4700 $cd \cdot m^{-2} \cdot lx^{-1}$ at 0,2°. This is provided that the retroreflectance within that range is 1.

Assuming that the luminous intensity of the headlamps is 100 cd, then the constant luminance would be approximately 20 cd/m^2. In practice the luminance would be less than that, because the retroreflectance within a cone of ±2° is a fraction only. Perhaps 5 to 10 cd/m^2 would be achievable.

NOTE: prEN 12899-6 uses actually a function of α that is in proportion to $\alpha^{-1,4}$ with the purpose of providing a constant luminance. The difference is caused by a systematic change of luminous intensity with distance that is not included in the considerations given above. Refer to B.4.

However, retroreflective sheeting materials are not made to supply a constant luminance for a large range of distances, but only for reduced ranges that do not cover all applications of retroreflective sheeting materials. This is the topic of the next section.

B.3.5 The width of the beam

Figure B.14 shows the observed field at a medium distance between the road sign and the vehicle, but with three different widths of the field.

It is fairly clear, when comparing to figure B.14 to figure B.12, that the narrow beam will fail at short distances because the headlamps will leave the field, but manage well at long distances. Likewise, the broad beam will provide a low luminance at long distances because the weight is low, but manage well at short distances. The medium beam width is in between.

The width of the retroreflected beam is a characteristic of retroreflective sheeting materials and, accordingly, a particular retroreflective material is best suited at a range of distances, which may be relatively short, medium or relatively long.

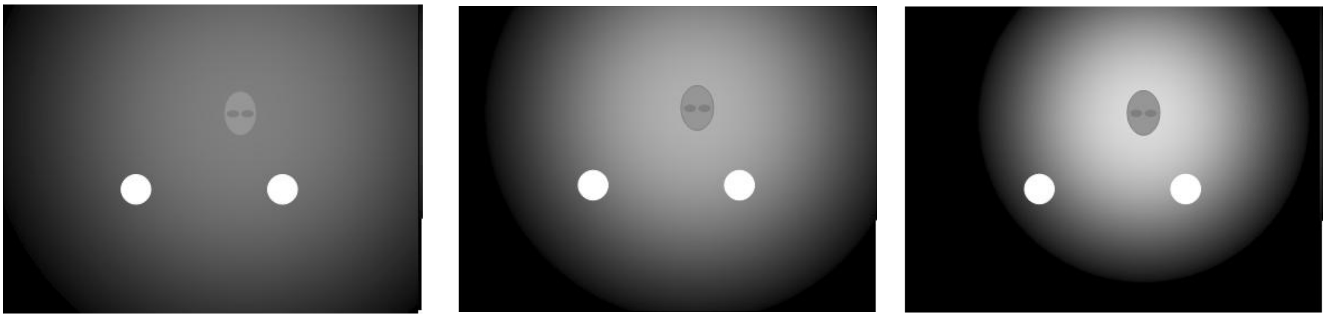


Figure B.14: Observed fields of different widths.

This reduction of the range of distances at which a particular material is suitable, allows for higher luminance coefficients and higher sign luminance within that range. The potential raise is approximately a factor of 3, which brings potential sign luminance of 15 to 30 cd/m^2 into reach for headlamp intensities of 100 cd.

The account in this and the previous section shows that retroreflection is a scarce resource in spite of impressive luminance coefficient values. The limitation is actually set by the meagre light that is available from the headlamps. Headlamps are discussed in B.2.

As it is, high sign luminance can only be obtained by means of some selection of the materials for the different applications. This, however, does not solve all problems because the vehicle geometry also plays a role as described in the next section.

B.3.6 The vehicle geometry

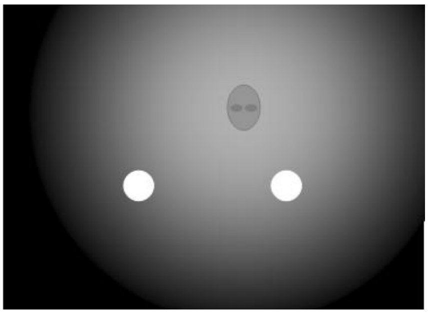
Figure B.15 shows the observed field with either a small or a large separation between the driver's eyes and the headlamps. These cases represent respectively a passenger car and a large vehicle like a truck.

The headlamps are clearly positioned in the observed field with a larger weight in the case of the passenger car than in the case of the truck. Therefore, the truck driver will see the sign with a lower luminance than the car driver, unless of course his headlamps are more powerful.

This is inevitable, when the luminance coefficient varies with the observation angle as discussed in the previous sections.

In practice, as illustrated in figure B.16, the truck driver gets an additional contribution from two marker lights at the top of the cabin. The marker lights are of a lower intensity than the headlamps, but they are closer to the driver's eyes and, therefore, provide a significant contribution.

Further, as also illustrated in figure B.16, most trucks have additional lights at the top of the cabin that give further contributions to the road sign luminance.



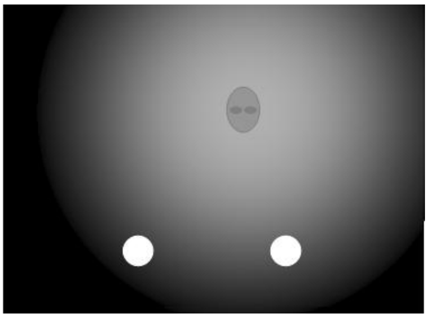
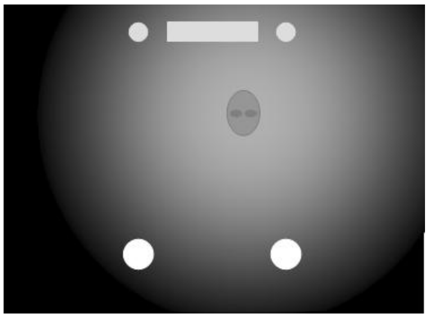


Figure B.15: The observed field with a small (left) and a large (right) separation between the driver's eyes and the headlamps.

Figure B.16: The observed field with headlamps and additional lights at the top of the cabin of a truck.



B.3.7 Contribution from other vehicles

Figure B.17 shows the observed field with the headlamps of the driver's own vehicle and headlamps of other vehicles.

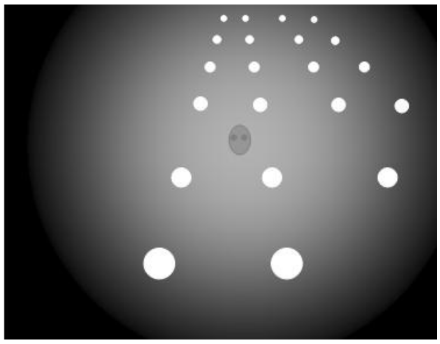


Figure B.17: The observed field with headlamps of the driver's own vehicle and headlamps of other vehicles.

Figure B.17 illustrates a situation with dense traffic on for instance a motorway and illustrates that the headlamps of other vehicles can provide a significant contribution to the sign luminance. General observations indicate that the signs may have an elevated luminance over an extended range of distances.

B.4 The basis for performance requirements

B.4.1 General

prEN 12899-6 Fixed vertical road traffic signs — Part 6: Performance of retroreflective sign face materials provides the basis for performance requirements of retroreflective sheeting materials as based on a number of elements.

These elements are of a geometrical nature and are accounted for in B.4.2, B.4.3, B.4.4 and B.4.5 which respectively:

- relates the sign position and the distance to the low beam headlamp intensity distribution and accounts for some typical variations of the sign illumination
- relates the distance to the observation angle α and accounts for the distance classification of prEN 12899-6 based on standard values of α
- accounts for the entrance angle β and the entrance angularity classification of prEN 12899-6 based on standard values of β
- accounts for two additional angles of retroreflection and how they are included in a comprehensive test that produces a "safe" R_A value that is a function of α and β only.

The above-mentioned distance and entrance angularity classifications are combined in prEN 12899-6 in classes of application. For each of these, a level of retroreflective performance can be derived for particular retroreflective sheeting materials as described in B.4.5, which also outlines the classes of retroreflective performance that are defined in prEN 12899-6.

Finally, the total basis for national road standards or regulations on retroreflective road signs is considered in B.4.6.

B.4.2 The sign position and distance

It is interesting to compare the intensity distribution of a headlamp with typical positions of signs as provided in table C.2 of prEN 12899-6 and as also shown in table B.4.

Table B.4: Typical positions of some signs

Sign mounting and location referring to the centre of the sign			
Typical mounting	Height above the road	Lateral distance from car axis	Proportion of luminance
a. Right shoulder *)	2,5 m	5,0 m to the right	1,0
b. Right shoulder	1,0 m	5,0 m to the right	4 to 13 (medium and short range)
c. Left reserve	2,5 m	9,0 m to the left	0,63
d. Overhead	6,5 m	directly above	0,47
*) prEN 12899-6 bases the sign luminance of this location.			

These positions are indicated in figure B.18 at a number of distances in a perspective as seen from a headlamp. The diagram for the UMTRI 2001 low beam intensity distribution, refer to figure B.2, is used as a background so that the intensities are available for each of the locations and distances.

A study of figure B.18 reveals some typical features:

a. the light received by a sign decreases with its mounting height
b. signs on the right shoulder receives more light than signs on the left shoulder
c. the intensity in the direction towards a sign increases with distance.

NOTE: It would have been more instructive to use the UMTRI 2003 distribution as the background for figure B.18, as this is the distribution that has been used for deriving the classifications of prEN 12899-6. However, the very similar UMTRI 2001 distribution is used instead, because it is available in a larger angular range and because it is similar to the UMTRI 2003 distribution. Any of the intensity distributions discussed in B.2. would in fact lead to the same general features.

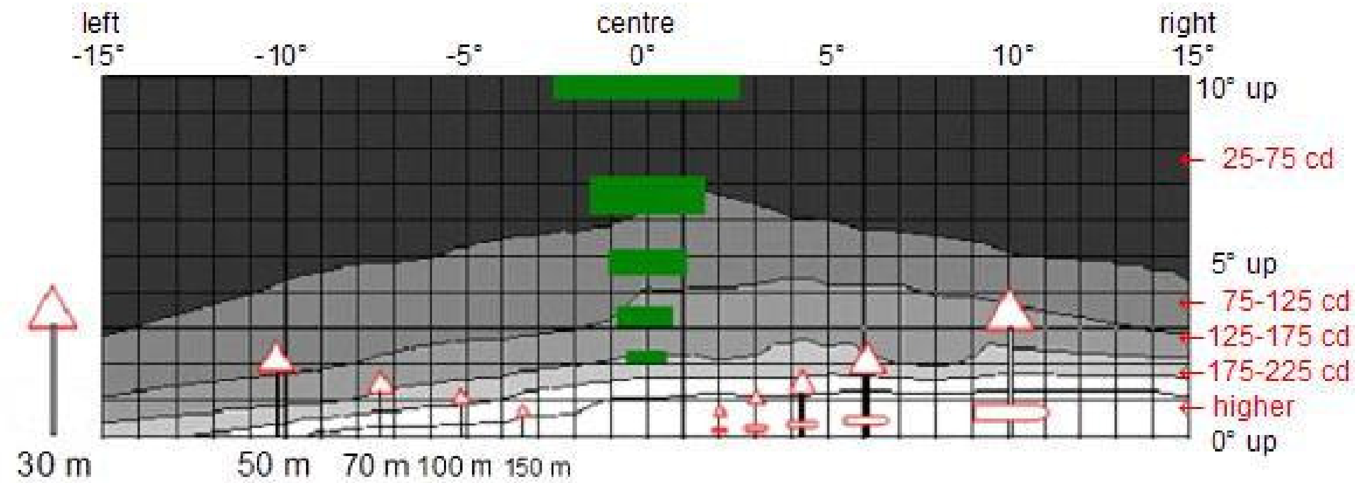


Figure B.18: Typical sign positions indicated in the intensity diagram for the UMTRI 2001 50 % European car.

The features a and b are unavoidable in view of the variation of the luminous intensity of the low beam. prEN 12899-6 bases the sign luminance on the sign locations indicated in table B.4 (right shoulder at a height of 2,5 m) and deals with other locations by giving the approximate proportions of sign luminance for the other locations. These proportions are also provided in table B.4.

The only thing that can be done about the influence of the sign position is to use sheeting materials with a higher retroreflective performance on signs placed at disadvantageous locations, such as the left reserve or overhead. Additionally, signs that are placed low should should have sheeting materials with a lower retroreflective performance so that they do not dominate over other signs.

The illuminance at a sign is given by $E = I \times D^{-2}$ where I is the intensity in the direction towards the sign and D is the distance. The factor D^{-2} represents the distance law of illumination, which predicts that's the illuminance decreases strongly with the distance.

However, the intensity increases with distance in accordance with the above-mentioned feature c, so that the net decrease of illuminance with distance is less strong. It is for this reason that the classifications of prEN 12899-6 are based on a net decrease in proportion with $D^{-1,4}$.

EXAMPLE: When doubling the distance, D^{-2} decreases by a factor of 0,25, while $D^{-1,4}$ decreases by a factor of 0,38.

NOTE: In terms of luminance, it is another compensation for distance that the luminance coefficient of retroreflective sheeting materials increases with distance. This is to be discussed later.

The positions of the signs are indicated in figure B.18 as if the road is without curve. Actual roads may have vertical and/or horizontal curve and this will shift the positions of the signs and thereby change their illumination. The shifts of positions are illustrated in figure B.19.

Figure B.19a: No curve.

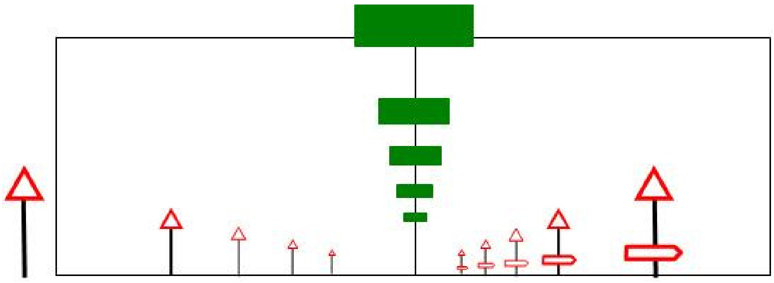


Figure B.19b: Upwards curve.
Positions are higher up, where there is less illuminance.

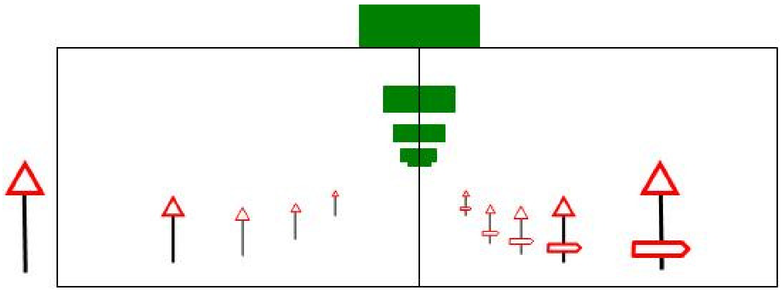


Figure B.19c: Downwards curve.
Positions are lower, where there is more illuminance. Downwards curve may result in obstruction of the headlamp illumination at the longest distances – because the road in the way.

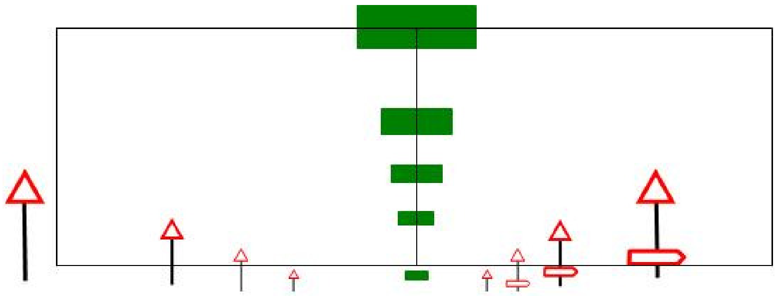


Figure B.19d: Left curve.
Positions are more to the left, where there is less illuminance.

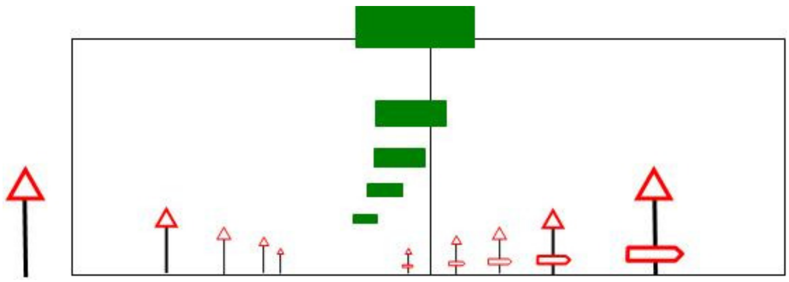
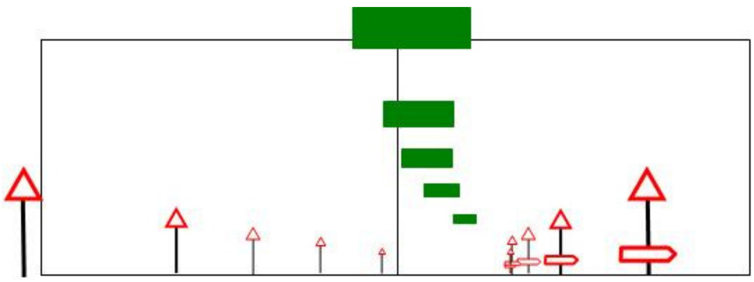


Figure B.19e: Right curve.
Positions are more to the right, where there is more illuminance.



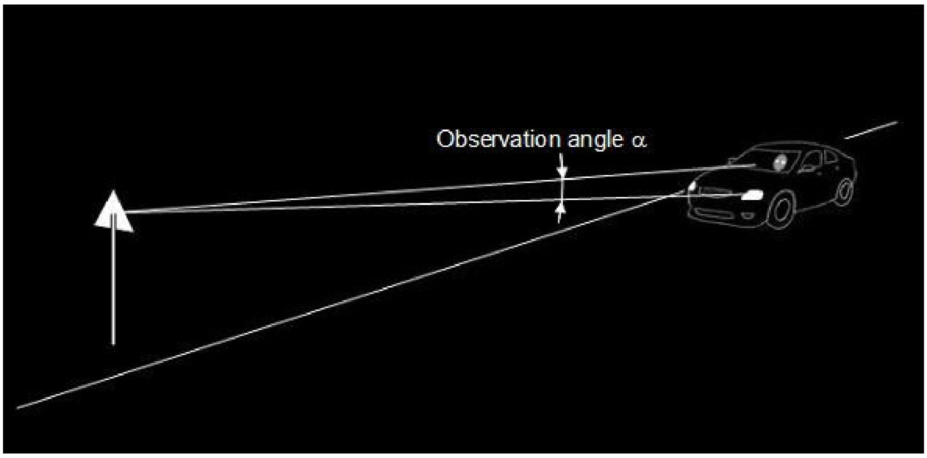
The signs shown in figure B.19 are placed at the same distances as considered in figure B.18, but at roads that are either without curve, curving up, curving down, curving left or curving right. The curve radius is 3000 m.

It is seen that road curve may have a strong effect on the illuminance on the road signs and thereby their luminance. Nevertheless, the classifications of prEN 12899-6 are derived as if the roads have no curve, so that an actual curve represents an additional factor.

B.4.3 The observation angle and its classification

The observation angle α is measured between the directions of illumination and observation, refer to figure B.20. Alternatively, the observation angle may be understood as the angular separation between the driver's eyes and the headlamp as seen from the sign.

Figure B.20: The observation angle α.



The significance of the observation angle is that the R_A values of the sign sheeting materials vary with the observation angle, generally so that the values increase strongly with decreasing observation angle.

For a particular vehicle, the observation angle of a headlamp is approximately in inverse proportion to the distance to the sign. Therefore, the R_A values generally increase with the distance.

The observation angle is mostly different for the two headlamps of a vehicle. Therefore, the two headlamps do not contribute equally to the sign luminance, even when their contributions in terms of sign illuminance are roughly equal.

However, prEN 12899-6 uses an average of the two observation angles as a fair representation for the average R_A value for the two headlamps. This average observation angle is then a rough measure of the inverse of the distance in the sense that a small observation angle means a large distance and vice versa.

There is no universal translation between the observation angle and the distance, as the observation angle at a particular distance depends on the location of the driver's eyes relative to the headlamps. In order to overcome this, a translation has been introduced for a standard passenger car with measures as shown in figure B.21.

The approximate relation between the standard observation angles used by prEN 12899-6 and distance is shown in table B.5.

Figure B.21: Standard passenger car of prEN 12899-6.

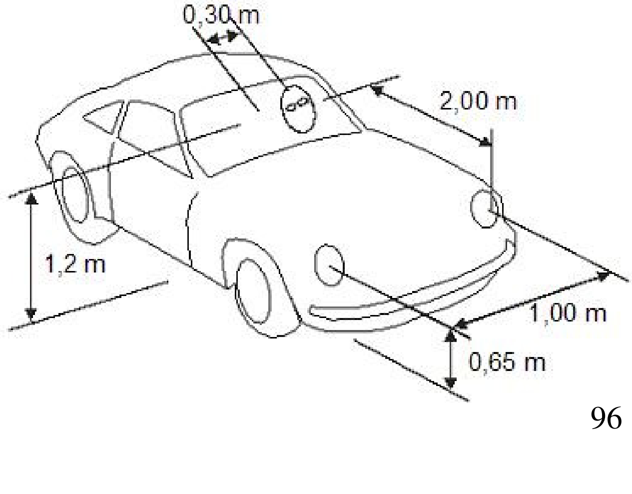


Table B.5: The approximate relation between the observation angle and the distance.

Observation angle	2,00º	1,50º	1,00º	0,70º	0,50º	0,33º	0,20º
Distance	30 m	40 m	50 m	65 m	90 m	120 m	200 m

Based on this, prEN 12899-6 introduces three distance ranges as part of the application classes Axy, where x stands for distance range and y stands for entrance angularity as described in B.4.4. These three distance ranges are labelled A1y, A2y and A3y with 1, 2 and 3 referring to distances by means of the selections of observation angles indicated in table B.6.

Table B.6: Selections of observation angles for distance in the prEN 12899-6 application classes.

Observation angle	2,00º	1,50º	1,00º	0,70º	0,50º	0,33º	0,20º
Classes							
A1y (long)			x	x	x	x	x
A2y (medium)		x	x	x	x	x	
A3y (short)	x	x	x	x	x		

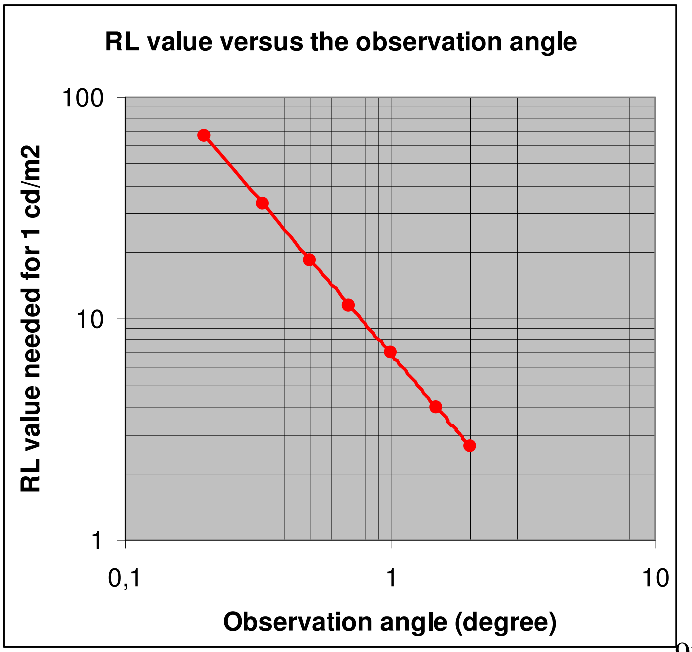
NOTE: It would be practical if sheeting materials could perform at all three distance ranges so that they could be used universally. However, it is possible to obtain a higher retroreflective performance by covering only one distance range. This is explained in B.3.

prEN 12899-6 introduces a standard situation by means of the passenger car with the geometry of figure B.21, the low beam headlamp intensity distribution in accordance with UMTRI 2003 and the sign location on the right shoulder at a height of 2,5 m as indicated in table B.4.

For this standard situation, a variation of the R_A value as $R_A = 6{,}99\times\alpha^{-1{,}4}\times\cos\beta$ provides a sign luminance of 1 cd/m^2. The entrance angle β is introduced in the next section. The R_A values are 2,6; 4,0; 7,0; 11,5; 18,4; 33,0 and 66,5 times cosβ for α equal to respectively 2,00º; 1,50º; 1,00º; 0,70º; 0,50º; 0,33º and 0,20º.

The above-mentioned variation of R_A can also be described as $R_A/\cos\beta = 6{,}99\times\alpha^{-1{,}4}$ or as $R_L = 6{,}99\times\alpha^{-1{,}4}$, where R_L is the coefficient of retroreflected luminance (which equals $R_A/\cos\beta$). This function is illustrated in figure B.22.

Figure B.22: The R_L value needed for a sign luminance of 1 cd/m^2 as a function of the observation angle α.



This is used in prEN 12899-6 to provide a sign luminance for the standard situation for each particular sheeting material. The exact procedure will be made clear in the following sections. At this point it is stated that the actual sign luminance depends on the actual situation.

As accounted for in B.2, the low beam headlamp intensity distribution will in practice often provide a higher sign illuminance than predicted by the UMTRI 2003 distribution. The actual sign luminance will be higher in the same proportion, often by a factor of 2.

As explained in B.3, the driver of a larger vehicle will see the sign with a lower luminance. prEN 12899-6 addresses this matter in an informative annex C by defining the geometry of a large vehicle and stating that the sign luminance seen by the driver of the large vehicle is approximately 35 % of the luminance seen by the driver of the passenger car.

NOTE: The large vehicle has the headlamps 0,80 m above the road with a distance between them of 1,80 m. The driver has his eyes 2,20 m above the road, 0,95 m behind the headlamps and 0,70 m from the centre of the vehicle.

Further, other sign locations result in different sign luminances in the proportions indicated in table B.5.

B.4.4 The entrance angle and its classification

The angle of incidence is measured from the normal of the sign to the direction of illumination and ranges from 0° at illumination perpendicular to the sign to 90° at illumination parallel to the sign. This angle is called the entrance angle β in connection with retroreflection. See also figure B.23.

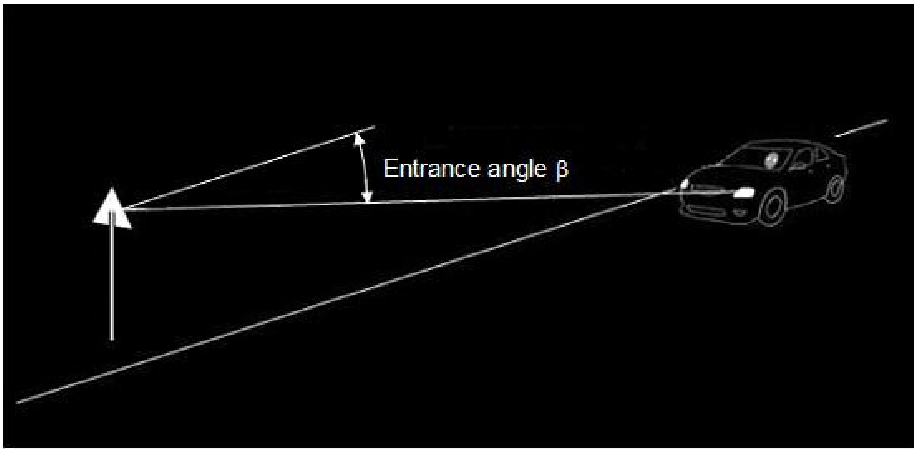
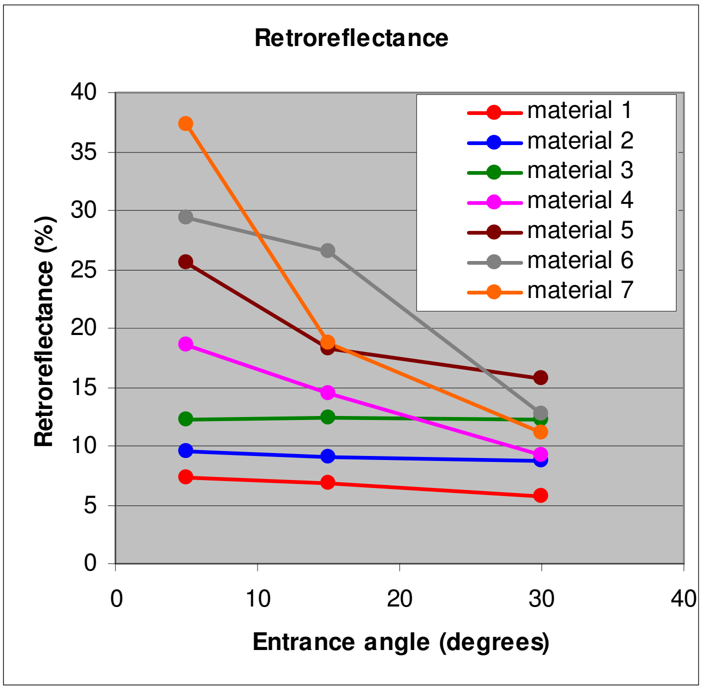


Figure B.23: The entrance angle β.

The significance of the entrance angle is that the R_A values of some sheeting material decrease relatively strongly with increasing entrance angle. This is illustrated in figure B.23, where the retroreflectance of a number of sheeting materials is plotted as a function of the entrance angle. The retroreflectance is for white materials and is summed up over the beams in cones up to 2° using R_A values derived in accordance with the comprehensive test of prEN 12899-6. For the comprehensive test refer to B.4.5.

The materials 1, 2 and 3 in figure B.24 are glass beaded materials, while the materials 4 to 7 are microprismatic. It is seen that the microprismatic sheeting materials have the largest retroreflectance values for small entrance angles, and that the retroreflectance decreases rather strongly with the entrance angle. With a decreasing retroreflectance follows unavoidably loss of individual R_A values.

Figure B.24: The retroreflectance of a number of sheeting materials as a function of the entrance angle.



Based on this, prEN 12899-6 introduces four entrance angularities as part of the application classes Axy, where x stands for distance range as described in B.4.3 and y stands for entrance angle range. These four entrance angularities are labelled Ax1, Ax2, Ax3 and Ax4 with 1, 2, 3 and 4 referring to the selections of entrance angles indicated in table B.7.

Table B.7: Selections of entrance angles for entrance angularity in the prEN 12899-6 application classes.

Classes	Ax1 (narrow)	Ax2 (medium)	Ax3 (wide)	Ax4 (extra wide)
Entrance angle				
5º	x			
15º	x	x		
30º	x	x	x	
40º	x	x	x	X

In order to evaluate the need for entrance angularity consider figure B.18, in which the signs are shown as if they are perpendicular to a straight road. Because of this, the entrance angle of a sign is the angular distance of the sign from the origin. It seems therefore that the entrance angle can range from close to 0° at long distances up 10° - 15° for short distances.

However, signs are often placed with a small twist of a few degrees away from the road. This is in order to avoid that headlamps can cause mirror reflections in the sign surfaces, which would make them unreadable. This adds to the need for entrance angularity. Additionally, roads have curves and bends as shown in figure B.19, and these also add to the need for entrance angularity.

In the general case, the classes Ax1 are not sufficient as it cannot be avoided that the entrance angle exceeds 5º. This is also expressed clearly in prEN 12899-6. These classes should not have been introduced.

The actual need for entrance angularity depends on the class of the road expressed by the driving speed.

At high speed roads, such as motorways, it is necessary that drivers can start reading the signs at long distance, or they will not have sufficient time available for the reading task. Simultaneously, the roads have gentle curves even compared to the long distance and, therefore, the need for entrance angularity is moderate. The relevant class is A12, which combines long distance with medium entrance angularity.

In the case of medium speed roads, such as interurban roads, the relevant class is either A22 or A23 combining medium distance with either medium or wide entrance angularity.

For other roads with low speeds, the relevant class is mostly A33 combining short distance with medium entrance angularity.

On particular road areas, such as some roundabouts or road crossings, it may be necessary to place signs with awkward orientations so that class A34 with extra wide entrance angularity may become relevant.

The actual combinations as defined in prEN 12899-6 are called application classes and are shown in table B.8. Those that are marked in red font are hardly relevant.

Table B.8: Application classes defined in prEN 12899-6.

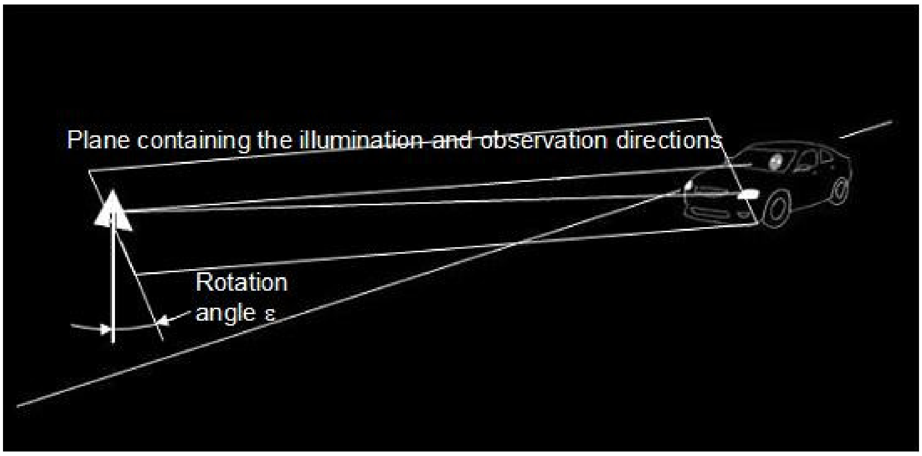
Entrance angularity	Narrow	Medium	Wide	Extra wide
Distance				
Long	A11	A12	A13	
Medium	A21	A22	A23	A24
Short	A31	A32	A33	A34

B.4.5 Other angles

The observation angle α species the angular distance from the centre of the retroreflected beam to the observation direction, but not the rotation of the plane that contains the illumination and observation directions. As the retroreflected beam need not to be of rotational symmetry, one additional angle is needed to specify the actual position and thereby the actual R_A value of a sheeting material.

This angle is the rotation angle ε illustrated in figure B.25. It is the tilt away from the vertical of the above-mentioned plane. The values are widely different for the two headlamps of the vehicle. The value is 0° for a particular headlamp, when the driver looks at a sign in a direction that passes directly above the headlamp, but varies in general with the geometry of the vehicle and the location of the sign.

Figure B.25: The rotation angle ε.



The variation of the rotation angle is complex and not interesting for application purposes. Additionally the effect of the sign luminance is averaged for the two headlamps. Therefore, prEN 12899-6 specifies a comprehensive test in which measurements at particular combinations of α and β is to be carried out for ε = -90°, 0° and 90°. The average of the resulting three R_A values is used as the R_A value for the particular combination of α and β.

This represents an artificial way of avoiding the influence of ε, but it is practical and acceptable in practice.

The entrance angle β specifies the angle of incidence on the sign, but not the plane in which the illumination takes place, for instance if it is from below or from one of the sides or in between. As the retroreflectance and the shape of the retroreflected beam need not be of rotational symmetry, one additional angle is needed to specify the actual direction of illumination and thereby the actual R_A value of a sheeting material.

This angle is the orientation angle ω_S illustrated in figure B.26. It is the tilt away from the vertical of the plane that contains the illumination direction and the normal to the sign. The values are slightly different for the two headlamps of the vehicle. The value is 0° for a headlamp, when the sign is directly above the headlamp, but varies in general the location of the sign relative to the vehicle, for instance if the sign is above the headlamp or to one of the sides or in between.

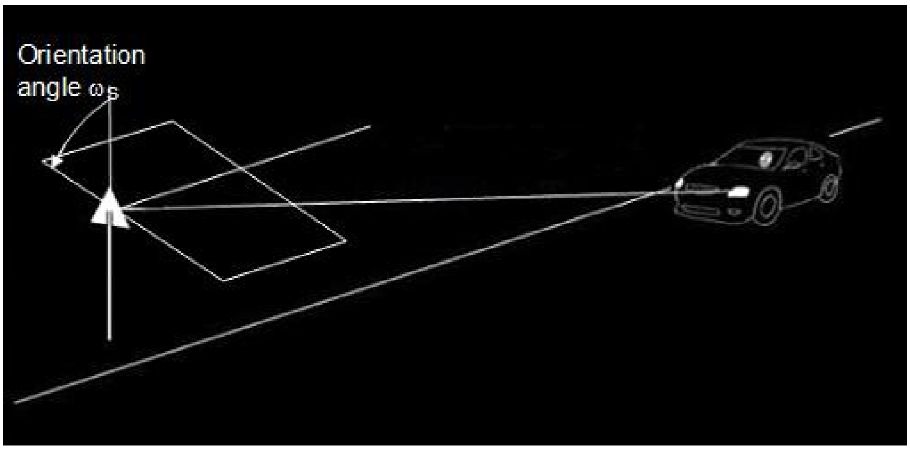
The variation of the orientation angle may be interesting for application purposes in the sense that it is interesting to know if the R_A value of a particular sheeting material is higher for some sign locations that for other; for instance if it is higher for overhead signs that for signs on the shoulders.

However, it is difficult to handle one more angle in addition α and β in an application system. Therefore, the comprehensive test of prEN 12899-6 requests that R_A values – as averaged for the above-mentioned three cases of ε - are determined for a selection of ω_S = -90°, -75°, 0°, 75° and 90° and that the smallest R_A is selected.

Accordingly, the comprehensive test results in a single value of R_A for a given combination of α and β. This value is called the $R_{A,C}(\alpha,\beta)$ value, where C stands for the calculations used to derive the $R_{A,C}(\alpha,\beta)$ from several measured R_A values.

The comprehensive test is to be used only for a white material of the particular type of sheeting material, while other white materials and materials of other signal colours are tested in a way that is simplified, but leads to results that are reduced in the same proportion as the $R_{A,C}(\alpha,\beta)$ for the white material. Materials of contrast colours are tested in an even simpler way.

Figure B.26: The orientation angle ω_S.



NOTE 1: The actual selection of cases of ω_S to be applied depends of the values of both α and β. Refer to prEN 12899-6.

NOTE 2: For measurements, the above-mentioned angles ε and ω_S are set in a different angular system using α, two components of β called β_1 and β_2 and ε. β_1 and β_2 are set by turning the sheeting sample in a goniometer while ε is set by rotating the sample about its normal.

NOTE 3: prEN 12899-6 distinguishes between signal colours and contrast colours. Signal colours are defined as colours used as the brightest colour of sign faces, while other colours are contrast colours. Signal colours may be white, yellow, fluorescent yellow, fluorescent yellow-green, orange and fluorescent orange, while contrast colours are red, blue, green, dark green, brown and grey.

NOTE 4: Some additional tests defined in prEN 12899-6 relate to symmetries that the suppliers wish to declare for particular types of sheeting materials in order that they can be applied with different rotations on signs.

B.4.6 The level of retroreflective performance

The level of retroreflective performance is derived for signal colours.

For a particular sheeting material, the $R_{A,C}(\alpha,\beta)$ values of the sheeting material (refer to B.4.5) are compared to the R_A values needed for a sign luminance of 1 cd/m^2 (refer to B.4.3). This is done for all the relevant cases of α and β of an application class.

If, for instance, the $R_{A,C}(\alpha,\beta)$ values are in all cases in the proportion 5:1 to the R_A values needed for a sign luminance of 1 cd/m^2, then the performance level is set to 5 cd/m^2 for the particular sheeting material and application class.

This illustrates the principle, but in practice the proportion varies. If do, it is permissible to form a harmonic mean, which introduces some penalty compared to the simple average. The idea is that some variation with distance about for instance 5 cd/m^2 should be permissible if the average is higher.

The penalty is harder for variation with β as the smallest proportion is to be selected. Refer to prEN 12899-6.

The final proportion determines the level of retroreflective performance and is called the R_A index. It is used to determine the class of retroreflective performance P1, P2, P3, P4, P5, P6, P7, P8 and P9 for which the minimum requirements are provided in table B.10.

Table B.10: Minimum requirements for retroreflection performance classes.

Retroreflection performance class	Signal colour		
	White	Yellow Fluorescent Yellow and Yellow-green	Orange Fluorescent Orange
P1	R_A index ≥ 1,4	R_A index ≥ 1,0	R_A index ≥ 0,7
P2	R_A index ≥ 2,0	R_A index ≥ 1,4	R_A index ≥ 1,0
P3	R_A index ≥ 2,8	R_A index ≥ 2,0	R_A index ≥ 1,4
P4	R_A index ≥ 4,0	R_A index ≥ 2,8	R_A index ≥ 2,0
P5	R_A index ≥ 5,6	R_A index ≥ 4,0	R_A index ≥ 2,8
P6	R_A index ≥ 8,0	R_A index ≥ 5,6	R_A index ≥ 4,0
P7	R_A index ≥ 11,3	R_A index ≥ 8,0	R_A index ≥ 5,6
P8	R_A index ≥ 16,0	R_A index ≥ 11,3	R_A index ≥ 8,0

It may be noted from table B.10 that the minimum requirement changes by a factor of 2 in two steps of the P class.

A colour that is darker than the signal colour used on a sign face is called a contrast colour. Such colours are subject to the requirements regarding the contrast to white provided in table B.11. The contrast is expressed as the ratio of $R_{A,C}(\alpha,\beta)$ values.

Table B.11: Permissible contrasts to white for contrast colours.

Contrast colour	Ratio	
	Minimum	Maximum
Red	0,12	0,50
Blue	0,03	0,35
Green	0,05	
Dark green	0,03	0,15
Brown	0,015	
Grey	0,40	0,60

B.5 An example of performance requirements

B.5.1 Introduction to the example

This annex describes the performance requirements for retroreflective road signs of the Danish tender specifications “Almindelig arbejdsbeskrivelse (AAB) afmærkningsmateriel” for marking equipment, various road standards for road signs and some regulations including “Bekendtgørelse om anvendelse af vejafmærkning” and “Bekendtgørelse om vejvisning på almindelige veje”.

The performance requirements are based on three types of retroreflective sign faces that are introduced in B.5.2.

The requirements for retroreflection for each of these types are similar to those provided in prEN 12899-6 Fixed vertical road traffic signs — Part 6: Performance of retroreflective sign face materials for certain combinations of application and retroreflective performance classes. Additionally, as in prEN 12899-6, the testing of the retroreflective performance involves a comprehensive test.

Other requirements relate to the luminance factor and the chromaticity for daylight illumination.

The types have actually a long history, but the requirements for retroreflection were redefined on the basis that was obtained by the CEN/TC 226 WG3 in an attempt to establish performance requirements in the late 90’s. It is the intention to redefine these types in accordance with prEN 12899-6, once this proposal appears as an EN. It is discussed in B.5.3 how this can be done. In 5.4.4 it is argued that the signs will generally have a luminance, as measured for white parts of the signs, of 5 to 10 cd/m^2 irrespective of the type of the material.

The performance requirements themselves are considered to have two aspects.

One aspect is the balance of sign luminance among different signs, which is considered in B.5.5 in terms of rules for the use of the three types of retroreflective sign faces.

The other aspect is the sizes of character legends, symbols and signs needed for legibility, which is considered in B.5.6, B.5.7, B.5.8 and B.5.9 on the basis of levels of retroreflective performance, the legibility of retroreflective signs at night and the legibility distances needed for particular signs.

B.5.2 Types of retroreflective sign faces

The Danish tender specifications for marking equipment “Almindelig arbejdsbeskrivelse (AAB) afmærkningsmateriel” defines five types of sign faces:

- Type 1: transmitting and intended for transilluminated signs
- Type 2: ordinary reflection intending for non-retroreflective signs
- Type 3: retroreflective at short distance
- Type 4: retroreflective at medium distance
- Type 5: retroreflective at long distance.

Only the sign face types 3, 4 and 5 that are intended for retroreflective signs need to be considered. These are assumed to correspond to sign luminance values of white parts of signs of respectively 3, 5 and 10 cd/m^2.

The requirements for retroreflection are expressed as minimum requirements for a calculated value of the coefficient of retroreflection R_A for a combination of the observation angle α and the entrance angle β.

The calculated value is derived in a comprehensive test, which is similar but not identical to the comprehensive test defined in prEN 12899-6. Therefore, the calculated value is designated $R^*_{A,C}(\alpha,\beta)$ in the following in order to distinguish it from the calculated value $R_{A,C}(\alpha,\beta)$ derived in accordance with the comprehensive test of prEN 12899-6.

The minimum requirements for white sign face materials of the types 3, 4 and 5 are indicated in table B.12. The minimum requirements for materials of other colours are those provided in table B.12 after multiplication with the relevant factors provided in table B.13.

Table B.12: Minimum $R^*_{A,C}(\alpha,\beta)$ values for white sign face materials of types 3, 4 and 5.

α	β	Type 3	Type 4	Type 5
0,2°	5°			359
	15°			348
	30°			
0,33°	5°	43	72	144
	15°	42	70	140
	30°	38	63	
0,5°	5°	25	40	82
	15°	24	39	79
	30°	21	35	
1,0°	5°	9,3	15	31
	15°	9,0	15	30
	30°	8,1	13	
1,5°	5°	5,4	9,0	
	15°	5,2	8,6	
	30°	4,7	7,8	
2,0°	5°	4,2		
	15°	4,1		
	30°	3,6		
	40°	3,2 1)		
1) This requirement can be applied for signs that must be read at a short distance and under a large entrance angle. This can for instance be the case for directional arrow signs at roundabouts				

Table B.13: Reduction factors for minimum $R^*_{A,C}(\alpha,\beta)$ values for sign face materials of other colours.

Yellow	Orange	Red	Green	Blue	Brown
0,70	0,50	0,20	0,14	0,06	0,03

It may be noted from table B.12 that an additional requirement can be applied for some signs for type 3.

Other requirements relate to the luminance factor and the chromaticity. These are similar but not identical to those of prEN 12899-6.

The types, including the comprehensive test, are confirmed in an annex to a regulation "Bekendtgørelse om anvendelse af vejafmærkning".

The types and the underlying comprehensive test date back to 1998 and reflect essentially the status of the work of the CEN/TC 226 WG3 in its first attempt to derive performance requirements for retroreflective road signs.

The types 3, 4 and 5 provide sign luminances of white parts of signs of minimum respectively 3, 5 and 10 cd/m^2 in the same standard condition as defined in prEN 12899-6 (a passenger car as shown in figure B.21 and a sign on the right kerb as indicated in table B.4). However, these sign luminance values are based on the CEN 1997 headlamp distribution as opposed to the UMTRI 2003 distribution used in prEN 12899-6.

EG materials of good quality meet the requirements for type 3, while HI materials of good quality meet the requirements for type 4. Some microprismatic materials including the 3M VIP (this sheeting material is no longer on the market) meet the requirements of type 5.

The types reflect a conservative strategy with an extended use of the glass beaded materials EG and HI and a restricted use of microprismatic materials. The practice is even more conservative, as HI materials of type 4 are used even for overhead signs on motorways in spite of the intention of using microprismatic materials of type 5.

Fluorescent materials have been given no use at all, not even at road works. This reflects a policy not to let some signs intrude unnecessarily in the road scene with strange colours and high levels of retroreflection (fluorescent materials are microprismatic) on the cost of other signs.

B.5.3 Re-definition of the types in accordance with prEN 12899-6

Type 3 can be interpreted as application class A33, which covers the observation angles α of 0,5°; 0,7°; 1,0°, 1,5° and 2° and the entrance angles β of 5°; 15° and 30°.

There is an additional requirement for the observation angle α of 0,33°, but this requirement is intended for situ testing with portable instruments and could be replaced with a different requirement. The most suitable requirement is probably that the R_A value at an α of 0,33° and a β of 5° is minimum 50 $cd \cdot lx^{-1} \cdot m^{-2}$ for a white surfaces of a new sign and to allow some depreciation during the warranty period to minimum 40 $cd \cdot lx^{-1} \cdot m^{-2}$. These are the minimum values used traditionally for EG materials.

The additional optional requirement for the entrance angle of 40° at the observation angle α of 2° is sensible in itself, but does not fit into the application classes. The only solution is probably to maintain such an optional requirement.

Type 4 is clearly interpreted as application class A23 and type 5 as A12.

It is sensible and practical to introduce the comprehensive test of prEN 12899-6 and also to apply it for only one white material and allow reduced testing for other materials of signal colours in accordance with prEN 12899-6.

This corresponds to deriving the calculated $R_{A,C}(\alpha,\beta)$ values of prEN 12899-6 instead of the present $R^*_{A,C}(\alpha,\beta)$ values.

The difference lies in how the three cases of the rotation angle ε are handled – the $R_{A,C}(\alpha,\beta)$ is based on the average R_A value while the $R^*_{A,C}(\alpha,\beta)$ is based on the smallest R_A value for the three cases. Some examples show that the $R_{A,C}(\alpha,\beta)$ values tend to be 10 to 20 % higher than the $R^*_{A,C}(\alpha,\beta)$ values.

This, however, applies only for microprismatic materials. Glass beaded materials are presently considered to be of rotational symmetry and are measured in a simplified manner with the additional angles of ε and ω_S kept at 0°. The application of the comprehensive test to these materials – as requested by prEN 12899-6 – would probably lead to a 10 % decrease of the $R_{A,C}(\alpha,\beta)$ values.

It is also sensible and practical to evaluate the retroreflective performance in terms of the R_A index defined in prEN 12899-1 instead of applying minimum requirements for each of the relevant $R_{A,C}(\alpha,\beta)$ values.

This has two consequences of which the first is that the R_A index will seem to be low compared to the assumed sign luminance of the three types of 3, 5 and 10 cd/m^2. The reason is that the R_A index is based on the UMTRI 2003 headlamp distribution while the minimum requirements are based on the CEN 1997 headlamp distribution.

Figure B.27 shows that The R_L value needed for a sign luminance of 1 cd/m^2 is approximately twice as high for the UMTRI 2003 than for the CEN 1997 distribution, which means that the R_A index values will tend to be only half of the above-mentioned luminance values.

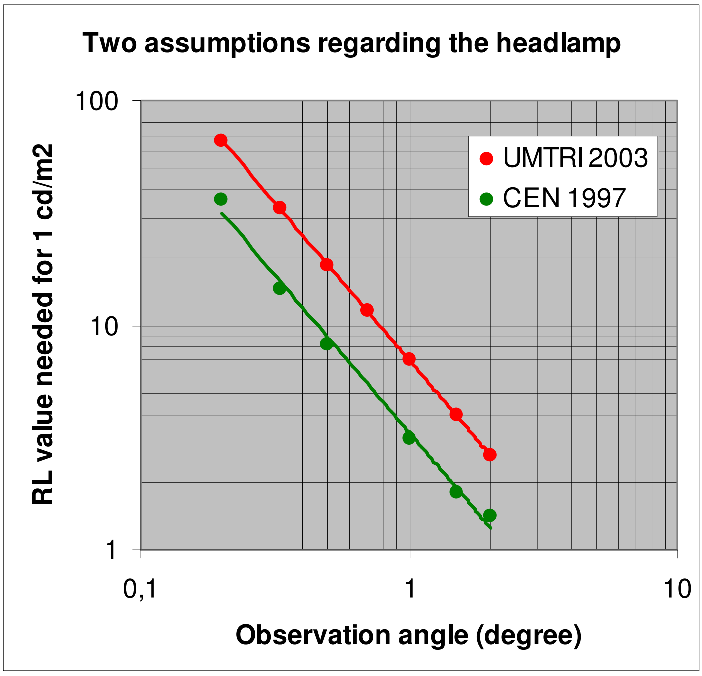


Figure B.27: The R_L value needed for a sign luminance of 1 cd/m^2 for two assumptions regarding the headlamp.

The other consequence is that the R_A index is obtained as the harmonic average of the relevant $R_{A,C}(\alpha,\beta)$ values instead of the minimum. This tends to raise the R_A index values compared to the above-mentioned sign luminance values.

A closer analysis shows that this increase is fairly small for EG materials placed as type 3, approximately 20 %, but more than 60 % for HI materials placed as type 4. This, on the other hand, reflects that signs with EG materials keep a relatively constant luminance over the relevant range of distances, while HI materials show a considerable variation. Microprismatic materials can be expected also to show a considerable variation of the luminance with distance and, therefore, a considerable increase of the R_A index.

Additionally, EG and HI materials of a good quality have some reserve compared to the present minimum requirements.

In total, the R_A index for EG materials that meet the present requirements for type 3 can be expected to be approximately 2,0, while the R_A index for HI materials that meet the present requirements for type 4 can be expected to be approximately 4,0. Microprismatic sheeting materials that meet the present minimum requirements for type 5 can be expected to have an R_A index of 8.

Accordingly, types 3, 4 and 5 may be interpreted as respectively (A33,P2), (A23,P4) and (A12,P6) with, however, some uncertainty if EG and HI materials do actually meet the retroreflective performance classes of respectively P2 and P4. This should be clarified by testing before the requirements are introduced.

The above applies for white materials. However, the reduction factors for yellow and orange of 0,7 and 0,5 as supplied in table B.13 are precisely the factors that are inherent in the classifications of prEN 12899-6 for these signal colours, refer to table B.10. Additionally, the minimum and maximum values of prEN 12899-6 for the various contrast colours, refer to table B.11, are lax in comparison to the factors provided in table B.13. Therefore, there should be no problem in introducing the requirements of prEN 12899-6 for other colours than white.

Finally, it is sensible to introduce the requirements for the luminance factor and the chromaticity of prEN 12899-6.

In conclusion, it should be fairly simple and safe to re-define the types 3, 4 and 5 in accordance with prEN 12899-6, but some testing may be needed in order to determine the proper retroreflective performance class of types 3 and 4.

B.5.4 The luminance to be expected for road signs

The types 3, 4 and 5 after re-definition as accounted for in the previous section are assumed to be associated with retroreflective performance classes of respectively P2, P4 and P6. These correspond to R_A index values of respectively 2, 4 and 8 cd/m^2 and accordingly to these sign luminance values for white parts of the signs.

When trusting in the assumption that the CEN 1997 headlamp distribution is more realistic than the UMTRI 2003 headlamp distribution, the sign luminance values can be set twice as high, i.e. to approximately 4, 8 and 16 cd/m^2.

However, this applies for a specific sign location (2,5 m above the road and 5,0 m to the right), while other sign locations may result in lower or higher sign luminances. Refer to table B.4, which is repeated below as table B.14 for convenience.

Table B.14 (repetition of table B.4): Typical positions of some signs.

Sign mounting and location referring to the centre of the sign			
Typical mounting	Height above the road	Lateral distance from car axis	Proportion of luminance
a. Right shoulder *)	2,5 m	5,0 m to the right	1,0
b. Right shoulder	1,0 m	5,0 m to the right	4 to 13 (medium and short range)
c. Left reserve	2,5 m	9,0 m to the left	0,63
d. Overhead	6,5 m	Directly above	0,47
*) prEN 12899-6 bases the sign luminance of this location.			

It is a typical connection that signs with materials intended for longer distances, such as types 3, 4 and 5 in that sequence, are placed higher up or in otherwise less favourable locations. Therefore, signs that are equipped with type 3 materials tend to be placed relatively low on the right shoulder, while signs equipped with type 4 materials tend to be placed higher up or to the left, and signs with type 5 materials are overhead signs.

When taking this into account, it is seen that the signs will generally have a luminance of 5 to 10 cd/m^2 irrespective of the type of the material.

B.5.5 The use of sign face types to create luminance balance with promotion of only a few signs

The general rule is that traffic signs (danger warning signs, priority signs, prohibitory or restrictive signs and mandatory signs) shall be retroreflective or illuminated. As an exception from this rule, give way signs, stop signs and all traffic signs on motorways shall be retroreflective, even if illuminated.

It is an additional rule that retroreflection or illumination must not be used in such a way that a particular traffic sign reduces the perception of other traffic signs. Give way and stop signs in particular must have at least as strong a retroreflection or illumination as other signs in the vicinity.

As a consequence of this rule, signs mounted on the same pole shall – with a few specified exceptions – have the same type of material.

As accounted for in the above, the types 3, 4 and 5 are mainly intended for use on retroreflective road signs that are to be read at respectively short, medium and long distance ranges and that the distance range is mostly related to the mounting height of the sign. Because of this, and because car headlamp illumination decreases with the mounting height, the level of required retroreflection is raised in the sequence of types 3, 4 and 5.

For this reason, it is a general rule that sign faces of traffic signs on ordinary roads must be type 3 while sign faces of traffic signs on motorways must be of type 4.

There is a number of exceptions from the general rule as based on these observations:

- There are cases where more than one of the types can be applied for a particular sign. In such cases the sign achieves a higher luminance level when having a sign face with a higher type number.
- A few signs are of such importance that they are promoted by the use of type 4 instead of type 3.
- Some signs are generally placed to the left, where they receive less headlamp illumination and, therefore, must be equipped with type 4 instead of type 3 in order to obtain as much luminance as signs placed on the right kerb.
- Signs with large white surfaces that are placed low to the right must be equipped with type 3 in order not to become glaring.

The exceptions for ordinary roads are shown in figure B.28. The reader may be able to identify which of the above-mentioned observations that is relevant in the individual case. The exceptions for motorways are few and not accounted for.

In accordance with this, a particular traffic sign may need to be of type 3 for ordinary roads and type 4 for motorways. However, traffic signs on ordinary road are of the normal size or a reduced size, while traffic signs on motorways are of an oversize.

Therefore, each individual traffic sign of a particular size always has a particular type of sign face. This is highly practical and acts as a safeguard against mistakes.

The road standards addresses other signs in a similar manner. As an example, specific direction signs are to be type 3 on ordinary roads and type 4 on motorways.

be type 3 on ordinary roads and type 4 on motorways.

A particular type of direction sign may be of either type 3 or 4, with a one step reduction of the character height if it is of type 4 which provides a higher sign luminance and, therefore, a higher legibility index.

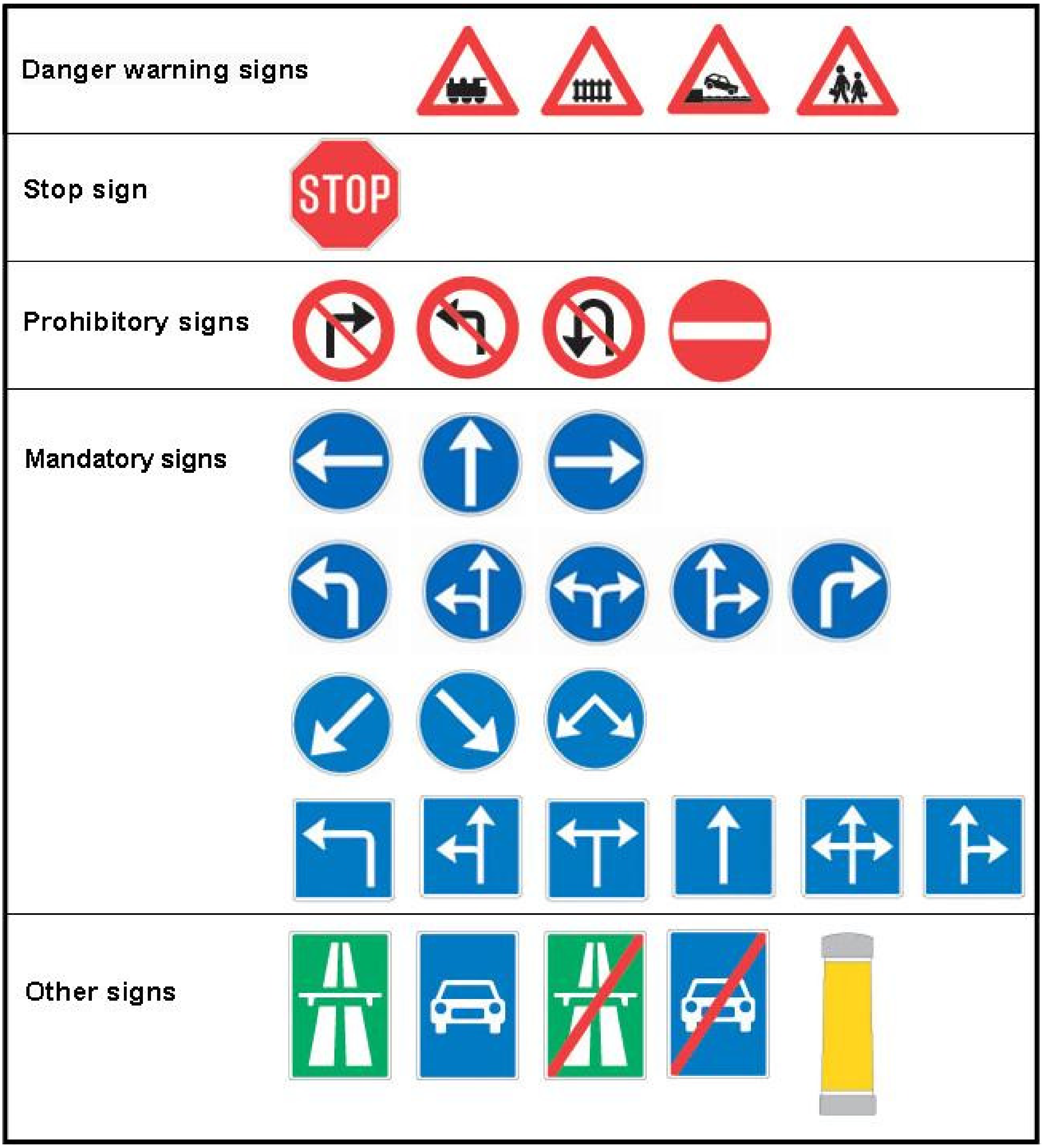


Figure B.28: Signs for ordinary roads that use sign face type 4.

B.5.6 The legibility index and its dependence on luminance

Drivers visual performance for character legends can be described by the legibility index LI, which measures the maximum legibility distance in proportion to the letter height. The letter height is described by the height of upper case letters as lower case letter are as legible as upper case letters, or even slightly more legible.

The legibility index of character legends is limited by imperfections of the eye, which put a lower limit to the angular size of details that can be discriminated. With increasing distance, the angular size of details of character legends decreases and eventually, when too few details can be discriminated, the characters themselves can no longer be discriminated and the legend ceases to be legible. See figure B.29.

Figure B.29: With increasing distance, less detail can be discriminated.

The legibility index for persons with normal visual acuity is approximately 7 m per cm in optimum conditions of luminance and contrast. This reflects that that the eye can, in optimum conditions, resolve a detail of 1 minute of arc and that 5 details are need in the height of the character legends.

At a distance D, an angular extension of 5 minutes of arc takes up a height H of D×tan(5'). Accordingly, D/H = 1/tan(5') = 1/tan(0,0833°) = approximately 700 = 7 m per cm.

In less good conditions, the legibility index is reduced. This is illustrated in figure B.30 for data derived by T. W. Forbes, "Luminance and contrast for sign legibility and colour recognition", Transportation Research Board (1976) for glance legibility in experiments involving practical driving. More data in the literature agree essentially with these data.

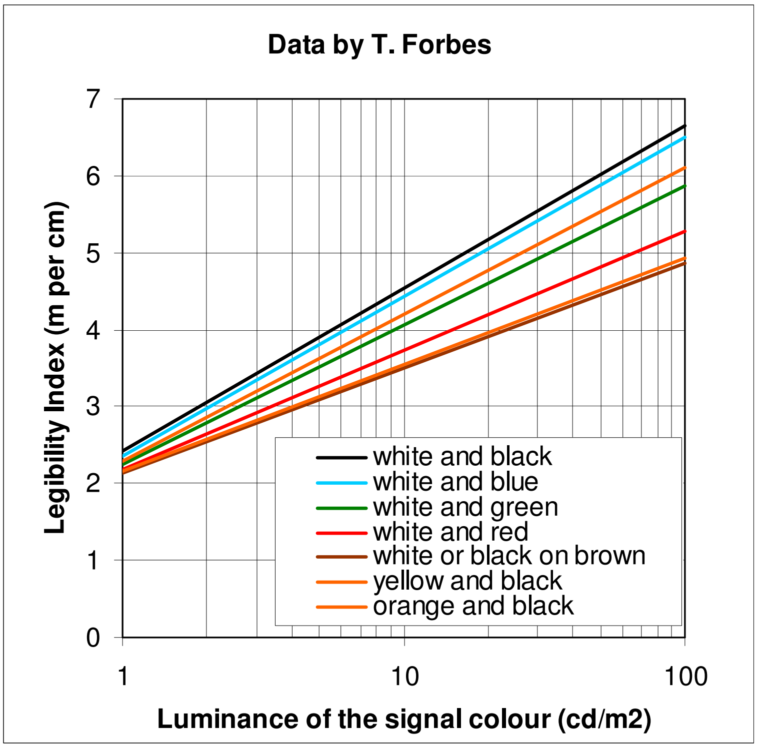


Figure B.30: Data by T. W. Forbes regarding the legibility index with respect to the luminance of the signal colour and combinations of signal and contrast colours.

The best contrast is supplied by white as the signal colour and black as the contrast colour. This combination provides a legibility index of approximately 6 m per cm at the optimum luminance, which is normally considered to be in the region of 30 tor 100 cd/m^2. At the above-mentioned realistic luminance levels of retroreflective signs at night the legibility index is reduced to approximately 4,5 to 5,0 m per cm.

A less good contrast is supplied with an often used combination of white and green, which provides a legibility index at realistic luminance levels of approximately 4,0 to 4,5 m per cm.

This illustrates that the night situation is the more critical for the legibility of retroreflective signs and that these should be designed so that they offer the necessary legibility distances at night.

B.5.7 The time needed to read a sign

A driver has to stop reading a sign at some distance to the sign D_2, where he gets too close to the sign to continue reading or where he has to start acting on the message displayed on the sign. It is often assumed that a driver gets too close to a sign at a distance of 25 m, when the sign is shoulder mounted, and 50 m, when it is overhead mounted. When an action is needed, such a reducing speed, the reading of the sign may need to be completed at a longer distance.

On the other hand, the driver needs a time period t to read the sign and in this period he moves a distance $D_1 = t \times V$ metres during t seconds, where V is the driving speed in metres per second. It is normally assumed that t is given by $t = 2 + N/3$ seconds, where N is the number of legends displayed on the sign. A legend may a word such as a city name, a number such as a road or route number of a symbol.

Accordingly, the driver must be able to start reading the sign at a distance of $D = D_1 + D_2$ metres. Refer to figures B.31 and B.32.

Figure B.31 The distance D to a sign where reading can start.

Figure B.32: The distance D_2 to a sign where reading must stop.

B.5.8 The basis for choosing the sizes of character legends

In accordance with the above, the letter height of character legends must be minimum
$H = D/LI$ centimetres.

where H is the letter height measured in centimetres
D is the distance where reading must start measured in metres
and LI is the legibility index measured in metres per centimetres.

At a luminance level of retroreflective signs of 5 to 10 cd/m^2, the value of LI should be set to 4 to 5 m/cm.

Character legends on for instance direction signs are covered by a number of standard character heights in a sequence of 101 mm, 120 mm, 143 mm, 170 mm, 202 mm, 240 mm, 286 mm, 340 mm and 405 mm. It may be noted that each step is by a fixed factor and the height doubles in 4 steps. The character font has been developed with the aim of good legibility.

Direction signs on ordinary roads are covered by a regulation ”Bekendtgørelse om vejvisning på almindelige veje”.

Road standards give rules for the size and character height that is permissible in specific cases in order to ensure sufficient legibility distances.

EXAMPLE: An overhead sign on a motorway has three city names (Odense, Kolding and Esbjerg) and three motorway numbers (E20, E45 and E20). The city names and the motorway numbers are considered to be alternatives to each other as some drivers search for city names and some for motorway numbers. This leaves three character legends to be counted. In addition there is a distance (3 km) bringing the total number of legends to be considered up to N = 4. The interchange symbol is large and is, therefore, assumed to have been read in advance of the legends at a longer distance. The time t needed to read 4 legends is t = 2+N/3 =2 +4/3 = 3,33 seconds

The driving speed V is 110 km/h corresponding to 30,6 m/s (multiply by 1000 m/km and divide by 3600 s/h) so that the distance to drive during reading is $D_1 = t \times V = 30{,}6\ m/s \times 3{,}33\ s = 102\ m$. The reading has to stop at a distance D_2 = 50 m in front of the overhead sign, so that the legibility distance has to be minimum $D = D_1 + D_2 = 102\ m + 50\ m = 152\ m$.

The legibility index LI is assumed to be 4,5 m per cm, so that the letter height H has to be minimum H = D/LI = 152 m/4,5 m/cm = 33,8 cm. On the scale of standard letter heights, the height of 340 mm may be selected.

The standard height for an overhead sign with 4 legends is actually 340 mm at a driving speed of 110 km/h, but 405 mm at a driving speed of 130 km/h.

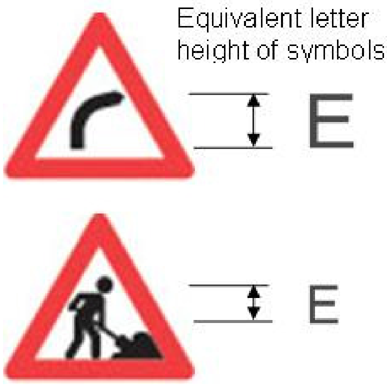
B.5.9 The basis for choosing the sizes of symbols

The above forms the basis for choosing the sizes of character legends and thereby the sizes of the signs on which they are placed.

The same basis can be used for the sizes of symbols, such as presented on for instance warning signs, when these are represented by equivalent characters heights that represent their legibility distances as if they were character legends. This requires an initial step in which a value of the equivalent character height is assigned to each symbol.

Symbols have legibility distances that depend on the size of the details of the symbols that must be identified in order that the symbols can be recognized and comprehended.. Simple symbols are legible at longer distances than complex symbols. Refer to figure B.33.

Figure B.33: The legibility of symbols can be represented by equivalent letters heights. A simple symbol (top) can be assigned a relatively large equivalent letter height, while a complex symbol (bottom) must be assigned a smaller equivalent letter height.



When assigning an equivalent letter height to a symbol, one can study the symbol and identify the details that need to be discriminated in order the symbol can be correctly identified. The equivalent letter height can then be selected as 5 times the size of the smallest of those details. The factor of 5 reflects the need to discriminate 5 details in the height of letters.

The simple symbol shown in figure B.32 can probably be assigned an equivalent letter height equal to the height of the symbol. For the more complex symbol also shown in figure B.32, the critical details include probably the limbs of the worker and the shovel, and as these are relatively narrow, the equivalent letter height should be set lower that the height of the symbol.

Another, more direct but also more tedious way, to assign an equivalent letter height to a symbol is to study it from a long distance and compare its legibility to the legibility of character legends. See figure B.34.

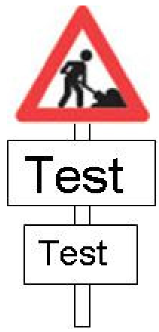
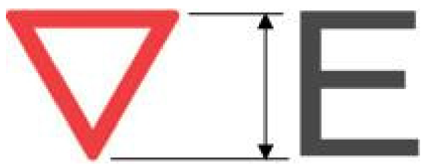


Figure B.34: Possible method to compare the legibility of symbols and character legends.

Additionally, there is a value for road users to distinguish the shape of a sign itself from a distance, i.e. if it is a warning sign, a prohibitory sign, give way sign, a stop sign etc. Therefore, it has a value to determine the distance in which the shape of the sign is discernible. For that purpose a sign can be assigned an equivalent letter height equal to its smallest dimension; for instance the height of a give way sign. See figure B.35.

Figure B.35: For the legibility of the shape of the sign itself, the sign can be assigned an equivalent letter height equal to its smallest dimension.



Symbols are mostly used on standard shape signs (triangular, circular, octagonal and rectangular signs such as danger warning signs, priority signs, prohibitory and restrictive signs) and these are generally covered by regulations that define a small number of sizes such as mini, reduced, standard, oversize and megasize.

Therefore, the size of a particular symbol is in proportion to the size of the standard shape sign on which it is placed. Se figures B.36 and B.37.

Figure B.36: Triangular signs are measured by the side length and relevant standard sizes are indicated for each type of sign.

Figure B.37: The size of the symbol and the equivalent letter height is in proportion to the size of the sign.

Other regulations define when to use particular standard sizes in view of the type of road and the driving speed.

EXAMPLE: A warning sign, warning of a junction with a minor road ahead, is placed on the right kerb 50 m ahead of the junction.

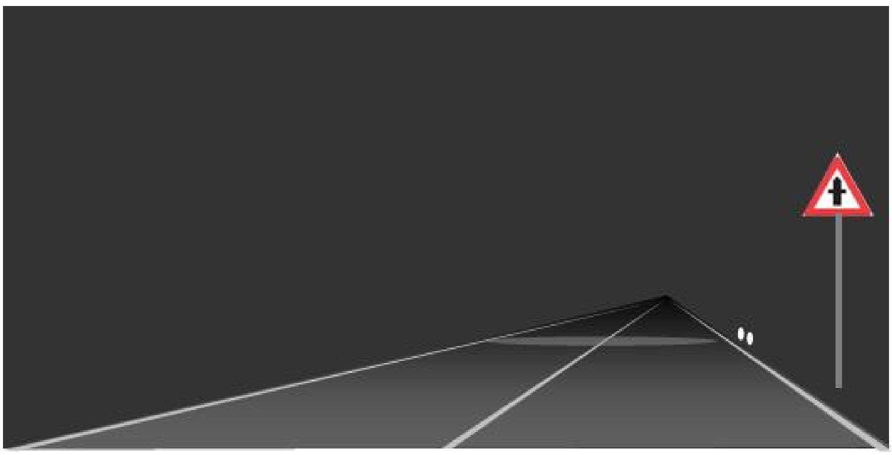
The smallest detail of the symbol is the width of the minor road. The equivalent letter height is assumed to be five times this detail, which turns out to be approximately 0,25 times the size of the sign expressed by the side length. The size of the sign is 90 cm corresponding to an equivalent letter height h of H = 0,25×90 cm = 22,5 cm.

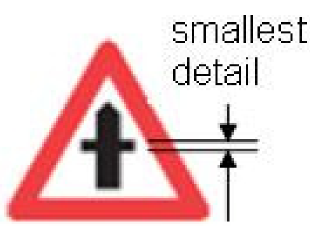
The legibility index LI is assumed to be 4,5 m per cm, so that reading can start at a distance ahead of the sign D of D = H×LI = 22,5 cm×4,5 m per cm = 101 m.

The time t needed to read one legend is t = 2+N/3 =2 +1/3 = 2,33 seconds. The driving speed V is 80 km/h corresponding to 22,2 m/s (multiply by 1000 m/km and divide by 3600 s/h) so that the distance to drive during reading is D_1 = t×V = 22,2 m/s × 2,33 s = 52 m. The reading can therefore be completed, when the driver is 49 m in front of the sign or 99 m in front of the junction.

This leaves ample time for the driver to react on a vehicle entering the junction from the minor road.

The standard size for this warning sign, when used on an 80 km/h road, is actually 90 cm. This is deemed to be sufficient.





Literature

prEN 12899-6 ” Fixed vertical road traffic signs — Part 6: Retroreflective sign face materials”.

UMTRI-2001-19 “High-beam and low-beam headlighting patterns in the U.S. and Europe at the turn of the millennium”.

UMTRI-93-36 ”'Light output of U.S., European, and Japanese low-beam headlamps”.

”European low beam headlamps in view of retroreflective road signs”, draft report by Kai Sørensen and Bent Rasmussen, DELTA, August 2003.

T. W. Forbes, “Luminance and contrast for sign legibility and colour recognition”, Transportation Research Board (1976)

“Almindelig arbejdsbeskrivelse (AAB) afmærkningsmateriel”, the Danish Road Directorate, 2010.

“Bekendtgørelse om anvendelse af vejafmærkning”, the Danish Road Directorate, 2006.

“Bekendtgørelse om vejvisning på almindelige veje”, the Danish Road Directorate, 2007.

Annex C: Measurement of retroreflection

C.1 Introduction and summary

The directly measured value of a retroreflective object is the ratio between the retroreflected luminous intensity I (candela, cd) and the illuminance E (lux, lx) at the object on a plane perpendicular to the illumination direction. When the retroreflective object is a retroreflector, this ratio is also the final result of the measurement. It is called the coefficient of luminous intensity CIL. The unit is candela per lux.

When the retroreflective object is a sample of a retroreflective surface, the CIL value is converted to the coefficient of retroreflection R_A by division with the surface area A (square metres) of the sample. The unit is candela per lux per square metres ($cd \cdot lx^{-1} \cdot m^{-2}$).

CIL values are small, because retroreflectors generally are small. For this reason, CIL values are normally presented with the 1000 times smaller unit of millicandela per lux ($mcd \cdot lx^{-1}$) in order to provide convenient values. This is not the case with R_A values for which the full unit in itself provides convenient values. A value of the CIL or the R_A applies for a specific geometrical situation.

Laboratory measurement of retroreflection is presented in C.2.

It is explained that laboratory measurements of retroreflection can be made with a good accuracy and generally are considered to be reliable. After an introductory discussion of laboratory equipment for multi purpose measurements, the specialised use for retroreflection measurement and also calibration is accounted for.

Testing in accordance with specifications for retroreflection is discussed with some emphasis on the comprehensive test of retroreflective sheeting materials of prEN 12899-6 " Fixed vertical road traffic signs - Part 6: Retroreflective sign face materials".

Retroreflection measurement with handheld retroreflectometers is considered in C.3. It is explained that the optical principles of handheld retroreflectometers are relatively simple and that the requirements concerning accuracy of the angles, angular apertures, spectral correction etc. are in general the same as for laboratory measurements.

The particular matter for handheld retroreflectometers is that they use only one, or at most a few, of the geometrical situations that can be set in laboratory conditions. Handheld retroreflectometers can, therefore, be used for simplified testing only and involve typically geometrical situations that provide sensitivity to ageing of the sheeting material or retroreflector.

The most commonly used handheld retroreflectometers for the measurement of R_A values of road signs or samples of sign sheeting materials are mentioned and their uses are considered:

- Measurements of samples of sign sheeting materials may be done to give a first impression of the retroreflection properties of the materials, but are mainly carried out as part of factory production control at producers of sheeting materials and road sign.
- Measurement on road signs has the purpose to reveal if warranties are complied with within the warranty period, or to decide if the road sign still offers sufficient retroreflection to drivers.

It is argued that there is no real tradition of systematic in situ testing the retroreflectivity of road signs, but it is assumed that the 2008 revision of the "Manual on Uniform Traffic Control Devices", or MUTCD may lead to more testing of road signs in the USA.

It would be a breakthrough if testing of the retroreflection of installed road signs could be done with mobile equipment from a vehicle at normal driving speeds. Such mobile equipment is currently not available, but it is explored in C.4 how it could possibly be designed.

C.2 Laboratory measurement of retroreflection

C.2.1 Introduction to laboratory measurement

The retroreflection of sign sheeting material and retroreflectors is typically 1000 times stronger than ordinary reflection and the rather weak retroreflection of road markings. Further, the retroreflection is measured in directions that are easy from a measurement point of view, and easy to identify relative to the test samples. Additionally, there are various methods of calibration available that are sound of nature.

For these reasons, laboratory measurements of retroreflection can be made with a good accuracy and are generally considered to reliable.

Laboratory equipment for multi purpose measurements is introduced in C.2.2, while the specialised use for retroreflection measurements are discussed in C.2.3 and calibration methods in C.2.4.

Laboratory measurement of retroreflection serves often for testing in accordance with specifications for retroreflection. This is discussed in C.2.5 on the basis of a few specifications for retroreflection. These specifications serves as examples among a multitude of specifications for retroreflection.

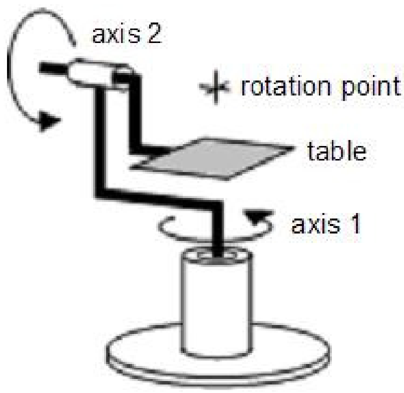
C.2.2 General about laboratory equipment

Laboratory measurements are carried out in a darkened room with black surfaces equipped with black curtains and other means to reduce offset of measured values by reflection. The room temperature is normally kept at 25 °C in order to keep light sources, photometers and electronics stable.

The main equipment is a photometer bench, which defines a horizontal axis, and a goniometer at the end of the bench.

A goniometer is illustrated in figure C1. It has a two axes of rotation that are perpendicular to each other. The first axis is vertical and fixed in space, while the second axis changes direction with rotation about the first axis, but stays in the horizontal plane.

Figure C1: A goniometer.



The second axis carries a table on which the object to be measured is mounted. The orientation of the object changes in space, when the rotations of the axes are changed. The sequence of changing the two rotations is without consequence for the final orientation of the object, which is therefore defined by the two angles of rotation.

The two angles of rotation are monitored by precise instrumentation. The origin for axis 1 (where the angle is 0°) is so that the axis 2 is perpendicular to the direction of the photometer bench, while the origin for axis 2 is so that table is horizontal. The two angles can mostly be monitored and set by a computer.

The directions of the two axes meet in a point, which is marked as the rotation point in figure C1. An object mounted on the table is rotated about this point, when the angles of rotation of the axes are changed.

Therefore, in order to avoid change of measuring distance by rotation, the object is mounted so that its optical centre coincides with the rotation point. The optical centre can be the centre of the light emitting surface of a lamp, luminaire or signal light, or the centre of the surface of a reflecting or retroreflecting object.

Additionally, the object is mounted so that its reference direction points into the axis of the optical bench, when the goniometer angles are 0°. The reference direction is normally the direction perpendicular to a characteristic surface of the object, which can be the light emitting surface of a lamp, a luminaire, a signal light, or the surface of a reflecting or retroreflecting object.

A goniometer is shown again in figure C2 together with a photometer bench.

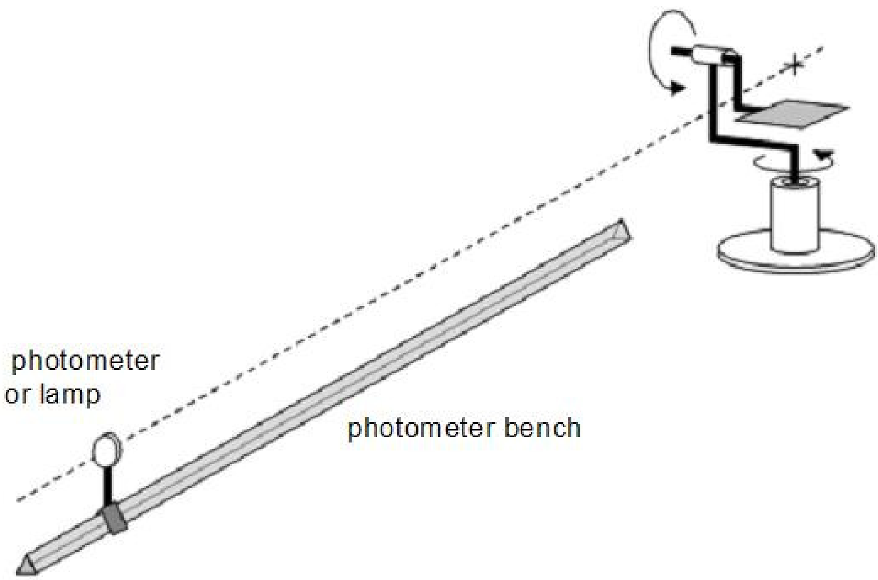


Figure C2: A photometer bench with a goniometer.

The photometer bench defines the direction of the optical axis, but is lower so that equipment mounted on the bench can be placed in the axis.

The characteristic value to be measured for a light emitting object is mostly the luminous intensity in one or more specified directions. To this purpose a photometer is mounted in the bench at a distance D. The measured value is the illuminance E which is converted to luminous intensity I by means of the distance law of illumination $E = I/D^2$ or $I = E \times D^2$.

There are different characteristic values to be measured for a reflecting or retroreflecting object depending of the object itself and other circumstances. However, it is normally a lamp that is mounted on the bench while a photometer is mounted in a different direction at an angle that depends on the characteristic value to be measured.

The photometer can be a luxmeter, a luminance meter or a spectrocolourimeter depending on the characteristic to be measured. Additional equipment includes means to define the rotation point, the measuring axis, distances along the bench axis, calibration standards, standard lamps, stabilized power supplies etc.

The distance along the bench at which the equipment is mounted is the measuring distance. This distance and the sizes of the optical parts of the object and of the photometer and/or lamp being used defines the angular apertures of measurement.

EXAMPLE: The angular aperture of a lamp of a diameter of 30 mm at a distance of 20 m is approximately 0,085° or 5 minutes of arc.

The angular apertures represents an averaging over directions within the angular ranges of the apertures. Therefore, they need to be sufficiently small depending on the angular resolution that is needed for the measurement of particular objects, and are often specified in standards or regulations.

Sometimes, goniometers are defined as A, B and C, and even X and Y. However, all such goniometers are of the type as illustrated is figure 34 and differ only by different origins of the angles.

C.2.3 Retroreflection measurement in the laboratory

Figure C3 illustrates the use of laboratory equipment for the measurement of retroreflection. A retroreflector or a sample of a retroreflective surface is mounted in the goniometer, a lamp for illumination is mounted in the axis of the photometer bench and a photometer for the measurement is mounted at a location above the lamp.

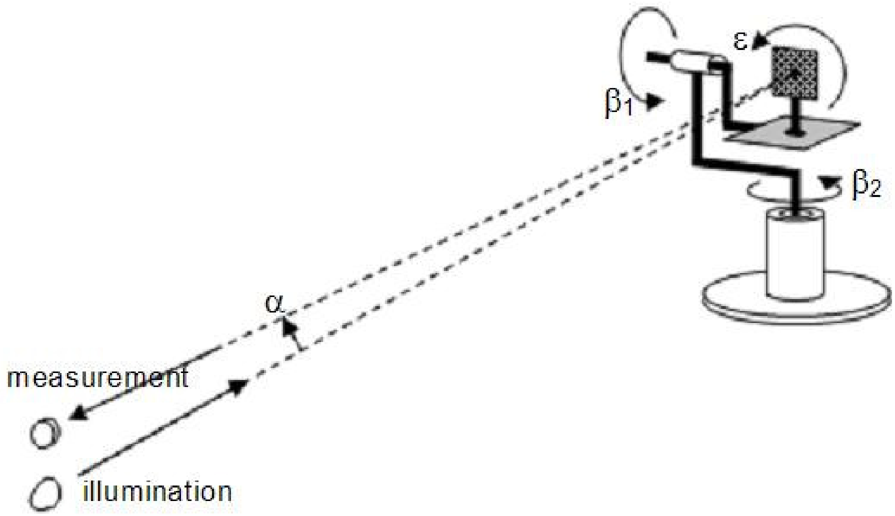


Figure C3: Use of laboratory equipment for the measurement of retroreflection.

The set of angles indicated in the figure C3 are:

α the observation angle (the angular separation between the directions of illumination and measurement)

β_1 and β_2 the two components of the angle of the entrance angle β (the angle of incidence)

ε the rotation angle.

The retroreflected beam is often narrow and, therefore, it is necessary that the observation angle α is set accurately and that the angular apertures for measurement and illumination are small. The normal specification for apertures is 6 ± 0,5 minutes of arc, refer to CIE 54.2 “Retroreflection: Definition and measurement”. The sample of the retroreflective surface need, on the other hand, not to be very small.

C.2.4 Calibration methods for laboratory measurement

CIE 54.2 provides also some advice on calibration for which there is at least three approaches.

The first approach is to measure the illuminance E_O at the retroreflective object with a calibrated photometer and also to measure the illuminance of the retroreflected light E_R at a distance D with another calibrated photometer.

The retroreflected luminous intensity is given by $I = E_R \times D^2$, the C.I.L. value of a retroreflector by C.I.L. = I/E_O and the R_A value of a retroreflecting surface by R_A = C.I.L./A, where A is the surface area of the sample mounted in goniometer.

This approach has the advantage that no reflection standard is needed, and also that the photometers can be calibrated at the approximate levels of the signals. However, it is a disadvantage that the measurement relies on the calibration of two photometers.

The second approach is to use the same photometer to measure first the illuminance E_O at the retroreflective object and then the illuminance of the retroreflected light E_R at the distance D. C.I.L. and R_A values are calculated as described above.

In this approach, the photometer need not be calibrated, because the calculations involve the illuminance values E_R and E_O only as the ratio E_R/E_O. Any error of scale cancels out.

NOTE 1: This shows that retroreflection characteristics do not really have any dimension for light. The units used do involve cd/lx, but candela is lumen per steradian and lux is lumen per m^2 so all that remains is m^2 per steradian. This applies actually for all reflection characteristics, not only for retroreflection characteristics.

It is an advantage that no reflection standard is needed and that the measurement does not rely on a calibration of the photometer. However, the two measured illuminance values may differ by decades and, therefore, the measurement relies on the linearity of the photometer over a large range. It is difficult to verify this linearity over a large range, and this is the disadvantage of this approach.

EXAMPLE: Assume that a sample of a retroreflective surface of an area of 0,004 m^2 (6,3×6,3 cm^2) is illuminated to 1 lx and that the sample has an R_A value of 10 $cd \cdot lx^{-1} \cdot m^{-2}$ in the particular measuring geometry. The retroreflected luminous intensity is then 0,004 $m^2 \times$ 1 lx $\times$ 10 $cd \cdot lx^{-1} \cdot m^{-2}$ = 0,04 cd. At a measuring distance of 20 m, the resulting illuminance is $0{,}004/20^2$ lx = 0,0001 lx. Accordingly, the photometer must be linear over at least 4 decades and in practice 5 or 6.

The third approach is to use a retroreflection standard with a known CIL value in the actual measuring geometry. The retroreflected illuminance value E_O is measured for the retroreflective object and also for the standard E_S. The CIL value of the object is then E_O/E_S times the CIL value of the standard.

If the object is a surface, the R_A value is obtained by division of the CIL value with the surface area of the object. Similarly, if the retroreflection standard is a surface with a known R_A value, the CIL value is obtained by multiplication with the surface area of the standard.

The advantage of this approach is that the measurement does not rely on the calibration of the photometer. It is sometimes a further advantage that traceability is obtained to the institute, which measured the calibration standard. However, the dependence of an institute for calibration may also be seen as a disadvantage.

It is sometimes best to provide calibration by more than one of the above-mentioned approaches so that each of them are tested against one or two other approaches.

Very often, reflection in the room will cause a contribution to the measured illuminance values, in particular to the smaller value measured at a distance. This contribution needs to be measured with a black surface placed in the goniometer (instead of the retroreflective object or covering the retroreflective object) and to be subtracted from the measured illuminance.

It is often an advantage to use a photometer of the luminance meter type, which excludes almost all the light from outside of the optically defined measuring field, and also provides a high sensitivity by collecting light from a relatively large objective lens onto a relatively small photodiode. The luminance meter is to be aimed, focussed and set with a measuring field that encloses the object.

NOTE 2: With a luminance meter it is best to fit an aperture in front of the objective lens that slightly reduces the entrance pupil and thereby provides insensitivity to focus adjustment. Else the calibration will change significantly with adjustments of the focus (because this changes the entrance pupil).

C.2.5 Laboratory testing of retroreflection in accordance with specifications for retroreflection

In most specifications for retroreflection, the rotation angle ε is fixed at 0°, so that the test can be carried out with the retroreflector mounted in a fixed position on the goniometer table. Further, in these specifications it is not necessary to set a combination of the components β_1 and β_2, but only to set one of the components and keep the other component fixed at 0°.

An example of such a specification is given by the classes RA1 and RA2 for glass beaded sheeting materials of EN 12899:2007 “Fixed, vertical road traffic signs - Part 1: Fixed signs”. There are three cases for the component β_1 of 5°, 30° and 40°, while ε and β_2 can both be kept at 0°. The situation is like being in front of an overhead sign.

Another example is found in EN 1463-1:2009 “Road marking materials – Retroreflecting road studs – Part 1: Initial performance requirements”. In various classes of retroreflection, there are two or three cases for the component β_2 of 5°, 10° and 15°, while ε and β_1 can both be kept at 0°. The situation is like being next to a low mounted sign.

In such specifications, the value of the actual component of the entrance angle, whether it is β_1 or β_2, is also the angle of the entrance angle β. The difference is the direction of the incident light, from below or from the side. Additionally, the observation angle α is varied in some steps in order to simulate different distances to the retroreflector.

prEN 12899-6 “Fixed vertical road traffic signs — Part 6: Performance of retroreflective sign face materials”, on the other hand, describes a comprehensive test in which all the four angles are varied. For this test, it is necessary to use both of the rotations of the goniometer, and also to mount an additional small goniometer on the goniometer table, so that the rotation angle ε can be set.

The intention is really to vary this set of angles:

α	the observation angle
β	the total entrance angle β (the angle of incidence)
ε	the rotation angle
ω_S	the orientation angle

These angles are illustrated in figure C4. As described in annex B, they are related to traffic situations, but they cannot be set directly in a goniometer.

Instead, the values of the set (α, β, ε, ω_S) are set indirectly by setting (α, β_1, β_2, ε) so that the identical geometrical situation is obtained. The equations to needed to convert from (α, β, ε, ω_S) to (α, β_1, β_2, ε) are provided in CIE 54.2 "Retroreflection: Definition and measurement". prEN 12899-6 provides itself the conversions that are needed for its purposes.

It should be noted that the rotation angle ε is set as a rotation of the sheeting material in the laboratory, but this does not indicate that the sign is rotated nor that the sheeting material is mounted with a rotation on the sign.

The intention is to provide a rotation of the plane containing the observation and illumination directions relative to the sign. Therefore, the situation produced in the laboratory compares to the desired situation by being rotated in space, but otherwise the situations are identical.

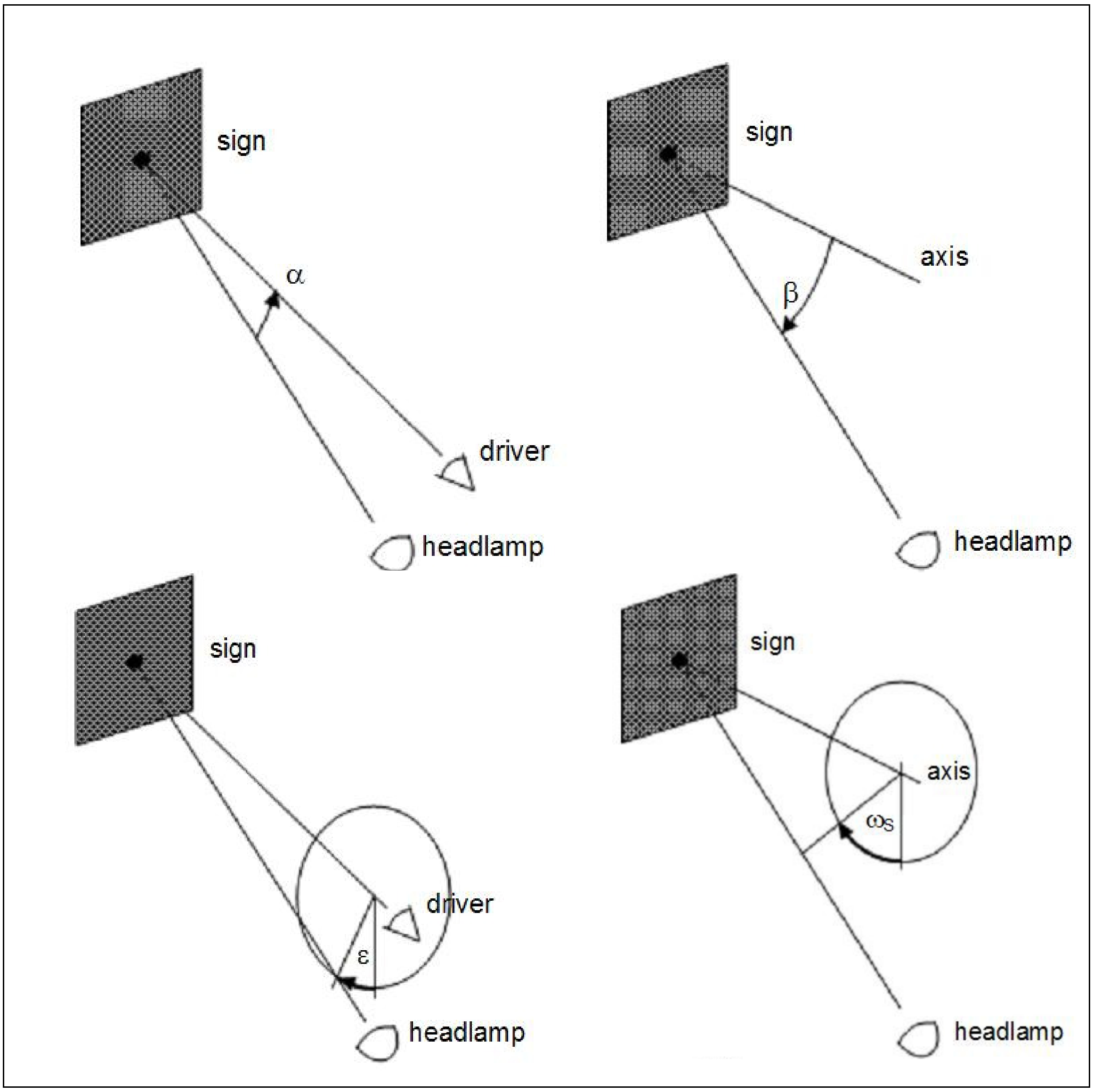


Figure C4: Angles related to traffic situations.

NOTE: The drawing showing the rotation angle ε in figure C4 is to be understood in the way that the plane in which it is drawn is parallel to the plane of the sign.

In most specifications, the requirements are formulated directly in terms of the measured values as minimum requirements for each combination of α and β.

For the specifications of prEN 12899-6, a generalized situation is also expressed in terms of a combination of α and β, but a comprehensive test involves setting a number of values of ε and ω_S.

The values of ε are -45°, 0° and 45° and correspond to different locations of the headlamp and the observer relative to each other. The three measured R_A values differ whenever the retroreflected beam does not have rotational symmetry. The average of the three R_A values is assumed to be a fair representation of an actual driving situation, where the driver sees a road sign in the illumination from typically two headlamps.

NOTE 1: Glass beaded are often considered to be of rotational symmetry in this sense, but do in practice show some deviation. Microprismatic sheeting materials, on the other hand, may show significant or even large deviations from rotational symmetry.

Such average R_A values are determined for up to five values of ω_S of -90°, 75°, 0°, 75° and 90°, which correspond to sign positions of respectively to low mounting to the left, mounting at some height to the left, directly above, mounting at some height to the right and low mounting to the right. These average R_A values differ whenever the sheeting material does not have rotational symmetry with regard to the plane of the incident light.

NOTE 2: Glass beaded are often considered to be of rotational symmetry in this sense, but do in practice show some deviation. Microprismatic sheeting materials, on the other hand, may show significant or even large deviations from rotational symmetry.

The smallest of the averages is the smallest average R_A value that can be expected in view of different sign positions. This value is selected and is the final value used to represent the particular combination of α and β. It is called the $R_{A,C}(\alpha,\beta)$ value.

The comprehensive test is used only for signal colours. These are considered to be white, yellow, fluorescent yellow and yellow-green, orange and fluorescent orange. The testing is simplified for contrast colours.

Additionally, prEN 12899-6 offers special tests for secondary mounting axes (with rotation of the sign or the sheeting material on the sign) and for symmetries. Refer to prEN 12899-6 for details.

C.3 Retroreflection measurement with handheld retroreflectometers

C.3.1 Introduction to retroreflection measurement with handheld retroreflectometers

The optical principles of handheld retroreflectometers are introduced in C.3.2. These principles are relatively simple and the signal is high. It is in fact much more simple to construct reliable handheld retroreflectometers for the measurement of road signs and retroreflectors than for road markings.

Some specifications for handheld retroreflectometers are discussed in C.3.3. The requirements concerning accuracy of the angles, angular apertures, spectral correction etc. are in general the same as for laboratory measurement. The particular matter for handheld retroreflectomers is therefore that they use only one, or at most a few, of the geometrical situations that can be set in laboratory conditions. Handheld retroreflectometers can, therefore, be used for simplified testing only and involve typically geometrical situations that provide sensitivity to ageing of the sheeting material or retroreflector.

The most commonly used handheld retroreflectometers are introduced in C.3.4. These are intended for the measurement of R_A values of road signs or samples of sign sheeting materials.

NOTE: Handheld retroreflectometers can also be used to measure CIL values of retroreflectors in some or most cases. When the retroreflector has a well defined homogeneous retroreflective area A, R_A values are measured on locations within that area and the CIL value is derived as the average R_A value times the area A. When the retroreflector is so small that it can be enclosed within the measurement area of the retroreflectometer, a single R_A value is measured and the CIL value is obtained as the measured R_A value times the measurement area. In other cases, at least an estimate of the CIL value can be obtained by more complex procedures.

Measurement on road signs has the purpose to reveal if warranties are complied with within the warranty period, or to decide if the road sign still offers sufficient retroreflection to drivers.

The retroreflectometer is to be held vertically and placed in contact with the road sign to be tested at a number of locations on the sign. Only low mounted signs, such as directional arrow signs or background signs, are within easy reach. Sign at low to medium height, such as warning sign, can be reached by the use of a pole, which can be supplied with the retroreflectometer. Gantry signs and portions of high signs, such as directional signs at motorways, can only be reached by an operator in a lift.

Measurement on road signs is tedious work and may involve personal danger, and blocking the traffic in some cases – in particular on motorways or when using a lift.

For this reason, and because sign sheeting materials are durable, there is no real tradition of systematic testing the retroreflectivity of road signs. On the contrary, road signs are often left for decades and only replaced when damaged or obviously not functioning or obsolete.

The 2008 revision of the “Manual on Uniform Traffic Control Devices”, or MUTCD, may lead to more testing of road signs in the USA.

Measurements of samples of sign sheeting materials may be done to give a first impression of the retroreflection properties of the materials, but are carried out mainly as part of factory production control at sheeting material and sign producers. The retroreflectometer is to be placed in contact with the sample with an orientation corresponding to vertical for the intended application of the material on road signs as provided by a datum mark on the material.

A retroreflectometer designed to measure the CIL values of retroreflectors on road studs is also mentioned in C.3.4. As for road signs, there is probably no real tradition for testing road studs.

C.3.2 Optical principles of handheld retroreflectometers

A handheld retroreflectometer has a housing with an aperture, a lamp that illuminates a retroreflective surface through the aperture and a detector that measures the light reflected from the retroreflective surface.

Figure C5 shows these essential parts: the lamp, the detector and the retroreflector. The observation angle is determined by the angular separation between the lamp and the detector as seen from a point in the aperture. The entrance angle, on the other hand, is defined by the illumination direction relative to the plane of the aperture.

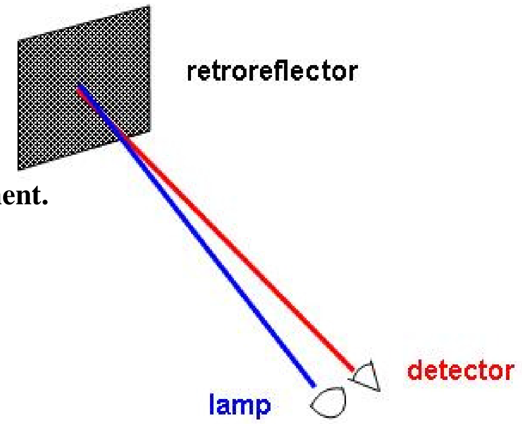


Figure C5: The essential parts in retroreflection measurement.

Figure C6 illustrates that the spread of illumination directions may be large, unless means are introduced in order to reduce the spread.

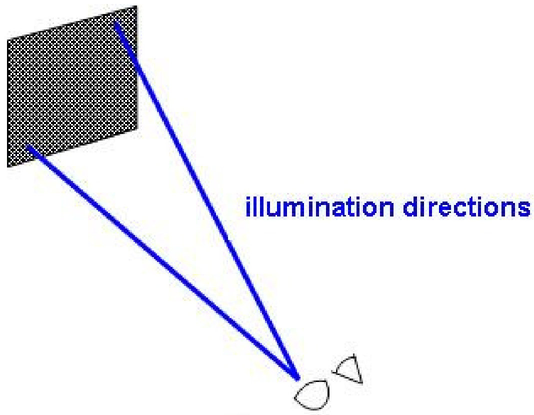


Figure C6: A large spread in illumination directions.

The aperture of the retroreflectometer will provide a limitation of the spread of illumination directions and may be designed in view of that. It is also possible to reduce the spread further by means of a diaphragm as illustrated in figure C7.

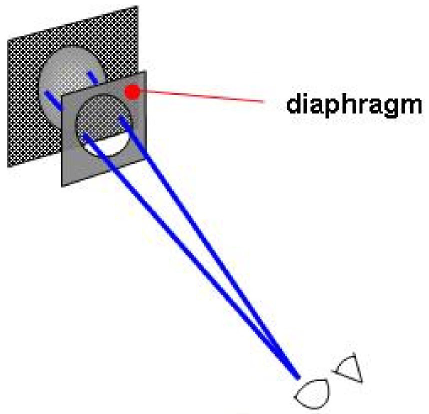


Figure C7: Reduction of the spread of illumination directions by means of a diaphragm.

An early version of ZRS 5060 by Zehntner (originally produced by a different company) had the simple optics shown in figure C7. Later version were given a collimating lens as used in all other retroreflectometers. The ZRS 5060 is now obsolete.

Figure C8 shows a diaphragm with a lens fitted in the opening. The focal width of the lens equals the distance to the lamp and the detector, so that these are in the focal plane of the lens.

Such a lens is called a collimating lens. It has the property that the lamp, when seen through the lens, is at the virtual infinite with an angular size determined by the diameter of the lamp in proportion to the focal width of the lens. This means that the angular spread of illumination directions caused by distance is eliminated, and that the only remaining angular spread equals the angular size of the lamp.

The same applies for the angular spread of measuring directions, which is determined by the diameter of the detector in proportion to the focal width of the lens. The observation angle is determined by the distance between the centres of the lamp and the detector in proportion to the focal width.

In practice, there is a unit in the form of a small block or component that defines the optical diameters of the lamp and the detector and also defines their mutual distance accurately in accordance with the specifications for the retroreflectometer.

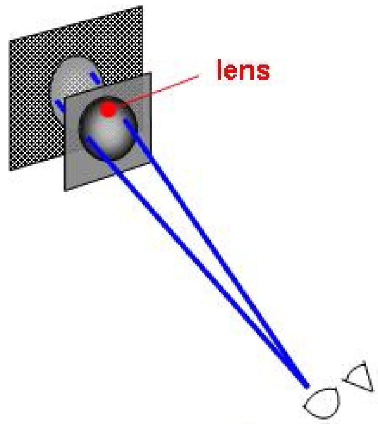


Figure C8: Further reduction of the spread of illumination directions by means of a collimating lens.

EXAMPLE 1: A retroreflectometer uses a collimating lens with a focal width of 150 mm and is designed to provide an observation angle of 0,33° and angular apertures of illumination and measurement of 6’ (minutes of arc). The distance between the lamp and the detector is therefore 150 mm times tan(0,33°) equal to 0,86 mm, and the diameters are 150 mm times tan(6’) equal to 0,26 mm.

In reflection measurements it is mostly necessary to take precautions that the measuring field is safely within the illuminated field – or vice versa. The optics shown in figure C8 do not include any means to this intent, and the two fields will actually shift location relative to each other with increasing distance from the lens. Additionally, the fields will develop unsharp edges with distance.

This is illustrated in figure C9, where one of the fields is shown in yellow, the other field in blue and the overlapping part in the mixed colour of a bluish white. The illustration applies for an observation angle of 0,33° and angular apertures of measurement and illumination of 6’ (minutes of arc).

Because of the relative shift of location, the measured signal decreases with distance (because the measured field is not fully illuminated). There is a further small effect of this nature because of the unsharp edges.

However, figure C9 shows that the decrease is insignificant as long as the distance is not large compared to the lens diameter D. Because of this, special precautions are not needed. On the contrary, the tolerance for distance is sufficient to allow for the adaptors that are mentioned later.

NOTE: The diameter D is 25 to 30 mm in existing handheld retroreflectometers.

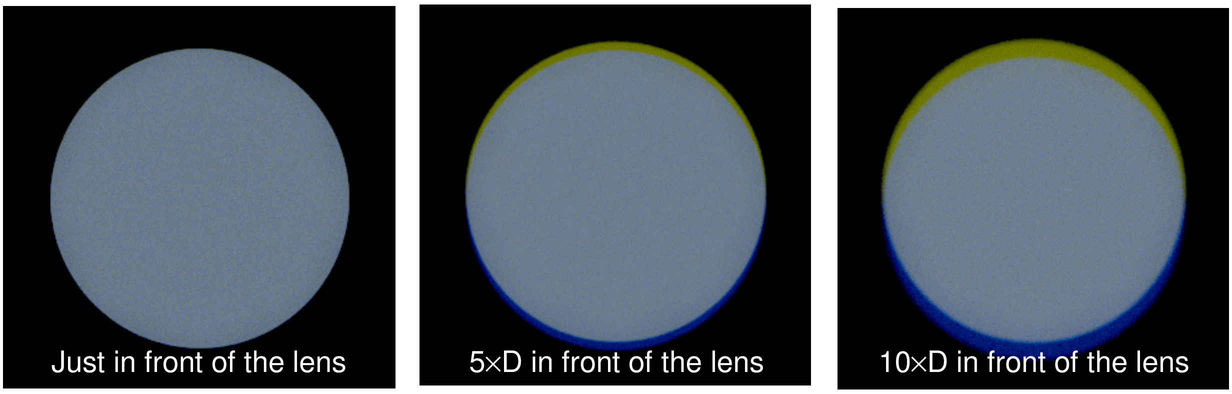


Figure C9: Relative shift of the fields of measurement and illumination with distance measured in the diameter of the lens D.

C.3.3 Specifications for handheld retroreflectometers

There are no direct European standards for handheld retroreflectors, only indirectly through this requirements for testing after accelerated weathering as provided in EN 12899-1 "Fixed, vertical road traffic signs - Part 1: Fixed signs":

> "When tested at an observation angle (α) of 20' and entrance angles (β_1 = 5° and 30°, with β_2 = 0°) the coefficient of retroreflection shall be not less than 80 % of the values required in 4.1.1.4 as appropriate".

This tests can be done be done in the laboratory, but is normally done with handheld retroreflectometers. There are no specific requirements to the testing instrumentation and procedure, but it is natural to apply the requirements of CIE 54.2 "Retroreflection: Definition and measurement".

The ASTM, on the other hand, provides detailed requirements in ASTM E 1709 "Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.2 Degree Observation Angle". This standard has a long history, with the latest version being dated 2009.

The title of ASTM E 1709 reveals that the observation angle is 0,2° as opposed to the value of 0,33° that is used for road signs in Europe. Another difference is that the entrance angle is given by β_1 = -4° with β_2 = 0° instead of the above-mentioned values used in Europe. Other requirements deal with the accuracy of angles, angular apertures, linearity, spectral correction, calibration etc.

Another ASTM standard is more recent and almost identical to ASTM E 1709, except that the observation angle is 0,5°. This is ASTM E 2540 - 08 "Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.5 Degree Observation Angle".

The reason for adding ASTM E 2540 is that the 0,5° observation angle is mentioned in a 2008 revision of the "Manual on Uniform Traffic Control Devices", or MUTCD. The MUTCD is administered by the FHWA of the USA.

It is a curiosity, to be discussed later, that ASTM E 1709 and E 2540 allow for two different versions of retroreflectometers, so-called point and annular instruments.

EN 471 “High-visibility warning clothing for professional use - Test methods and requirements” defines a different test geometry for warning clothing. The observation angle is 0,2° as in ASTM E 1709, but the entrance angle is the one of 5° defined as in EN 12899-1.

ASTM E1696 - 04 “Standard Test Method for Field Measurement of Raised Retroreflective Pavement Markers Using a Portable Retroreflectometer” requires the observation angle of 0,2° for retroreflectors on road studs. The measuring direction is horizontal so that the actual entrance angle relative to the retroreflector surface depends on the tilt of the surface.

C.3.4 Some handheld retroreflectometers on the market

C.3.4.1 introduction

The main suppliers of handheld retroreflectometers are DELTA and Road Vista. DELTA offers some versions of RetroSign while Road Vista offers some versions of model 922.

These handheld retroreflectometers are calibrated by means of calibration standards with retroreflective sheeting materials. These are generally of the type encapsulated lens (also called High Intensity or just HI) for the reason that this type has simple retroreflection properties and a suitable R_A value that is stable over time and insensitive to temperature and moisture. The R_A calibration values of standards are determined in laboratory measurements.

There are other companies and products on the market, but only the above-mentioned instruments are presented in the following. Additional equipment like GPS, bar code readers, extension poles etc. is not mentioned.

It may be noted that the RetroSign and the model 922 are respectively “point” and “annular” instruments. The two types of instruments are explained side by side in ASTM E 1709 and E 2540 and are both permissible.

At intervals, the two suppliers argue in the relevant ASTM E12.10 subcommittee about which type is best or more relevant. The types are explained in the following so that the reader can form his own opinion.

C.3.4.2 Retrosign

A RetroSign is shown in figure C10.

Figure C10: A RetroSign.

All versions of RetroSign are point instruments in the sense of ASTM E 1709 and E 2540. By point instrument is meant that a measured value represents a single illumination direction and a single measurement direction. This is as in laboratory measurements and probably what one would expect in a handheld retroreflectometer as well. The working principle is illustrated for GR3 models of RetroSign in figure C11.

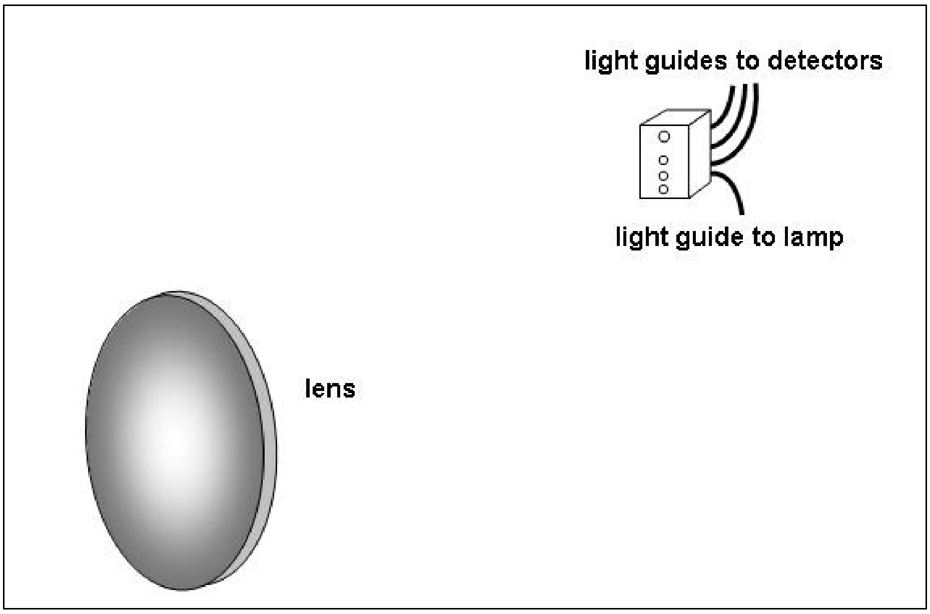


Figure C11: A small block with three light guides leading to detectors, and one light guide leading to a lamp.

A small accurately produced block has three light guides leading to detectors, and one light guide leading to a lamp. Accordingly, three values for three different observation angles are measured simultaneously. GR1 models have only one light guide leading to a detector and measures at only one observation angle. The following versions are available:

- GR1 ASTM complies with ASTM E 1709
- GR1 CEN complies with EN 12899-1
- GR1 Safety complies with EN 471.
- GR3 ASTM complies with ASTM E 1709 and E 2540 by measuring at both of the observation angles of 0,2° and 0,5° and also at an additional observation angle of 1°
- GR3 CEN complies with EN 12899-1 by measuring at the observation angle of 0,33°, and also at additional observation angles of 0,5° and 1°.

The GR1 and GR3 in the CEN versions incorporate an entrance angle of 5°, but not the entrance angle of 30° also defined in EN 12899-1. The second entrance angle is obtained by the use of an adaptor at the lens, that defines a contact surface with a tilt of the instrument of 25°.

The adaptor is simple, just leading to a tilt of the instrument that changes the entrance angle. The adaptor, when mounted, leads to an increase in the distance to the surface, but this is permissible in view of the insensitivity to relatively small changes in distance discussed in C.3.1.

However, the adaptor also takes care of an small problem that is illustrated in figure C12.

When the instrument is tilted by 25° relative to the retroreflective surface, the measurement field is elongated in the proportion of cos5°/cos30° = 1,15. The measurement area increase in this proportion and the R_A value, which is defined for a fixed area, becomes overestimated by 15 %. This is avoided by an aperture built into the adaptor, that reduces the area by a factor of 1/1,15 = 0,869.

There is a similar adaptor available for a 40° entrance angle.

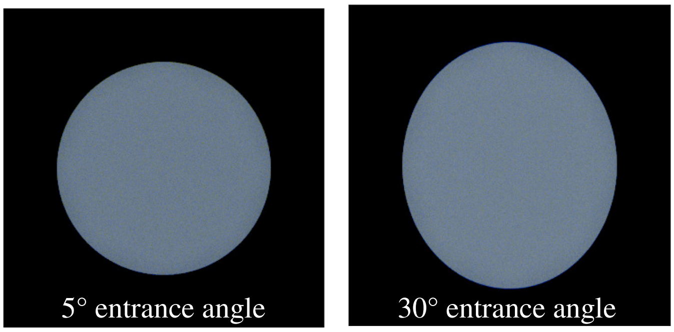


Figure C12: Measurement fields at two different entrance angles.

3.3.4.2 Road Vista Model 922

A model 922 is shown in figure C12.

Figure C12: A Road Vista Model 922.

All versions of model 922 are annular instruments. This means that measurement is in an annulus of directions, so that the measured value is an average for those directions. The principle is illustrated in figure C13.

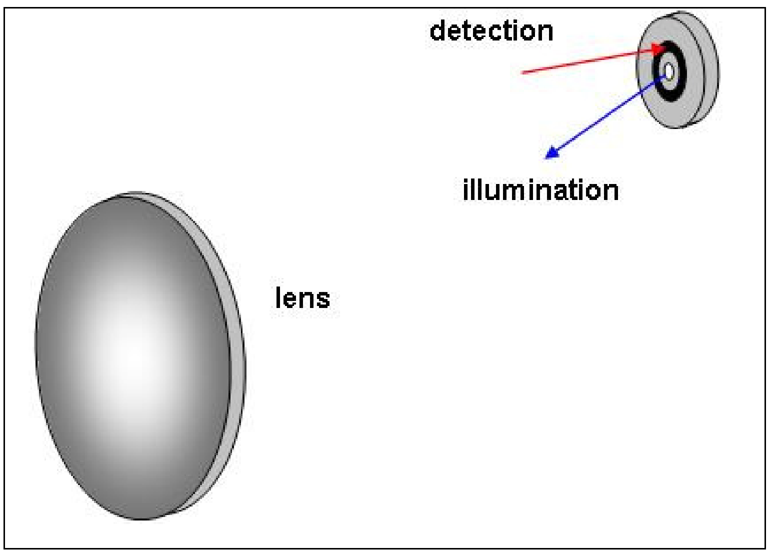


Figure C13: Principle of an annular instrument.

The following versions are available:

- Model 922 complies with ASTM E 1709 and E 2540 in the sense that it measures for both of the observation angles of 0,2° and 0,5°
- Model 922D offers the geometry of EN 12899-1 with 5° entrance angle, but seemingly not the other geometry with 30° entrance angle
- Model 922E complies with the geometry of EN 471 and offers measurement at an additional observation angle of 0,5° combined with the entrance angle of 5°.

It is questionable if the annular geometry of model 922D is acceptable for the purposes of EN 12899-1.

In addition, Road Vista offers a model 932 in which the observation angle and the entrance angle both can be set continuously in fairly large ranges.

Further, a model 1200F aims at measuring retroreflectors on road studs in accordance with ASTM E 1696. A different version is called “European” in spite of lack of any European specification in this area.

C.4 Mobile equipment for the testing of the retroreflection of installed road signs

C.4.1 Introduction

It would be a breakthrough if the testing of the retroreflection of installed road signs could be done with mobile equipment from a vehicle at normal driving speeds. However, such equipment is currently not available, but it is explored in the following if it can possibly be made.

NOTE: The FHWA had mobile equipment developed and mounted on four vehicles at some point during the 90's. This equipment was based on a powerful flash lamp and a camera. It did not perform satisfactorily.

In C.4.2 it is pointed out that it is only partly possible to include those geometrical situations that are used for specifications for retroreflection and for laboratory testing. However, it may be considered an advantage from a driver point of view that the measurements include situations that actually occur on the road

In C.4.3 it is concluded that the detection system should be able to resolve details of a fraction of 1' (minute of arc), for instance 0,5'. A modern camera offers 1400 times 1000 pixel and probably a sufficient field of view to cover road signs intended for one driving direction.

C.4.4 considers the need for sharpness of the image in view of optical imaging, forward movement of the vehicle and vibration. The camera lens needs to have a high F-number like f/11 or higher and the exposure time needs to be less than 0,001 s and possibly even shorter.

C.4.5 considers the need for luminous intensity. It is probably not possible to outshine the sun without causing offense to drivers. This may not either be technically possible. Some options are considered in view of that – the most promising is probably to avoid conditions of strong daylight.

A few additional observations are given in C.4.6.

In the various clauses there are references to DELTA's mobile equipment for road markings, the LTL-M. This is practical as the LTL-M does a job that is similar to a mobile equipment for road signs, and does it well. Some of the technical solutions for road markings may be applied also for road signs.

The camera should probably be turned 90° so that 1000 pixels are available for the width of the field of view while a bit less than the 1400 pixels can be made available for the height of the field of view.

Additionally, the illuminated field form a horizontal band only in the LTL-M and should be made much higher. This requires a Xenon flash lamp with a bigger bore and more energy per discharge.

The question is if such a modified LTL-M will work at much larger distances of 100 or 150 m than the 6 m for which the LTL-M was designed.

The illuminance will of course be much less at the longer distances because of the distance law of illumination (inverse proportion to the distance squared); actually 278 times less at 100 m and 625 times less at 150 m.

There is some compensation for the less powerful illumination by the much stronger retroreflection of road signs compared to road markings. This is by a factor of 100 or more, but not quite enough to compensate fully for the longer distances. It might be technically possible to raise the illumination so all to provide a full compensation, but this requires more power.

Further, the LTL-M does not outshine daylight. The sun in particular leaves a significant contribution to the road marking luminance. The LTL-M has a good and accurate method of measuring and subtracting the contribution from daylight., but it is not obvious how to introduce a similar method for road signs.

The principles of the LTL-M can perhaps not be applied for road signs without some compromise, for instance avoiding to measure in strong daylight, disregarding road signs at the longest distances or using a smaller field of view.

In any case, even when all the above-mentioned matters may be solved, the development of the software for analysing the images presents a large job. This proved to be the case for the LTL-M, and quite different and elaborate software will be needed for mobile equipment for road signs. The software needs among else to distinguish between legends and background, and probably to identify shapes and legends, and to derive dimensions of signs and legends.

C.4.2 Geometrical situations that may be included

It would be desirable if the geometrical situations could include those used for specifications for retroreflection and for laboratory testing. However, that is only partly possible.

If measurements are done frequently during driving, it would be possible to select measurements that correspond to commonly used values of the observation angle α such as 0,2°; 0,33°; 0,5° etc. If, for instance, an α of 0,33° occurs at 100 m distance and images are recorded for each metre along the road, one of the images will present 0,33° with an uncertainty of less than 1 %.

Other angles are out of control, because the vehicle has to stay in a driving lane on the road. On one hand, this is a weakness from a warranty point of view but, on the other hand, it is an advantage from a driver point of view that the measurements include situations that actually occur on the road.

C.4.3 Resolution of the legends and field of view

The legends of a road sign may be character legends or symbols.

The legends have a contrast by means of use of both bright signal colour and a dark contrast colour. The contrast is positive, when the legend has the signal colour, and negative, when the legend has the contrast colour. Signal colours may be white, yellow, fluorescent yellow and yellow-green, orange and fluorescent orange. Contrast colours are dark colour like black, blue, green, red and brown.

Persons with normal vision can as a rule of thumb read character legends with a particular character height H of capitals at a distance D, where H extends about 5’ (minutes of arc). With a stroke width of typically 1/6 of H, the stroke width extends an angle of a bit less than 1’.

The same rule of thumb can be applied for the legibility of symbols, when a critical details of the symbol is given the same role as the stroke width of a character legend.

However, this rule of thumb applies for conditions of optimum luminance levels and contrast. Retroreflective road signs do not provide optimum luminance at night, and the contrast is not optimum for the different combinations of signal and contrast colours. It is necessary that critical details extend more than 1’, perhaps 1’ to 2’ depending on the conditions.

NOTE: H extends 5’ at a distance D of approximately 700×H, which is the maximum legibility distance in good conditions. For retroreflective road signs at night, the maximum legibility distance is less, of the order of 400 to 500 times H.

Road signs are designed to provide a sufficient legibility distance at the less good conditions at night. Therefore, it can be assumed that critical details, like the stroke width of legends, do extend at least 1’ at all interesting distances.

A mobile equipment must be able to place measurements within the stroke width or details of the legends, and should be able to do that at all interesting distances. The detection system should, therefore, be able to resolve such details of a fraction of 1’.

A modern camera, such as the one used in DELTA’s mobile equipment for road markings, the LTL-M, has 1400 times 1000 pixels. If reserving 0,5´ for each pixel, the camera may cover a field of 11,7°×8,3°. The area covered at various distances is indicated in table C.1.

Table C.1: Area covered by a camera at various distances.

distance	area covered	
	width	height
30 m	6,1 m	4,4 m
50 m	10,2 m	7,3 m
70 m	14,3 m	10,2 m
100 m	20,4 m	14,6 m
150 m	30,6 m	21,9 m

The areas of table C.1 are probably sufficient to cover all road signs intended for one driving direction. However, the camera in the LTL-M uses more than half of the height for other purposes, and the remaining height may be critically small.

Therefore, it is concluded that a camera of this type can cover probably only some of the sign positions, for instance those to the right, to the left or overhead signs.

C.4.4 Sharpness of the image

The need to resolve details of 0,5’ requires that the image is optically sharp and that it is not blurred by movement of the vehicle or vibration during the exposure time.

It is probably feasible to produce an optically sharp image, but it requires focussing at the varying distances or use of a high F-number like f/11 or higher. This in itself may not be a problem.

Because of the forward movement of the vehicle, the sign seems to move to the side with a speed measured in minutes of arc per second given by $60 \times u \times V/D$, where u is the angle of the location of the sign relative to the driving direction, V is the driving speed in metres per second and D is the distance to the sign in metres.

This movement to the side causes a blurring of the image measured in minutes of arc given by $\tau \times 60 \times u \times V/D$, where τ is the exposure time measured in seconds. The blurring must be less than 0,5’ and for this reason the exposure time τ needs to be less than $0,5 \times D/(60 \times u \times V)$.

EXAMPLE: With a distance D of 30 m, a side angle u of 5° and a driving speed of 25 m/s (90 km/h), the exposure time needs to be less than 0,002 s.

Therefore, the exposure time needs to be rather short, like 0,001 s, if even short distances are considered.

Another matter is vibration of the vehicle and/or the equipment. In principle, the exposure time needs to be much shorter than the period of any vibration with a significant amplitude. It is known that the very short exposure time of 0,00002 s (20 µs) used with the camera of the LTL-M is safe in this respect, and it is known that there is vibration with large amplitudes within the time between exposures of 0,04 s (the rate is 25 frames per second).

It will probably require tests to determine a safe exposure time in view of both forward movement of the vehicle and vibration.

C.4.5 Need for luminous intensity

If measurements are to take place in full daylight, it has to be taken into account that sun illumination can produce a luminance of white parts of a sign of at least 5 000 cd/m^2 by ordinary reflection.

The illumination system has to be able to outshine the sun by producing a much higher sign luminance, for instance 50 000 cd/m^2, by retroreflection. If that is not possible, it is necessary to measure the daylight contribution to the sign luminance, and to subtract it.

The LTL-M is not quite able to outshine the sun and, therefore, the last-mentioned option is used. This is to measure the daylight contribution to the road marking luminance and to subtract it, which is fairly easy for the case of road markings.

Both options are considered in the following for the case of a mobile road sign retroreflectometer.

Assuming that the R_A value of white parts is 100 $cd \cdot lx^{-1} \cdot m^{-2}$ and that the luminance needs to be 50 000 cd/m^2 then the sign has to be illuminated to an illuminance of 50 000/100 = 500 lx. At a distance of for instance 100 m, the luminous intensity of the illumination system needs to be $500*100^2$ = 5 000 000 cd.

The value is actually set low, because the R_A value may be lower than 100 $cd \cdot lx^{-1} \cdot m^{-2}$ and because longer distances than 100 m may be needed. The minimum luminous intensity is therefore raised to 10 000 000 cd.

First of all, a vehicle cannot emit an effective intensity of 10 000 000 cd in directions towards other drivers, as it would temporarily blind them and perhaps damage their eyes.

The illumination system of the LTL-M also emits a powerful beam of light, but only to a few percent of the above-mentioned 10 000 000 cd. Further, the light is emitted in short flashes of a duration of approximately 20 µs. The rate is 25 flashes per second so that the total on time is 500 µs per second or 1 in 2000.

The human eye cannot discriminate the individual flashes and, therefore, the lamp appears to be 2000 times weaker, or to have an effective luminous intensity of the order of only 100 cd. This is not disturbing in full daylight, and as the beam is directed down to the road marking, it is not even noticeable except at night.

Accordingly, the above-mentioned 10 000 000 cd would appear 2000 times more weak to drivers, if the light is flashed in the same way as with the LTL-M. This still leaves an effective intensity of 5 000 cd, which is not disastrous, but nevertheless offending in daylight and strongly offending at night.

Therefore, the effective luminous intensity needs to be lower. Besides, it is probably not technically possible to provide luminous intensities like those mentioned above.

One way would be to reduce the flash rate to for instance 5 per second, but it should be considered that this is an annoying flicker rate for humans.

A second way would be to abandon the idea of outshining the sun and introduce some method to measure and subtract the daylight contribution. The basis for such a method could perhaps be to take camera frames without flashes in between camera frames with flashes. The effective luminous intensity could probably be reduced by a factor of 10 to 500 cd.

The third way – perhaps the most promising - could be to measure only at night or in weak daylight at for instance 400 lx and lower. A much lower luminous intensity of perhaps 100 000 cd with an effective intensity of 50 cd may be sufficient.

C.4.6 Other considerations

It is probably necessary to introduce various means of stabilising the measuring signal such a used in the LTL-M, where part of the image is used to monitor the dark level and another part is used to show and image of the light source.

Literature

CIE 54.2 Retroreflection: Definition and measurement, 2001.

CIE 15 Colorimetry, 2004.

EN 12899:2007 “Fixed, vertical road traffic signs - Part 1: Fixed signs

EN 1463-1:2009 “Road marking materials – Retroreflecting road studs – Part 1: Initial performance requirements”.

prEN 12899-6 ” Fixed vertical road traffic signs — Part 6: Retroreflective sign face materials”.

ASTM E 1709 “Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.2 Degree Observation Angle”.

ASTM E 2540 - 08 “Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.5 Degree Observation Angle”.

Annex X: Lighting concepts and units used for road equipment

X.1 Summary

Light, production of light and principles of light measurement are introduced in X.2. Light is electromagnetic radiation in a narrow range of wavelengths corresponding roughly to solar radiation. Radiation with these wavelengths acts on biological processes without being unduly harmful to life.

The concept of luminous flux is introduced. Incandescent lamps and other light sources are briefly mentioned. Additionally, principles of light measurement are mentioned. The luminous flux is provided in the technical documentation of light sources.

The concepts of luminous intensity and illuminance are introduced in X.3. It is pointed out that luminous intensity relates to a direction from a lamp and is most easily understood as the ability to provide illumination of objects or surfaces located in that direction. The illuminance is derived by means of the distance law of illumination. Additionally, when the illuminance is to be derived for a plane that is not perpendicular to the particular direction, the cosine law of illumination has to be taken into account as well.

The concept of luminous intensity is used in technical specifications for luminaires and signal lights. Illuminance, on the other hand, measures the level to which a surface is illuminated and is the target for the design of some indoor and outdoor lighting installations.

The concepts of reflection and luminance are introduced in X.4. Luminance is the stimulus for the eye. Only objects possessing a luminance by some process (light emission, reflection or scattering) can be seen. A particular ckaracteristic for reflection, the luminance coefficient, represents the ability of the illuminated surface to produce luminance.

Reflection is the subject of specifications for sign faces, road markings and other surfaces. The road surface luminance is the target for the design of road lighting installations of traffic roads.

In X.5 it is explained that nature really works in a simple way:

- The illuminance at a location on a plane is π times the average luminance of all the objects in front of the plane as seen from that location.
- A reflecting surface gets its luminance as an image of the surfaces in front. The luminance is normally reduced because of absorption in the surface and there may be more emphasis to some directions than to other directions due to shininess or other features of reflection.

Therefore, the concepts of luminous flux, luminous intensity, illuminance and reflection are not needed in order to understand how a surface gets its luminance. However, the concepts are practical in terms of applications by giving roles to specification writers, producers, testing laboratories and installation designers.

X.6 provides an introduction to the colour of light and of surfaces.

The concepts, units and definitions are summarized in table X.1.

It is easy to find literature on the internet. CIE 15:2004 “Colorimetry” is the bible on the rather difficult aspects of colour.

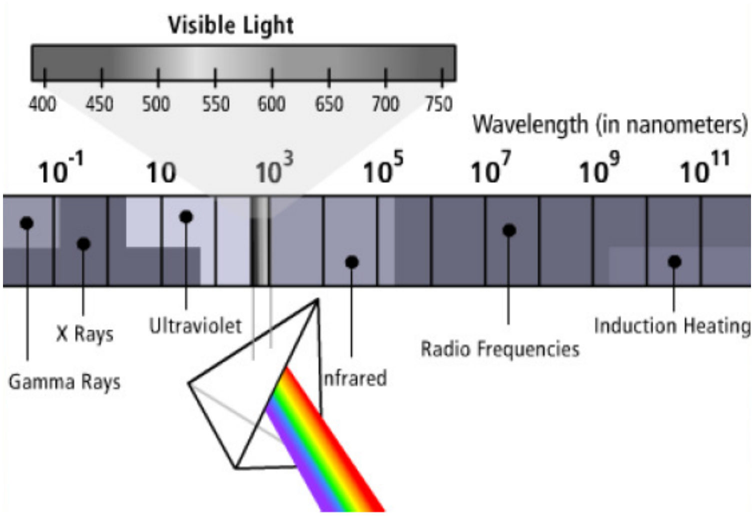
Table X.1: Concepts, units and definitions.

Concept	Unit	Definition
Luminous flux, Φ	lumen (lm)	The total amount of light emitted by a light source.
Luminous intensity, I	candela (cd)	The density of light in a direction, or the ability to produce illuminance on surfaces in a direction in conjunction with the laws of illumination.
Illuminance, E	lux (lx)	The density of light falling on a field of a surface
Luminance, L	candela/m^2 (cd/m^2)	The density of luminous intensity from a field of a surface. Luminance is the stimulus for the eye.
Luminance coefficient, q	$cd \cdot m^{-2} \cdot lx^{-1}$	The ratio between luminance and illuminance of a field of a surface in specified conditions of illuminance and observation.
x, y		CIE Chromaticity co-ordinates.

X.2 Light, production of light and principles of light measurement

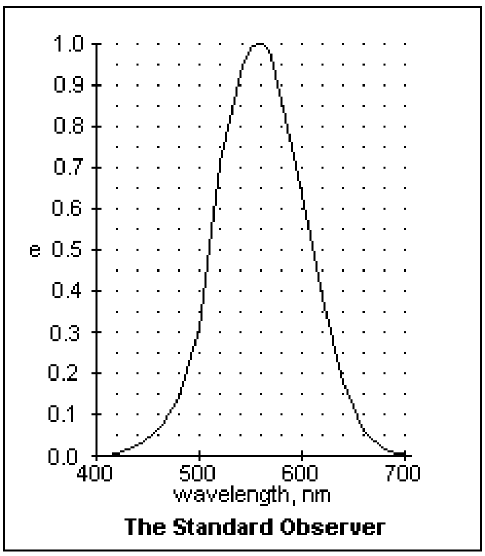
Electromagnetic radiation is characterized by its wavelength. In principle, there is no limit to the wavelength, but in practice it may be considered to be from less than 10^{-10} m up to more than 100 m. Radiation within that range is subdivided into gamma rays, X rays, ultraviolet radiation, visible radiation, infrared radiation, radio waves and heat radiation. See figure X.1

Figure x.1:
Electromagnetic radiation and light.



Visible radiation is found at wavelengths in a narrow band about 500 nm (1 nanometer equals 10^{-9} m). In principle, light is the radiant power summed up with relative weights of the so-called V(λ) curve and multiplied by a factor of 683 lumen/Watt. The V(λ) curve represents the spectral sensitivity of the eye, while the factor is there for historical reasons to provide a link to early definitions. The V(λ) curve is illustrated in figure X.2.

Figure X.2:
The V(λ) curve representing the spectral sensitivity of the eye (the standard observer).



Light summed up this way is called luminous flux Φ and has the unit of lumen (lm). The unit is rather small due to the above-mentioned factor of 683 lm/Watt. Because of this, a light source should be able to generate a large number of lumens compared to the number of Watts it consumes. The ratio is called the luminous efficacy.

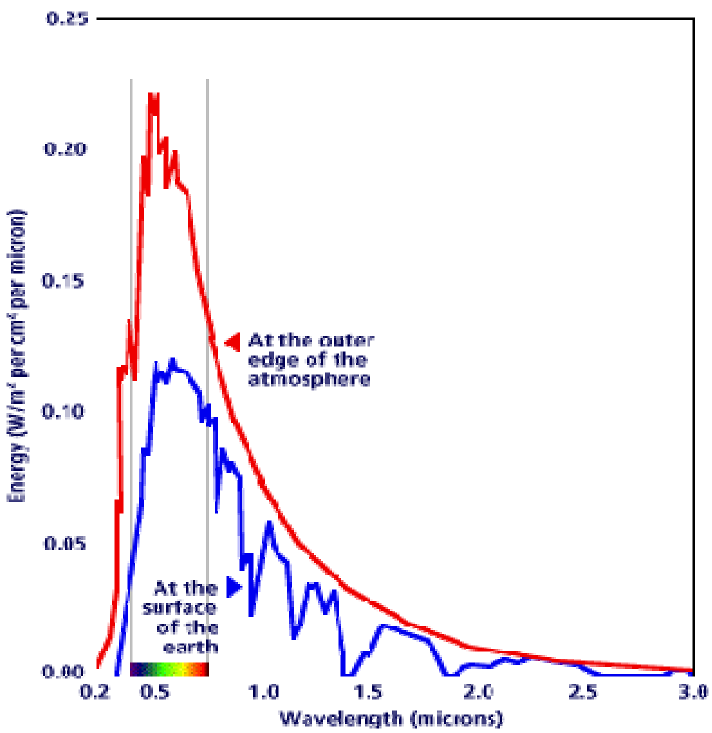
As also illustrated in figures X.1 and X.2, light can be split up into the different wavelengths, and each of these is associated with a colour of the rainbow. Colour is considered in X.6.

The energy of electromagnetic radiation comes in small packets called photons. The energy of a photon is in inverse proportion to the wavelength; it is large for gamma rays of short wavelenghts and decreases gradually with increasing wavelength.

Electromagnetic radiation with short wavelengths up to and including ultraviolet radiation has sufficient energy to cause damage to biological molecules and is thus harmful to life. The energy of radiation with longer wavelengths from infrared radiation and upwards is not sufficient to interact with biology, except when concentrated to provide a heating effect as in a microwave oven.

Visible radiation is just in between, it can drive the chlorophyll process of plants and it can stimulate the sensors of the eye without being undue harmful. It is a wonder that the solar radiation spectrum at sea level has its maximum in the visible range with only some ultraviolet radiation and some additional infrared radiation. See figure X.3.

Figure X.3:
The solar radiation spectrum (a micrometer equals 10^{-6} m).



The sun emits its radiation because it is hot at the surface, approximately 5250 °C. Any hot object emits radiation with a spectrum that depends on its temperature.

This is the principle of an incandescent lamp, which has a tungsten filament that is heated by the conduction of an electrical current. Unfortunately, the tungsten filament can be heated to only approximately 2300 °C or its life will be short. At this temperature, most of the radiation is infrared with only a low proportion in the visible range. Therefore, the luminous efficacy is low, normally in the range of 6 to 14 lm/Watt depending on the type of lamp.

Incandescent halogen lamps has a halogen gas surrounding the filament that allows a higher temperature of the filament and thereby a somewhat higher luminous efficacy, normally in the range of 10 to 20 lm/Watt depending on the type of lamp.

Actually, because electromagnetic radiation is the carrier of the electromagnetic force, there are numerous other processes for generating light than high temperature. Whenever an electron is disturbed, a quantum of electromagnetic radiation is emitted. The practical problem is to generate electromagnetic radiation that falls within the visible range and to allow it to leave. However, the principle is used in great variety of discharge lamps and other light sources like light emitting diodes (LED). In some of these lamps, radiation of short wavelenghts is converted to radiation of longer wavelenghts by fluorescence. Luminous efficacies are higher than for incandescent lamps, mostly in the range of 50 to 100 lumen/Watt.

Light is measured by means of photometers. These have a photo sensitive element, mostly a photodiode, whose spectral sensitivity has been corrected to match the $V(\lambda)$ curve to an acceptable degree. The correction is mostly by colour filters. Photometers also have suitable means to make them accept light from parts of the space around them with defined directional sensitivity.

The luminous flux of a light source is measured in a integrating sphere that accepts light uniformly from all directions of space. Other photometers are mentioned in the following.

The luminous flux is provided in the technical documentation of light sources.

Luminous flux is used not only in connection with light sources; it makes sense also to speak about the luminous flux falling on a surface or a field of a surface.

X.3 Luminous intensity and illuminance

Naked light sources are sometimes used for illumination, but normally they are mounted in a lamp with optics or shades to direct or reduce the light into specific directions.

NOTE: The word lamp is used in the following as a generic term for luminaires, lanterns, signal lights and other lighting devices.

The lamp, therefore, modifies the directional distribution of the light emission. In each particular direction, the intensity of light is described by a luminous intensity, I in the unit of candela (cd).

Luminous intensity has a definition of its own which, however, is complex. It is more easy to think in terms of figure X.4, which shows a luminous surface with a luminous intensity I in a direction towards a surface facing the luminous surface at a distance D. The luminous surface can for instance be the aperture of a headlamp.

The concept of illuminance applies for a field of a surface. It is the ratio between the luminous flux falling on the field and the area of the field. As the unit of luminous flux is lumen (lm), one might think that the unit of illuminance is lumen per square meter (lm/m^2). This is true, but with the modification that an individual unit of lux (lx) has been introduced.

The luminous surface causes an illuminance E on the illuminated surface given by: $E = I/D^2$. Accordingly, luminous intensity can be understood as the ability to produce illuminance. The equation illustrates the distance law of illumination - that the illuminance is in inverse proportion to the square of the distance.

EXAMPLE 1: A headlamp with a luminous intensity of 10.000 cd illuminates a surface at a distance of 50 m. The illuminance at the surface is $10.000/50^2 = 4$ lx.

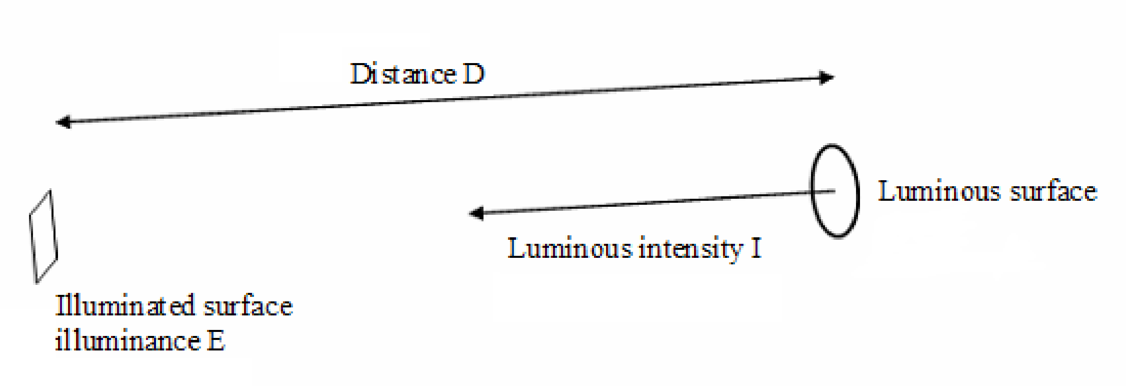


Figure X.4: A luminous surface with a luminous intensity I in a direction towards an illuminated surface at a distance D causes an illuminance of I/D^2.

There is an additional law of illumination, which is to be applied when the illumination is measured on a plane that is not perpendicular to the direction of illumination. The direction of illumination is described by an angle of incidence v, which is shown in figure X.5. The resulting illuminance is reduced by the factor cosv in accordance with the cosine law of illumination.

Figure X.5: The angle of incidence.

Consequently, the complete expression for illuminance is $E = I \times \cos v / D^2$. Contributions from more that one luminous surface can be summed up to a total illuminance.

Illuminance can be measured by means of a luxmeter, which is a photometer that accepts light from the hemisphere in front of the luxmeter with a directional sensitivity in accordance with the cosine law of illumination. A luxmeter can either be turned towards the light, or it can be placed with its back on the surface on which the illuminance is to be measured.

A luxmeter can either be anything from a cheap handheld instrument up to an expensive laboratory photometer.

The distance law of illumination is used for calculations of illuminance but can also be used to determine the luminous intensity of a lamp by means of the inverse equation, $I = E \times D^2$. The illuminance E is measured by means of a luxmeter at a known distance D and I is determined. This is the basis for laboratory measurement of luminous intensities of lamps.

EXAMPLE 2: A headlamp produces an illuminance at 20 m distance of 25 lx. The luminous intensity is $25 \times 20^2 =$ 10.000 cd.

The luminous intensity from a lamp depends generally on the direction relative to the lamp.

As an example, a low beam headlamp has large luminous intensities in directions below the cut-off, and much lower luminous intensities in directions above. Refer to figure X.6, which shows the distribution of average luminous intensity from a number of headlamps in use, after cleaning (the distribution for dirty headlamps is broader).

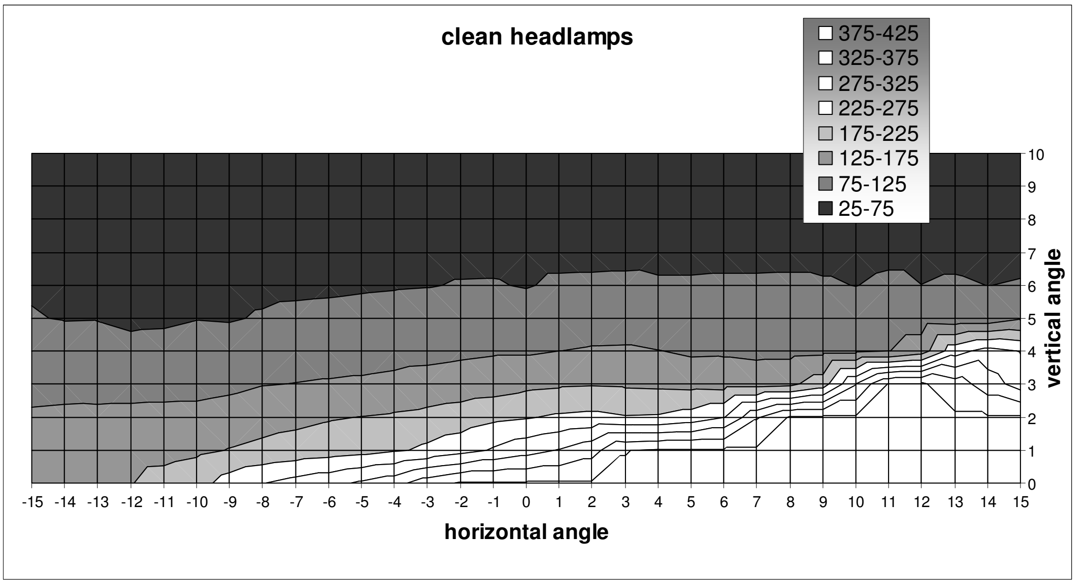


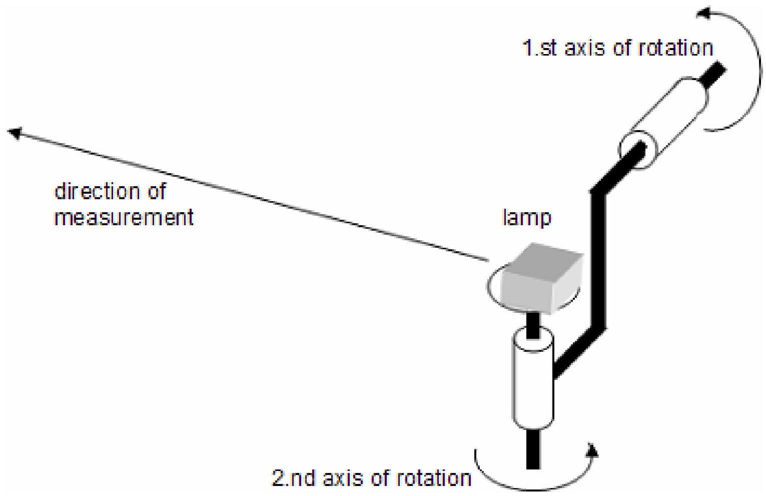
Figure X.6: Average intensity distribution of some clean headlamps in use (cd).

In this example, the purpose is to provide a reasonably high illumination at some distance in front of the vehicle without causing strong glare to oncoming traffic. Most luminaires and signal lamps have optics designed to provide variations in the luminous intensity for similar purposes.

Therefore, it is in general necessary to measure the luminous intensity in several directions relative to the luminaire or signal lamp. The particular set of direction is often defined in technical specifications, which in some cases also set requirements for the luminous intensities in the individual directions.

The most common method of establishing different directions is to keep a fixed horizontal measuring direction, but to turn the lamp in a goniometer with two axes of rotation. See figure X.7.

Figure X.7:
A lamp placed in a goniometer.



In another method, the luminaire is turned about a fixed vertical axis, while the measuring direction is varied with respect to the horizontal by tilting a large mirror (this is not illustrated). This method takes up more space, but is preferable for lamps with light sources that cannot be tilted, or light sources that changes luminous output when tilted.

A complete table of luminous intensity values is called a luminous intensity distribution or a light distribution. It is sometimes illustrated by means of a diagram as shown in figure X.6, and sometimes in other ways.

The concept of luminous intensity is used in technical specifications for various luminaires and signal lights. Illuminance is the target for the design of some indoor and outdoor lighting installations.

Luminous intensity is used not only in connection with lamps; it makes sense also to speak about the luminous intensity emitted by reflection from a surface or a field of a surface.

X.4. Reflection and luminance

A surface that is illuminated by a lamp obtains a luminance L by reflection as seen by an observer, see figure x.8.

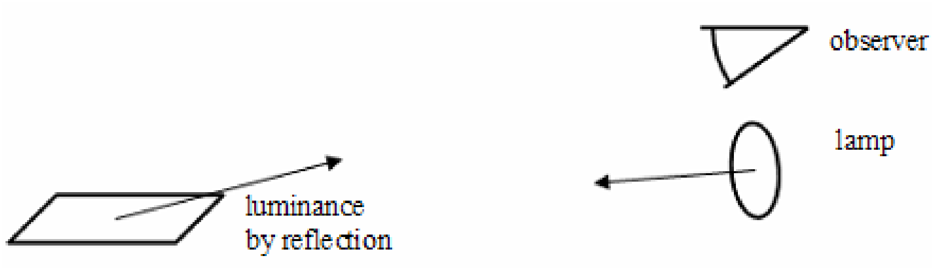


Figure X.8: A surface obtains a luminance by reflection as seen by an observer.

The luminance L of a field of a surface is L = I/A, where I is the luminous intensity of the field and A is the apparent area of the field. The luminance, the luminous intensity and the apparent area refer to a particular observation direction. The unit for luminance is candela per square metre (cd/m^2).

By apparent area of a field is meant the projection of the actual area of the field onto the direction of observation. Refer to figure X.9.

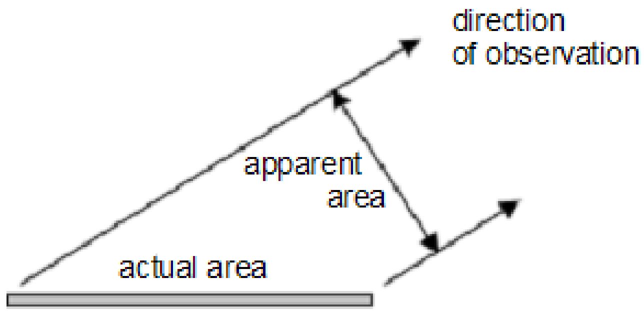


Figure X.9: Actual and apparent area.

Luminance is the stimulus for the eye. Objects that obtain a luminance by some process (light emission, reflection or scattering) can be seen, light as such cannot.

Luminance is measured by means of a photometer called a luminance meter, which has optics to allow light only from a field confined by a small cone. The size of the cone is measured by its angular diameter, which may typically be 6’, 20’, 1° or 3°. The field confined by the cone is called the measuring field.

A luminance meter is a handheld instrument looking somewhat like a video camera, in which the measuring field is indicated in a search image. A luminance meter can be rather cheap, or it can be fairly expensive with measuring fields down to 6 minutes of arc.

The road surface luminance is the target for the design of road lighting installations of traffic roads.

The luminance L obtained by reflection is in proportion to the illuminance E. The ratio between the two is called the luminance coefficient q; i.e.: $q = L/E$. The unit is $cd \cdot m^{-2} \cdot lx^{-1}$. The luminance coefficient is a measure of the ability of a surface to create luminance.

In a theoretical case, when the surface has perfect diffuse reflection, the value of q is independent of the geometry of illumination and observation. If so, the luminance coefficient is given by $q = \rho/\pi$ where ρ is the reflectance of the surface. The reflectance is a measure of the degree to which incoming light is reflected and is maximum 1. Therefore, for diffuse reflection, the maximum value of q is $1/\pi$ equal to approximately 0,318.

Diffuse reflection is approximated by surfaces of matt finish and is sometimes assumed as a simplification is some lighting conditions. However, in most practical cases that are relevant for road equipment, the luminance coefficient varies with the geometry of illumination and observation.

Reflection is the subject of specifications for sign faces, road markings and other surfaces. The specifications are based on particular characteristis and they define the geometry of illumination and observation. Additionally, specifications include the spectral composition of the incoming light; refer to X.6.

EXAMPLE 1: The luminance coefficient in diffuse illumination Qd of a surface is an average of the individual q values for the illumination directions of diffuse illumination. Diffuse illumination is obtained when the surroundings above the surface has a constant luminance and is best supplied from a photometric sphere. Qd is used with an observation direction that forms an angle of 2,29° to the surface.

A reflecting surface can at most show the same luminance as the luminance of the surroundings L which, on the other hand, creates an illuminance of $\pi \times L$. Therefore, the maximum value of Qd is $L/(\pi \times L) = 1/\pi$.

Qd is used for road markings, but can as well be used for road surfaces.

EXAMPLE 2: The coefficient of retroreflected luminance R_L of a surface has the same definition as the luminance coefficient q, except that the illuminance is measured on a plane perpendicular to the direction of illumination – instead of on the plane of the surface. This makes an R_L value smaller than a q value, but the same unit is used.

The R_L is used for road markings, but can as well be used for road surfaces. The R_L is normally used for a geometry that simulates that the driver of a passenger car looks on the surface 30 m ahead.

EXAMPLE 3: The coefficient of retroreflection R_A of a surface has the same definition as the luminance coefficient q, except that the area of the surface is the full area – not the apparent area in the observation direction. This makes an R_A value smaller than a q value. The unit is not $cd \cdot m^{-2} \cdot lx^{-1}$ as for a luminance coefficient, but $cd \cdot lx^{-1} \cdot m^{-2}$ in order to stress the difference in the use of the area.

The R_A is used for retroreflective sign face materials and sign faces.

X.5 A bit more about luminance

In X.3 it was shown that a luminous surface with a luminous intensity I creates an illuminance of $E = I/D^2$ at a distance D.

Actually, the luminous intensity I of the luminous surface is given by $I = L \times A$, where L is the luminance and A is the area of the luminous surface. The illuminance is then given by $E = L \times A/ D^2 = \omega \times L$, where ω is the solid angle of the luminous surface as seen at the distance D and as given by $\omega = A/ D^2$. Solid angles are really without dimension, but are formally given the unit of steradian (sr).

The expression $E = \omega \times L$ shows that the illuminance on the illuminated surface is really caused by a the presence of a luminous surface in the surroundings. The concept of luminous intensity is not needed to explain the illuminance, but it is practical in terms of technical applications. In other cases, it is more practical to think in terms of luminance.

An example is illumination by the sun, where it is not really practical to determine the luminous intensity as the product of luminance and area, and then apply the distance law of illumination. It is enough to multiply the luminance with the solid angle. The luminance of the sun is approximately 1.000.000.000 cd/m^2, and its angular diameter is 32 minutes of arc corresponding to a solid angle of 0,000086 sr, so that the illuminance is approximately 86.000 lx. In practice, the illuminance by the sun depends on the height position of the sun and on atmospheric conditions.

The above-mentioned illumination by the sun is on a plane perpendicular to the direction of the sunlight. The illumination on the horizontal plane is reduced by the cosine to the zenith angle of the sun.

Another example is illumination by the sky on the horizontal plane. Assume that the sky has a uniform luminance L of 5.000 cd/m^2 and be aware that the solid angle of the hemisphere is 2π and that the average cosine of all directions in the hemisphere is ½. The illuminance is then $E = \pi \times L$ = 15.700 lx.

This example makes it clear that the illuminance at a location on a plane is simply π times the average luminance of all the objects in front of the plane as seen from that location. There is nothing fundamental in the presence of the factor π, it is only due to the units of illuminance and luminance. See figure X.10.

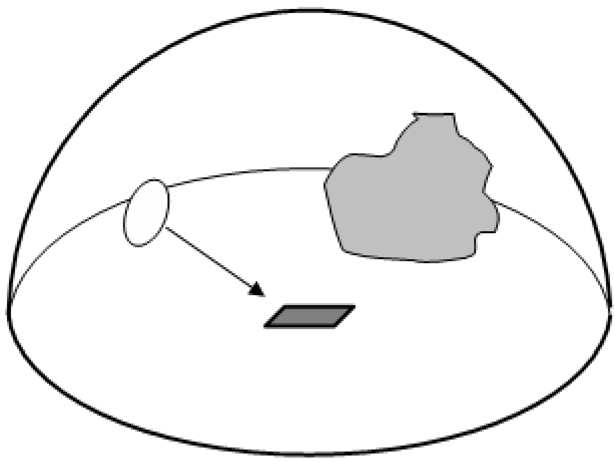


Figure X.10: The illuminance on a plane is π times the average luminance of all the objects in front of the plane.

In X.4 it was stated that an illuminated surface obtains a luminance by reflection given by L(illuminated surface) = q×E, where q is the luminance coefficient. Inserting E gives L(illuminated surface) = q×ω×L(luminous surface). This expression raises the suspicion, that the illuminated surface simply shows an image of the luminous surfaces in front of it.

This is true. A reflecting surface gets its luminance as an image of the surfaces in front. The luminance may be reduced because of absorption in the surface and there may be more emphasis to some directions than to other directions due to shininess or other features of reflection. The image is mostly diffused or blurred depending on the properties of the reflecting surface.

As an example, a road surface with a reflectance of 0,25 under a uniform sky has a luminance 0,25 times the sky luminance.

Therefore, the concepts of illuminance and luminance coefficient are not really needed in order to explain how an illuminated surface gets a luminance, but the concepts are practical for technical applications.

X.6 Colour of light and surfaces

The CIE 1931 colour space is the most widely used colour system for technical specifications of colours.

The tri-stimuli values X, Y and Z are found as weighted summations of the spectral radiant power. The weights are in accordance with the curves x(λ), y(λ) and z(λ) indicated in figure X.11. The curve y(λ) is actually the same curve as the V(λ) and appears in this connection with a different designation only.

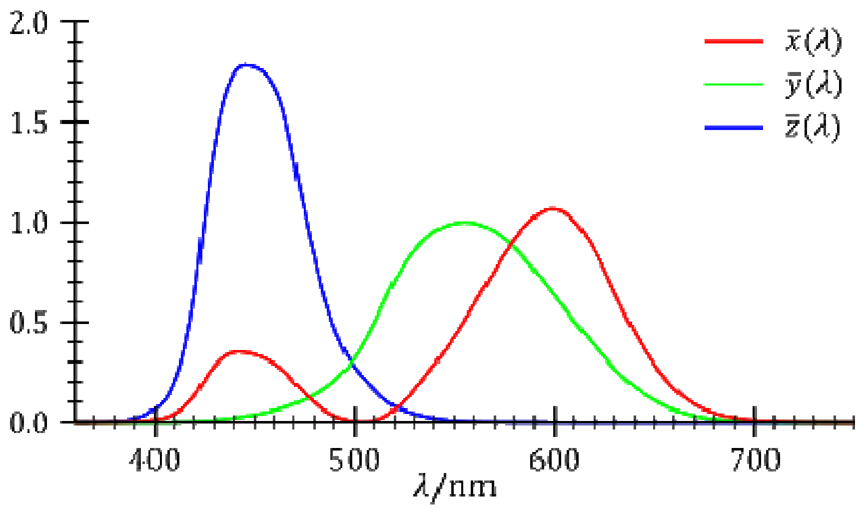


Figure X.11: The curves x(λ), y(λ) and z(λ) used to derive the tri-stimuli values X, Y and Z.

The two chromaticity co-ordinates x and y are found by x = X/(X+Y+Z) and y = Y/(X+Y+Z). Those two co-ordinates determine a location in the CIE chromaticity diagram shown in figure X.12. The numbers indicated around the curving part of the triangular colour region refer to the wavelengths of light of a single wavelength, i.e. to the colours of the rainbow. The curving part is called the spectrum locus. All other colours are mixtures of these colours.

Permissible colours of signal lights are generally indicated by colour regions or colour boxes in the chromaticity diagram.

Colours of light of light sources are indicated in similar ways or with reference to a curve for temperature radiators by means of a correlated colour temperature (this curve is not indicated in figure X.12).

Permissible colours of reflecting surfaces are also indicated by colour boxes in the chromaticity diagram. The surfaces represent for instance sign faces or road markings. However, the chromaticity of a reflecting surface depends on the illuminant used to illuminate the surface and on the geometry of illumination and observation. These matters are therefore specified and lie behind the requirements. The value of Y has a meaning as a measure of the reflection.

The illuminants are generally standard illuminant A, which represents a headlamp with an incandescent lamp, or standard illuminant D65, which represents daylight. The most used geometry of illumination and observation is the 45°/0° geometry. The value of Y is mostly in the scale of a luminance factor, which is π times the scale of a luminance coefficient.

As an example, the chromaticity boxes of retroreflective sheeting materials are shown in figure X.13. These apply for standard illuminant D65 and the 45°/0° geometry. The boxes include only non-fluorescent materials, as fluorescent materials have separate boxes.

Figure X.12:
The CIE chromaticity diagram.

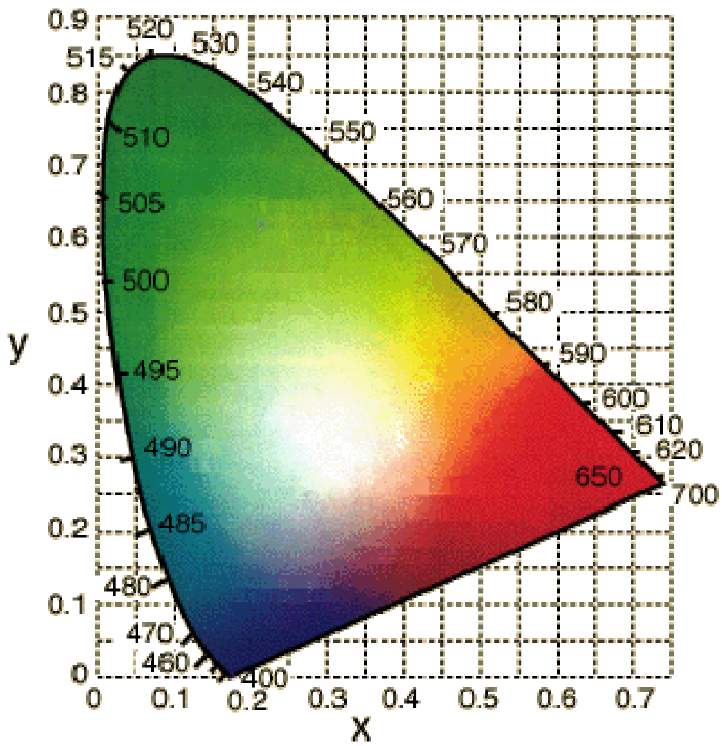
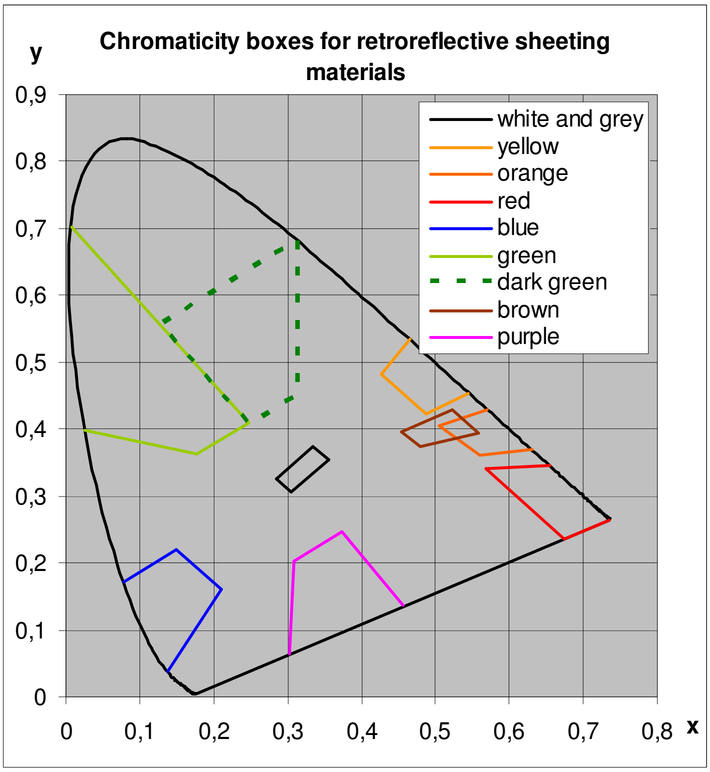


Figure X.13:
Example of colour boxes.



NOTE: The sizes of the colour boxes do not necessarily indicate the permissible variations of colour within the boxes, as the distances in figures X.12 and X.13 do not indicate degrees of visual distances.

Literature

CIE 15 “Colorimetry”.